Effect of Wide-Based Single Tires on Class-8 Combination Truck Fuel Efficiency

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ABSTRACT
In 2007 and 2008, the Oak Ridge National Laboratory, in collaboration with several industry partners, collected real-world performance and situational data for long-haul operations of Class-8 trucks from a fleet engaged in normal freight operations. Such data and information are useful to support Class-8 modeling of combination truck performance, technology evaluation efforts for energy efficiency, and to provide a means of accounting for real-world driving performance within combination truck research and analyses.

This paper presents some general statistics, including distribution of idling times during long-haul trucking operations. However, the main focus is on the analysis of some of the extensive real-world information collected in this project, specifically on the assessment of the effect that different types of tires (i.e., dual tires vs. new generation wide-based single tires or NGWBSTs) have on the fuel efficiency of Class-8 trucks. The tire effect is also evaluated as a function of the vehicle load level. In all cases analyzed, the statistical tests performed strongly suggest that fuel efficiencies achieved when using all NGWBSTs or combinations of duals and NGWBSTs are higher than in the case of a truck equipped with all dual tires. The results show that the fuel efficiency improvement increases as the number of NGWBSTs on the truck increases, with observed improvements of around 6% when either the tractor or the trailer was equipped with NGWBSTs, and more than 9% when both were mounted with these types of tires.

BACKGROUND

Combination truck-based long-haul operations involve trips in areas beyond 300-to-500 miles of a garaging area. When considering refueling, topography, congestion, size/weight/safety inspections, anti-idling laws and hours-of-service, the typical long-haul trip involve many stops. In an effort to collect, analyze, and archive data and information related to Class-8 combination truck operation in real-world highway environments, the U.S. Department of Energy's (DOE's) Office of Vehicle Technologies (OVT) sponsored the Heavy Truck Duty Cycle (HTDC) Project. Over a period of two years, the Oak Ridge National Laboratory (ORNL), in collaboration with several industry partners, collected real-world performance and situational data for long-haul operations of Class-8 trucks from a fleet engaged in normal freight operations. Such data and information is useful to support Class-8 modeling of heavy-truck performance, technology evaluation efforts for energy efficiency, and to provide a means of accounting for real-world driving performance within heavy-truck research and analyses. The project also supported the development and evaluation of combination truck modeling within the Powertrain Systems Analysis Toolkit (PSAT) with Class-8 data and information. PSAT is a DOE-sponsored light and heavy duty vehicle modeling and simulation tool developed at Argonne National Laboratory (ANL).

The focus of this paper is on the analysis of some of the extensive real-world information collected in this project, specifically on the assessment of the effect that different types of tires (i.e., dual tires vs. new generation single wide-based tires) have on the fuel efficiency of Class-8 trucks. The paper also presents some general statistics, including distribution of idling times during long-haul trucking operations and the effect of vehicle weight on fuel efficiency.

METHODOLOGY

Literature Review

Over the past thirty years, many studies involving heavy vehicles have been conducted to investigate the effect of different technologies on the fuel economy of these vehicles. As early as 1978, the US Department of Transportation and the Society of Automotive Engineers developed the "Tripmaster" system (consisting of an on-board instrumentation computer, a sensor set, data monitoring display unit, and a magnetic tape cassette that store the collected data) to conduct fuel economy studies under heavy-vehicle in-service conditions [1]. A year later, Doyle et al. [2], equipped a Class-8 truck with a diesel-organic Rankine compound engine (a device that recovers the waste heat in the exhaust gases) for a year-long test consisting of, among other things, over-the-road fuel economy measurements. Other engine technologies for heavy vehicles have also been studied to assess their effect on fuel efficiency. Hrynyk et al. [3] conducted a 33-month test of turbocharged propane engines for Class-8 trucks and used a diesel-powered tractor, in similar service, as the baseline for the fuel economy comparison.

Similarly, An et al. [4] studied the impacts of hybrid powertrains in reducing fuel consumption for heavy vehicles. Hybrid powertrains are of particular interest for commercial vehicles that operate in urban areas (i.e., under stop-and-go conditions). The researchers showed that the fuel economy and emissions benefits of vehicle hybridization could range between 35% and 75% depending on the type of vehicle. They also showed that those figures were very sensitive to different duty cycles (i.e., a mapping of a vehicle's velocity over time). Rafael et al. [5] considered the same duty cycle (i.e., the standard five-mile cycle driving test procedure), but with acceleration rates modified to study different driver behavior. The researches also found that there was a difference among each driving style studied in terms of fuel economy and emissions, and that there was a need to test terrain configurations other than flat terrain (i.e., to consider more realistic duty cycles). That is, in order to assess the real-world impact of engines and vehicles, and for the purposes of setting emissions and fuel efficiency standards, duty cycles should ideally reflect characteristics of real-world vehicle usage patterns. In addition to collecting data specific to the formation of duty cycles, the project described in this paper also collected situational data associated with the duty cycle data. That is, information regarding a vehicle's payload, the road grade over which it travels, the type of roadway, the time of day (which is related to congestion), weather conditions, road conditions, etc., were also collected. For the purposes of modeling real-world performance, such duty-cycle situational data allows for the calibration and validation of models that simulate engine or vehicle performance.

Specifically related to the effect that tires have on fuel economy of heavy trucks, Bachman et al [6] conducted fuel efficiency and NO_x emission tests on two similar Class-8 trucks (a test truck and a control truck) to assess the benefits of several technologies, including aerodynamic devices and wide-base tires. The results of these tests, conducted on a test track using drive cycles simulating highway operations at 55 mph and 65 mph and suburban stop-and-go traffic, showed that wide tires increased fuel economy in all of the drive cycles and there appeared to be no significant differences between the drive cycles. The 95% confidence intervals for gains in fuel efficiency were between 2 and 10% for highway cycles (55 mph) and 8-12% for suburban duty cycles.

In a similar test conducted in 2007 at the Transport Canada's Motor Vehicle Test Centre in Blainville, Quebec, Canada [7], the fuel economy variation that resulted from heavy-truck equipment installation was measured and compared against that of an unaltered "baseline" vehicle. Both vehicles performed runs on the same course, at the same speeds and at the same time. The fuel was weighted in special tanks before and after each set of runs, and the difference was used to calculate, by weight; the fuel efficiencies of the test and control vehicle. The results of these tests showed that the largest gains in fuel efficiency were achieved by the use of wide-based single tires (9.7% improvement when compared against standard dual tires) and by certain aerodynamic devices such as trailer side skirts and other such devices (5 to 9 % improvement).

The same level of fuel efficiency increases are reported by Al-Qadi and Elseifi [8], who found that utilizing the new generation of wide-base tires reduces rolling resistance by as much as 12%. This, in turn, results in fuel consumption reductions ranging from 2% and 10%. The authors also report on a survey conducted in Canada in which six of the seven truck fleet companies that used wide-based tires indicated significant reduction in fuel consumption of between 3.5% and 12% (which roughly translates to 3.6 to 13.6 % increases in fuel efficiency for a baseline of 6.5 mpg). Similarly, a 2006 European heavy duty vehicle study conducted in Finland [9] found that that significant savings in fuel consumption can be reached by many independent technical improvements, among them wide-based tires, could improve fuel efficiency between 5% and 15%.

Studies based on modeling have also suggested important increases in fuel efficiency due to the reduced rolling resistance and lighter weight of wide-based tires. Ang-Olson and Schoeer [10] indicate a 2.7% improvement in fuel economy over dual low-profile radial tires when using computer simulation. Other similar studies suggest higher improvements. For example, Muster [11] analyzed several factors that can significantly improve the fuel efficiency of heavy-duty trucks, including rolling-resistance reductions, optimized propulsion systems and other factors such as driver skills. The results of the simulations showed that low resistance tires could improve fuel efficiency by as much as 10%.

There are also informal inferences (i.e., non-formal studies) on the fuel saving benefits provided by wide-based tires. For example, a fleet owner conducted his own tests by outfitting one of his trucks, leased to FedEx on a dedicated run, first with new dual tires and after some period of time with singles to evaluate the difference in fuel efficiency. An increase of two-tenths of a mile per gallon, or 4% in fuel efficiency was observed in this informal test [12]. Other, much larger fleets reported the same type of gains in fuel efficiency. Con-way Freight, which has an 8,400 truck fleet, based on internal studies, expected gains in fuel economy of more than two-tenths of a mile per gallon, or about 3% improvement in fuel efficiency when switching to wide-based single tires [13]. Other sources [14] and [15] indicate that fleets have reported savings ranging from 1% to 8% on fuel when the vehicle is mounted with wide-based single tires on all axles compared to equivalent dual tires.

Data Collection and Management

Six Class-8 trucks from the selected fleet, which operates within a large area of the country extending from the east coast to Mountain Time Zone and from Canada to the US-Mexican border, were instrumented to collect 60 channels of data for over a year at a rate of 5 Hz (or 5 readings per second) using a data acquisition system (DAS). Those channels included information such as instantaneous fuel rate, engine speed, gear ratio, vehicle speed, and other information read from the vehicle's databus; weather information (wind speed, precipitation, air temperature, etc.) gathered from an on-board weather station; spatial information (latitude, longitude, altitude) acquired from a GPS (Global Positioning System) device; and instantaneous tractor and trailer weight obtained from devices mounted on the six participating tractors and ten trailers. Three of the six instrumented tractors and five of the ten instrumented trailers were mounted with new generation single wide-based tires (hereupon referred as singles, S, or NGWBSTs) and the others with regular dual tires (hereupon referred as duals or D). (Note: The tires used in this test were Michelin 445/50R22.5 XOne XDA and 445/50R22.5 XOne XTA for the NGWBSTs and Michelin 275/80R22.5 XDN2, 275/80R22.5 XDA5, and 275/80R22.5 XT-1 for the duals; in all cases the steer tires were Michelin 275/80R22.5 XZA3.) Over the duration of the project, the six tractors traveled nearly 700,000 miles collecting over 295GB of uncompressed data.

ORNL developed software that permitted the parsing and cataloguing of this information by criteria such as time-of-day (peak-and off-peak periods), type of roadway (freeways or surface streets), spatial location (urban or rural areas), topography (severe upslope, mild upslope, flat terrain, mild down slope, severe down slope), weather conditions (air temperature, rain intensity, and wind speed), congestion level, truck tire configuration (duals or singles for tractor and trailer), vehicle weight (empty, light load, medium load, and heavy load), vehicle dynamic condition (e.g., truck stationary, truck accelerating, etc), and other conditions. This database expedited the search process of specific sub-sets of data that matched any user-selected criteria combination.

Truck Weight Information

One of the most important variables in Class-8 truck fuel economy variations is the weight of the payload. For this study, weight information was collected using a device which was mounted on the six participating tractors, and provided instantaneous weight measurements at the steer and drive axles. This information was saved as two of the 60 DAS data channels. The device was also mounted on the ten instrumented trailers; therefore, when one of these ten trailers was coupled to one of the six tractors, the DAS collected weight data for the entire truck. However, the mating of an instrumented tractor with an instrumented trailer was not a very common event (less than 6% frequency of occurrence), and as a result, most of the time the six tractors were coupled to non-instrumented trailers (i.e., trailers without the weight-measuring device on board). For those occasions, only weight at the steer and drive axles were registered.

Using the weight information that was collected, a truck total weight prediction model was developed by ORNL that used the tractor weight, which was always available, and principals of inertial physics. From the project database, 272 long-haul trips for which weight information existed for both the tractor and trailer were selected to calibrate the weight model. The weight model was tested against information from another 98 trips that also had complete (i.e., tractor and trailer) weight information showing, on average, an error (i.e., difference between measured and predicted truck weight) of about 5%. The truck-weight model developed was then used to assign a trailer weight to each one of the records in the database of data collected in this project.

Fuel Information

The main objective of the data analysis for this project was to determine the effect of the different types of tires (i.e., regular duals vs. NGWBSTs) on the fuel efficiency of Class-8 trucks. In order to evaluate the effects that each of the different types of tires (i.e., regular duals vs. NGWBSTs) have on fuel efficiency of Class-8 trucks, fuel consumption needed to be measured. Furthermore, to study fuel efficiency under different trip conditions (e.g., freeway vs. surface street, peak-hour vs. off-peak, urban vs. rural, etc.) it was necessary to determine fuel consumption instantaneously. This type of information (i.e., the instantaneous fuel consumption rate, measured in liters/hour) was gathered from the vehicle databus and saved every 0.2 seconds by the DAS.

In order to determine the absolute fuel efficiency of any vehicle, the fuel consumption needs to be measured accurately. Several studies have shown that the errors introduced by measuring fuel consumption with databus information are small. For example, Bohman [16] reports that databus fuel consumption estimation was within 1% of the readings obtained using a fuel measurement tube (i.e., a two-meter long tube with known diameter that is used instead of the fuel tank). Hogan et al.[18] used databus readings to collect engine speed, throttle position, and fuel rate data. The latter was compared against the actual fuel rate, which was measured by suspending the fuel tank and attaching it to a strain gage meter that was accurate to 0.0023 kg or 0.005 lb. The comparison of measured and CAN fuel rates was shown to be highly correlated (0.992 correlation coefficient) thus providing a high level of confidence in the measurements of fuel consumption using the vehicle databus information.

Similarly, a 2002 EPA study indicates that the fuel consumption obtained from databus information is accurate, as long as severe “spikes” in the data stream are capped [17]. For this study, this precaution was followed by restricting the maximum rate of change for fuel flow to approximately 0.018 (gal/sec)/sec. Browand et al. [19] indicate that the use of the databus fuel rate signal is accurate and reliable, particularly if differences in fuel consumptions are measured rather than absolute values. In other words, systematic errors in the estimation of fuel consumption are not important (and in fact are irrelevant) when comparing fuel economies to, for example, determine if a given type of tire is more efficient than another type.

Data Analysis

The data collected in this study was divided into the four categories that reflect the four possible combinations of tires mounted on the tractor and mated trailer –that is: 1) tractor with duals and trailer with duals, 2) tractor with duals and trailer with NGWBSTs, 3) tractor with NGWBSTs and trailer with duals, and 4) tractor with NGWBSTs and trailer with NGWBSTs). For each one of these tire-combination categories, the total distance traveled during the entire data collection period was divided into 100-mile segments and the fuel consumed while traversing these segments was computed. With these two pieces of information, it was possible to calculate fuel efficiencies for each of the 100-mile segments for any given truck-tire category.

A test of hypothesis was used to conduct statistical comparisons of the distributions of the fuel efficiencies for the different tire combinations analyzed. That is, a null hypothesis asserting that the there is no difference between the distribution of fuel efficiencies for any tire combination that has NGWBSTs and that of the base case (i.e., all duals) was tested against an alternative hypothesis stating that the average of the distributions of the fuel efficiencies of the former are larger than that of the latter. In other words, calling μ_{xx} the mean of the distribution of 100-mile segment fuel efficiencies, where at least some of the tires (i.e., either those on the tractor, the trailer, or both) are NGWBSTs, and μ_{DD} the mean of the distribution of 100-mile segment fuel efficiencies computed for vehicles with all dual tires; then the null and alternative hypotheses are represented by equations (1) and (1) below.

$$H_o: \mu_{xx} = \mu_{DD} \qquad \text{Eq. (1)}$$

$$H_a: \mu_{xx} > \mu_{DD} \qquad \text{Eq. (2)}$$

RESULTS

The effect of the type of tires on fuel efficiency was studied for the general case in which all the other variables that may affect fuel consumption, such as vehicle weight, traffic conditions, type of terrain, weather, etc. were considered to equally affect all the six vehicles that participated in the experiment. That is, due to the extent of the data collected, it could be safely assumed and shown that any particular truck encountered similar (traffic, weather, load, etc.) conditions over the course of the year-long data collection period as any of the other five trucks. Besides this general case, particular conditions such as the effect that vehicle weight has on the fuel efficiency of the Class-8 trucks equipped with different type of tires were also studied using the same methodology.

General Statistics

During the data collection phase of this project, the six participating trucks logged almost 688,000 miles and consumed 103,000 gallons of fuel while undertaking 1,100 trips and visiting 37 states in the U.S. and one Canadian province. Table 1 presents a summary of these statistics for each one of the six participating tractors. The table includes information regarding fuel efficiencies for the entire data collection period, for each of the six vehicles as well as their overall fuel efficiency. These calculations were made using fuel consumption information obtained from the vehicles' databus (last row in Table 1) and include both the fuel consumed while the vehicle was moving, as well as the fuel spent while idling. Notice that, in general, tractors equipped with the NGWBSTs had higher fuel efficiencies than those equipped with regular dual tires. That is, using the information presented in Table 1 it is possible to compute the fuel efficiencies of tractors equipped with NGWBSTs (6.86 mpg) and regular dual tires (6.46 mpg), hauling any type of load and with trailers mounted with any type of tires. This information shows that, overall, trucks with tractors equipped with NGWBST tires present better fuel efficiencies (i.e., above 6% improvement) than those mounted with dual tires, independent of the type of tires on the trailer.

The extensive data collected and catalogued in this project permitted investigating other statistics that, in general, are not readily available for Class-8 trucks. One such statistic is the distribution of idle times (i.e., the vehicle is static and the engine is running) and fuel consumed while idling. Table 2 presents the distribution of idling time and idling fuel consumption as a percentage of total time and total fuel consumed, respectively. Seven intervals of time are considered, ranging from 0-5 minutes (i.e., the vehicle was idling for less than five minutes) to more than 240 minutes (4 hours). The short intervals (0-5 minutes and 5-15 minutes) correspond to idling due to traffic conditions (i.e., delays at traffic lights, congestion), and the largest interval corresponds to overnight parking. A significant proportion of idling time and fuel consumed while idling correspond to idling intervals that last between 15 and 60 minutes. Those 15-60 minute idling intervals correspond mostly to fueling and lunch/dinner stops, although some of the lower-end idling intervals may be due to extremely congested roadway conditions (e.g., lanes blocked due to crashes or simply recurring congestion). The largest proportion of idling time (50.0%), and associated fuel consumption (46%), corresponds to overnight parking, i.e., idling intervals of more than four hours. Overall, 7.0% of the total fuel was consumed while idling and about 0.8% was spent in congestion. However, more than 6.0% of the total time was spent in congested conditions.

The Effect of Tire Types on Class-8 Truck Fuel Efficiency

As discussed earlier, the collected data was divided into four tractor-trailer tire combination categories, and for each one of them, the total distance traveled was divided into 100-mile segments. The fuel consumed while traversing these segments was computed generating a distribution of fuel efficiencies for the each tire combination. Table 3 presents a summary of the statistics describing these distributions. For each one of the truck-tire configurations, the first three rows of Table 3 present the average, standard deviation and sample size of each of the distributions. Notice that the minimum sample size is 850 observations (i.e., for the duals on the tractor and NGSWTs on the trailer – the duals-NGWBSTs situation) with a maximum of 1,956 observations for the NGWBSTs-duals case. The fourth row in Table 3 presents the mean of the difference between the sample average fuel efficiency of the truck-tire combination of the corresponding column and that of the duals-duals case, and the following row presents the standard deviation of the difference.

For the three truck-tire configurations that have some or all NGWBSTs, the null hypothesis, which states that there is no difference in terms of fuel efficiency that can be explained by different tire configurations, can be rejected with 100% confidence in favor of the alternative hypothesis, which indicates that on average the fuel efficiencies obtained when using the duals-duals combination is lower than in the other cases. This strongly suggests that fuel efficiencies in cases using some or all NGWBSTs are higher than in the case of a truck equipped with all dual tires. In other words, the percent improvements in fuel efficiencies that are achieved when using all NGWBSTs or combinations of duals and NGWBSTs are statistically significant.

The Effect of Vehicle Weight on Class-8 Truck Fuel Efficiency

One very important variable affecting fuel efficiency is the weight of the vehicle. The extensive database collected in this project permitted the study of the effects that different tractor/trailer tire combinations have on the fuel efficiency of Class-8 trucks, when additional variables, such as vehicle weight, are taken into account.

As discussed above, there were improvements of the fuel efficiency of the types of vehicles studied here, when at least some of the tires (either those mounted on the tractor, the trailer, or both) were NGWBSTs. Those results were obtained without controlling for any particular variable (other than the type of tires) since it could be assumed that any of the participating vehicles would experience the same situations (terrain, weather, payload) over the course of the year-long experiment. However, it is important to determine whether the observed increases in fuel efficiency due to the type of tires used is maintained once the data is controlled for vehicle weight. That is, it is important to determine if the fuel efficiency gains due to the type of tires used are more significant when the vehicle is hauling light or heavy loads, since most of the Class-8 truck trips fall into the second weight category.

In order to study the effects that the type of tires and vehicle weight have on the fuel efficiency of combination trucks, the data was parsed by truck-tire combination and vehicle load level. The vehicle weight was divided into four categories: 1) Tractor Only (trips made without any trailer), 2) Light Load (total vehicle weight between 24,000lbs and 44,000lbs); 3) Medium Load (total vehicle weight between 44,000lbs and 62,000lbs); and 4) Heavy Load (total vehicle weight between 62,000lbs and 80,000lbs). As in the previous case, 100-mile segments were considered for which the fuel efficiency was computed and counted as one observation. Table 4 presents the results of this analysis. Under each load level category, the column labeled "Avg. FE" shows the average of the fuel efficiencies across all of the 100-mile segments in which each particular truck-tire combination was divided, with the column immediately to the right presenting the percent difference in fuel efficiencies when compared against the base case (i.e., the case in which the tractor and trailer are equipped with dual tires). For all load levels considered, there is always an observed improvement in fuel efficiency with respect to the base case (i.e., duals-duals). Notice also that fuel efficiency improvement increases as the number of NGWBSTs increases. Moreover, for the particular case in which all tires are NGWBSTs, there are considerable improvements in fuel efficiency with respect to the base case (10+%), and those improvements are more significant as the load level increases.

A series of tests of hypothesis were performed to statistically corroborate these results as was done in the previous case. Table 5 presents a summary of the statistics describing each one of the 12 fuel efficiency distributions corresponding to the truck-tire combinations and load levels (light, medium, and heavy). Within each one of the three load levels in Table 5, and for each one of the truck-tire configurations, the first three rows show the average, standard deviation and sample size of each of the distributions. The fourth row presents the mean of the difference between the sample average fuel efficiency of the truck-tire combination of the corresponding column and that of the duals-duals case, and the following row shows the standard deviation of the difference. For the three truck-tire configurations that have some or all NGWBSTs, and for any of the three load levels analyzed, the null hypothesis could be rejected with more than 99% confidence in favor of the alternative hypothesis; thus strongly suggesting that fuel efficiencies in these cases are higher than in the case of a truck equipped with all dual tires. In other words, the percent improvements in fuel efficiencies that are achieved when using all NGWBSTs or combinations of duals and NGWBSTs are statistically significant at any vehicle load level.

CONCLUSIONS

The information gathered in this study permitted the computation of fuel efficiencies for Class-8 trucks as a function of the type of tires mounted on the tractor and trailer. These calculations, which were made using fuel consumption information obtained from the vehicles' databus, showed an overall fuel efficiency above 6.0 mpg. This level of fuel efficiency is on the upper limits of today's large-truck fleets and is mostly a result of the participating trucking company being a very technologically minded organization, its excellent programs in driver training, and their extensive vehicle maintenance program (including, for example, maintaining a constant tire pressure).

The results of the data analysis showed that there is always a statistically significant improvement in fuel efficiency with respect to the base case (duals-duals) when NGWBSTs are involved. Moreover, the fuel efficiency improvement increases as the number of NGWBSTs on the truck increases, with observed improvements of around 6% when either the tractor or the trailer was equipped with NGWBSTs, and more than 9% when both were mounted with these types of tires. When the data was parsed by tractor-trailer tire configuration and load level, the results of the analysis show that there was again an improvement in fuel efficiency with respect to the base case (i.e., duals-duals) when NGWBSTs are used. In fact, for the particular case in which all tires are NGWBSTs, there was considerable improvement in fuel efficiency with respect to the base case (i.e., improvements that were above 10%), and those improvements were more significant as the load level increased. They were also statistically significant at the 99% level of confidence.

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TABLE 1 General Statistics for the Instrumented Tractors

Statistics	T1 (M^1-S^A)	T2 (M^1-D^B)	T3 (A^2- S^A)	T4 (M^1- D^B)	T5 (A^2- S^A)	T6 (A^2- D^B)	Grand Total
Distance Traveled [miles]	106,891	114,095	117,355	124,917	127,626	97,417	688,302
Total Time for Which Data was Collected[3] [hrs]	3,783	4,451	3,779	4,413	4,281	3,067	23,774
Avg. Speed[4] [mph]	28.26	25.63	31.05	28.31	29.81	31.76	28.95
Avg. Moving Speed[5] [mph]	57.24	55.61	58.85	58.98	58.43	59.29	58.04
Total Fuel Consumed [gal]	15,982	16,701	16,805	19,361	18,494	15,995	103,336
Overall Fuel Efficiency [mpg] From the Databus Sensor	6.69	6.83	6.98	6.45	6.90	6.09	6.66

[1]Manual Transmission; [2] Automatic Transmission; [3] Includes Idling times; [4]Distance Traveled/Total Time for Which Data was Collected (includes idling times); [5]Does not include idling time; [A] NGWBSTs; [B] Dual Tires

TABLE 2 Distributions of Time Spent and Fuel Consumed while Idling (All Trucks, All Trips)

Idling Interval [min]	Number of Incidences*	Time			Fuel		
		[hrs]	% Total Idling Time	% Total Time	[gal]	% Total Idling Fuel	% Total Fuel
0-5	53,269 (0.7)	664	5.6	2.8	371	5.2	0.4
5-15	5,310 (9.0)	784	6.6	3.3	398	5.6	0.4
15-60	3,085 (29.0)	1,479	12.5	6.2	1,454	20.4	1.4
60-120	767 (83.5)	1,067	9.0	4.5	570	8.0	0.6
120-180	384 (149.2)	947	8.0	4.0	525	7.4	0.5
180-240	287 (211.6)	980	8.3	4.1	539	7.6	0.5
240+	939 (371.6)	5,874	49.8	24.7	3,269	45.9	3.2
TOTAL		**11,795**	**100.0**		**7,125**	**100.0**	

* Numbers in parentheses indicate average length of interval in minutes.

TABLE 3 Fuel Efficiency Comparison by Tractor-Trailer Tire Configuration

	Truck-Trailer Tire Configuration			
	Duals-Duals	Duals-NGWBSTs	NGWBSTs-Duals	NGWBSTs-NGWBSTs
Sample Average Fuel Efficiency[1] (mpg)	6.60	7.00	7.03	7.22
Sample Standard Deviation	1.21	1.32	1.19	1.19
Sample Size	1,798	850	1,956	871
Mean of Difference with Duals-Duals		0.40	0.42	0.61
Std. Dev. of Difference with Duals-Duals		0.05	0.04	0.05
Test Statistic Value (Z)		7.41	10.77	12.43
Reject Ho at Confidence Level[2] =		100.00%	100.00%	100.00%

[1]Fuel efficiencies computed using collected databus information.
[2] Null Hypothesis: all fuel efficiency distribution means are the same.

TABLE 4 Fuel Efficiency as a Function of Load Level and Truck-Tire Configuration

Tractor-Trailer Tire Configuration	Load Level							
	Tractor Only		Light Load		Medium Load		Heavy Load	
	Avg. FE[1] [mpg]	% Diff with Duals-Duals	Avg. FE[1] [mpg]	% Diff with Duals-Duals	Avg. FE[1] [mpg]	% Diff with Duals-Duals	Avg. FE[1] [mpg]	% Diff with Duals-Duals
Duals-Duals	9.01	0.00	8.06	0.00	7.17	0.00	6.24	0.00
Duals-NGWBSTs	NA	NA	8.61	6.75	7.48	4.34	6.50	4.22
NGWBSTs-Duals	NA	NA	8.63	7.06	7.51	4.76	6.56	5.16
NGWBSTs-NGWBSTs	10.52	16.77	8.79	8.94	7.93	10.60	6.88	10.20

[1]Fuel efficiencies computed using collected databus information.

TABLE 5 Fuel Efficiency Comparison by Truck-Tire Configuration and Load Level

		Tractor-Trailer Tire Configuration			
		Duals-Duals	Duals-NGWBSTs	NGWBSTs-Duals	NGWBSTs-NGWBSTs
Light Load	**Sample Average Fuel Efficiency[1] (mpg)**	8.06	8.61	8.63	8.79
	Sample Standard Deviation	1.25	1.13	0.96	1.07
	Sample Size	172	76	181	55
	Mean of Difference with Duals-Duals		0.54	0.57	0.72
	Std. Dev. of Difference with Duals-Duals		0.16	0.12	0.17
	Test Statistic Value (Z)		3.37	4.77	4.17
	Reject Ho at Confidence Level =		99.96%	99.99%	99.99%
Medium Load	**Sample Average Fuel Efficiency[1] (mpg)**	7.17	7.48	7.51	7.93
	Sample Standard Deviation	1.09	1.16	1.04	1.15
	Sample Size	238	151	286	133
	Mean of Difference with Duals-Duals		0.31	0.34	0.76
	Std. Dev. of Difference with Duals-Duals		0.12	0.09	0.12
	Test Statistic Value (Z)		2.64	3.65	6.24
	Reject Ho at Confidence Level =		99.58%	99.99%	99.99%
Heavy Load	**Sample Average Fuel Efficiency[1] (mpg)**	6.24	6.50	6.56	6.88
	Sample Standard Deviation	0.87	0.93	0.81	0.91
	Sample Size	655	264	665	343
	Mean of Difference with Duals-Duals		0.26	0.32	0.64
	Std. Dev. of Difference with Duals-Duals		0.07	0.05	0.06
	Test Statistic Value (Z)		3.95	6.96	10.63
	Reject Ho at Confidence Level =		99.99%	99.99%	99.99%

[1]Fuel efficiencies computed using collected databus information.