Title
Heavy-Duty Truck Idling Characteristics: Results from a Nationwide Survey

Authors
Lutsey, Nicholas P.
Brodrick, Christie-Joy
Sperling, Dan
et al.

Publication Date
2004-12-01

Peer reviewed

Heavy-Duty Truck Idling Characteristics

Results from a Nationwide Truck Survey

Nicholas Lutsey, Christie-Joy Brodrick, Daniel Sperling, and Carollyn Oglesby

Heavy-duty truck engine idling results in significant costs, fuel consumption, emissions, noise, and engine maintenance. Two promising alternatives to idling, grid connection ("shore power") and onboard auxiliary power units (APUs), are being pursued by industry and government. Their attractiveness is uncertain, however, because of limited information about truck operations and driver behavior. A nationwide survey of long-haul truck drivers was conducted to characterize truck operations and driver behavior better. Key variables included usage rates for accessories, duration of idling, and engine speed at idle. It was found that long-haul truck engines idled for an average of 34% of total engine run time, roughly 1,700 h per truck annually. But these averages are deceptive. Approximately 10% of drivers reported idling 10% or less of engine run time, while another 10% reported idling more than 54% of engine run time, with differences related to season, truck ownership, company idling strategies, and driver experience. The mean annual fuel used during idle was estimated to be 1,600 gal per year, but the standard deviation was 1,300. An estimated 25% of drivers consumed more than 2,300 gal of fuel during idle (worth more than $3,000 per year in U.S. dollars), and 10% of drivers consumed more than 3,400 gal per year. These findings suggest that grid connections and APUs have the potential to provide large energy, environmental, and possibly even economic benefits.

According to the U.S. Department of Commerce's *Vehicle Inventory and Use Survey* (VIUS), there are approximately 400,000 Class 7 and 8 trucks that travel more than 500 mi from their home base on most trips (*1*). These trucks, referred to as long-haul trucks, generally have sleeper cabs to accommodate the federally mandated truck driver rest periods. Truck drivers spend most of the year in their trucks, which are commonly equipped with various "hotel accessories," including appliances and climate control technologies similar to those found in recreational vehicles (RVs). In contrast to RVs, which often use a propane or diesel-fueled auxiliary power system, the trucks' main engines are usually idled to provide power for climate control and accessories. Furthermore, the air conditioner is most often mechanical and belt driven directly off the main engine.

Heavy-duty truck idling is widely recognized as undesirable. Unlike with many environmental issues in which industry and government are in conflict, idling alternatives are being actively sought by both groups. The trucking industry seeks to reduce idling to lower fuel consumption and reduce engine maintenance, and local and state public agencies have enacted idling restrictions and bans to reduce emissions (*2, 3*). The 2001 proposed national energy program of the Bush administration targeted idling trucks as a means of reducing petroleum use (and emissions) (*4*). Cooperative industry–government working groups are being formed to address idling, but deliberations are hindered by uncertainty about the extent and severity of the problem.

This paper builds on an Argonne National Laboratory study of technology alternatives to idling (*5*); various studies of idling emissions (*6–12*); and the authors' previous work on the potential use, benefits, and requirements of fuel cell auxiliary power units (APUs) (*7, 13–17*). The state of New York, among others, is researching and demonstrating the potential of grid connections at truck stops (referred to as "shore power") (*18, 19*).

The potential benefits for idling alternatives, such as APUs and shore power, are highly dependent on truck operation and driver behavior. Variables such as number of idling trucks, idling duration, idling locations, and idle accessory use must be quantified. Representative nationwide data on idling duration have not been available, but industry data indicate that idling duration varies with season and route (*5*). Several groups have made statistically nonrigorous estimations of aggregate average idling duration (*15, 17, 20*), but quantitative evidence of how idling duration varies with respect to driver traits and driving parameters has been missing. In January 2003, the authors conducted a nationwide survey to characterize truck idling and the market for idling alternatives. The survey generated detailed data on truck driver behavior and truck operations related to idling. This paper discusses survey results concerning fuel consumption, accessory use, idling duration, and variance, with respect to season, fleet size, and other factors.

RESEARCH METHOD

Hypotheses Tested

The survey was designed to quantify behavioral and attitudinal variables. Behavioral variables included vehicle operation time, idling duration, idling locations, and motivations for idling. The specific hypotheses that were tested for these behavioral variables are included in Table 1. A future follow-on study will report on the attitudinal variables, which include perceptions of idling impacts, opinions on idling-related technologies, awareness of idling and idle reduction devices, and anticipated future purchasing practices of idle reduction devices.

N. Lutsey and D. Sperling, Institute of Transportation Studies, University of California, Davis, 1 Shields Avenue, Davis, CA 95616. C. J. Brodrick, Integrated Science and Technology Department, James Madison University, MSC 4102, ISAT/CS Building, Room 307, Harrisonburg, VA 22807, and Institute of Transportation Studies, University of California, Davis, 1 Shields Avenue, Davis, CA 95616. C. Oglesby, Integrated Science and Technology Department, James Madison University, MSC 4102, ISAT/CS Building, Room 307, Harrisonburg, VA 22807.

Transportation Research Record: Journal of the Transportation Research Board, No. 1880, TRB, National Research Council, Washington, D.C., 2004, pp. 29–38.

TABLE 1 Behavioral Hypotheses Tested in Survey

Response Type	Area of Question	Hypotheses Tested in Survey of Long-Haul Truck Drivers
Behavioral	Vehicle use	Truck driver patterns, including annual operation and daily driving and idling times are diverse.
	Idling duration	Idling duration averages about 6 h per day, but varies by season, driver demographic, truck ownership, company size, and company-driven idle reduction strategy.
	Motivation for idling	Motivations for idling are, in order of importance, cabin climate control, cabin electric hotel accessories, engine maintenance issues, and auxiliary power take-off accessories.
	Idling characteristics	Idling characteristics, like accessory load and engine setting for engine at idle, vary widely among drivers.
	Idling consequences	Idling results in substantial fuel costs for the owners of many long-haul trucks.

Administration of Survey

A 10-page questionnaire was administered to truck drivers in mid-January 2003 at six locations across the country by graduate students from the University of California, Davis. The six locations, all owned by the private truck stop chain, TravelCenters of America, were Cartersville, Georgia; Columbia, New Jersey; Elgin, Illinois; Lodi, Ohio; Richmond, Virginia; and Troutdale, Oregon. These locations were chosen on the basis of their high traffic volumes at the time of surveying. Most of the truck stops dedicate a section of the facility to services for long-haul truck drivers (e.g., diesel, truck maintenance, washing facilities, television, and arcade games) and another section to services for both truck drivers and non-truck-driving patrons (e.g., restaurants, convenience store, and gasoline). Standing between these sections, our interviewers solicited passing truck drivers to sit down at booths to take the survey. Generally, drivers filled out the survey at the booth, although some took the survey to fill out as they ate in the restaurant. The questionnaires took about 20 min to complete, although times ranged from 10 to 50 min. Either one or two students sat at each of the locations soliciting drivers to complete the survey, as well as offering guidance on the meaning of questions that were unclear to respondents. Incentives for completing the survey included a coupon immediately redeemable for a food item (soda, coffee, or candy bar) at that truck stop and entry into a raffle for a $100 gift certificate at Walmart stores. A total of 365 questionnaires were collected, including some that had a small number of item nonresponses.

The number of completed surveys varied as follows: Cartersville, Georgia (113 questionnaires); Columbia (10); Elgin (48); Lodi (64); Richmond (42); and Troutdale (88). The variability largely reflected the varying number of drivers traveling through each facility because the residence time of student interviewers was roughly equal at each site. Responses were lower in Columbia and Richmond because of snowstorms in the area. More than 50% of drivers spending time inside each truck stop completed a questionnaire. This high response rate was attributed partially to the fact that the drivers had mandated rest periods owing to hours-of-service rules.

Survey Population, Sampling, and Bias

Drivers of long-haul Class 7 and 8 tractors were the targeted population. The VIUS estimates that there are about 2.4 million Class 7 and 8 trucks, about 400,000 of which regularly travel more than 500 mi from the vehicle home base (*1*). No directory is available for this population. As a result, and because of the difficulty of creating a random sample of drivers, a representative sample of high-traffic truck stops scattered across the United States was selected, and then as many drivers as possible were interviewed at those sites. The survey locations were selected to capture traffic for the main east–west and north–south thoroughfares.

Sampling bias resulted from on-site difficulties in sampling drivers, use of only one brand of truck stop, and failure to survey truck drivers who do not stop at truck stops. To some extent, sampling bias was mitigated by the geographically dispersed survey locations and the largely national nature of most long-haul drivers (who traverse the nation and cover hundreds of miles per day).

Response bias may result from the survey's subject matter, the incentives offered for survey completion, and the written format. Some of the subject matter, such as the portions on fuel efficiency and emission reduction technologies, induced strong responses relating to government regulation of trucks from some drivers. Some individuals may have been more likely to participate in the survey as a result of the topic, and some not; and some refused because they said it felt like they were taking an exam.

The response rate was enhanced, and response bias reduced, by the fact that the surveyors were from a university, the survey was endorsed and funded by a member of the trucking industry (the truck manufacturer Freightliner LLC), and neutral incentives (snack coupon and a raffle for gift certificate) were offered.

RESULTS AND DISCUSSION

Comparison of Sample and Population Vehicle Characteristics

One gauge of the representativeness of the survey sample was its correlation to the sample in the VIUS. The VIUS database, released in 2000 with data from 1997, uses U.S. Department of Commerce data on 131,000 registered trucks to characterize the roughly 75 million registered trucks in the United States. The VIUS database excludes vehicles owned by federal, state, and local governments and several other vehicle types. The data are collected by stratified sampling. Although the representativeness of the VIUS is uncertain, it is the largest truck data set available [for details on the survey design and analysis, see the VIUS (*1*)]. The database has individual truck entries and can be used to cross-tabulate and segment the truck population to estimate the number of vehicles that meet a variety of chosen characteristics (e.g., truck age, range, state of registration, maximum gross vehicle weight, body type).

Several survey questions were formulated identical to those of the VIUS so that the two samples could be compared. Trucks that had gross vehicle weights of more than 26,000 lb (i.e., Class 7 and 8 trucks) and that were reported to have traveled primarily more than 500 mi from their home base (i.e., long-haul trucks) were used for comparison. Vehicle characteristics from the VIUS and the authors' survey are compared in Table 2. Generally, vehicle characteristics reported by truck drivers in the survey sample appear to be in close agreement with the VIUS with respect to distributions of body type, ownership, vehicle age, and fleet size. The largest discrepancy between the two samples appears to be the ratio of owner-operators to fleet drivers. The VIUS database reports that about 21% of respondents are owner-operators (including those driving a vehicle as an independent and those driving a vehicle that was leased to a company), compared with 32% reported by the authors' survey. (That percentage is very similar to the 30% owner-operator sample of the authors' previous pilot survey (*16*) and that reported by the trucking industry.) A comparison of the VIUS and the authors' survey in regard to the distribution of company sizes also showed a marked difference, with the authors' survey reporting a higher proportion of single-truck companies (27%) than did the VIUS database (12%). In summary, the authors believe that the survey is fairly representative and not subject to too much bias.

Truck use data from the authors' survey and the VIUS are shown in Table 3. Responses to questions on annual miles driven, total lifetime miles on engine, range of driving, and fuel economy are consistent with the VIUS.

Driving and Idling Time

Results for key operational variables are shown in Figure 1. Although averages are useful when making rough estimates, variation in truck idling data is often so great that the average alone can be misleading. Accordingly, results are presented as distributions as well as averages. Results indicate that an average long-haul truck driver travels about 112,000 mi annually during a 292-day period. The distribution is heavily weighted near the center, with more than half the drivers traveling between 100,000 and 150,000 mi per year. More than two-thirds of the drivers drove more than 100,000 mi per year. An average long-haul day includes about 10.4 h driving, about 5.9 h idling,

TABLE 2 Comparison of Vehicle Characteristics from VIUS and Survey Data

Survey Question	Survey Response	VIUS, 2000[a]		Survey	
		Percentage of Trucks	Number of Trucks	Percentage of Responses	Number of Responses
Body type	Basic enclosed van	49%	195,318	55%	194
	Insulated refrigerated van	20%	82,131	27%	96
	Basic platform	12%	49,338	8%	30
	Tank truck (liquids or gases)	4%	15,182	1%	3
	Insulated nonrefrigerated van	4%	14,434	2%	8
	Low boy or depressed center	2%	6,837	1%	4
	Other	8%	38,641	6%	20
	Total	100%	401,881	100%	355
Ownership	Owner-operator (independent or leasing)	21%	62,105	32%	115
	Company driver	79%	238,504	68%	249
	Total	100%	300,609	100%	364
Tractor age (yrs)	0 - 2	35%	140,324	35%	121
	3 - 4	29%	117,422	34%	118
	5 - 6	14%	58,265	12%	41
	7 - 8	8%	31,073	7%	24
	9 - 10	6%	23,794	4%	13
	>10	8%	31,006	8%	28
	Total	100%	401,884	100%	345
Fleet size (tractors and trailers)	1	12%	42,277	27%	93
	2 - 5	9%	32,226	14%	48
	6 - 9	3%	12,330	4%	13
	10 - 24	7%	23,951	4%	13
	25 - 99	13%	46,624	9%	31
	100 - 499	15%	55,356	11%	37
	500 - 999	8%	29,642	7%	23
	1,000 - 4,999	13%	45,776	13%	45
	5,000 - 9,999	5%	18,193	6%	22
	10,000 or more	15%	52,609	7%	23
	Total	100%	358,984	100%	348

[a] VIUS data from 1997 registered trucks. These data include trucks with average gross vehicle weight in excess of 26,000 lb and that primarily drive greater than 500 mi from home base (*1*).

TABLE 3 Comparison of Vehicle Use Characteristics Between VIUS and Survey Data

Survey Question	Survey Response	VIUS, 2000[a]		Survey	
		Percentage of Trucks	Number of Trucks	Percentage of Responses	Number of Responses
Annual miles	>50,000	12%	46,417	13%	46
	50,000 - 99,999	30%	122,496	18%	62
	100,000 - 149,999	44%	177,600	50%	171
	150,000 - 199,999	10%	40,837	12%	42
	200,000 - 249,999	3%	12,517	2%	8
	>249,999	1%	2,014	5%	16
	Total	100%	401,881	100%	345
Lifetime miles on engine	<500,000	68%	272,186	69%	247
	500,000 - 999,999	27%	106,781	26%	94
	1,000,000 - 1,499,999	4%	16,279	4%	13
	>1,499,999	2%	6,635	1%	4
	Total	100%	401,881	100%	358
Percent of trips beyond 500 mi from home base	81 - 100	67%	268,442	54%	182
	61 - 80	15%	60,138	17%	58
	41 - 60	13%	52,749	15%	52
	21 - 40	5%	20,453	5%	16
	0 - 20	0%	91	8%	28
	Total	100%	401,873	0	336
Fuel economy (mpg)	<4.5	4%	15,623	1%	6
	4.5 - 4.9	5%	16,502	4%	6
	5.0 - 5.4	14%	52,235	9%	29
	5.5 - 5.9	21%	76,825	21%	68
	6.0 - 6.4	25%	91,874	30%	76
	6.5 - 6.9	18%	65,773	22%	77
	7.0 - 7.4	5%	17,826	12%	36
	7.5 - 7.9	2%	7,082	0%	20
	8.0 - 8.4	2%	8,731	1%	6
	>8.4	4%	13,060	1%	5
	Total	100%	365,531	100%	329

[a] VIUS data from 1997 registered trucks. These data include trucks with average gross vehicle weight in excess of 26,000 lb and that primarily drive greater than 500 mi from home base (*1*).

and about 3.3 h with the engine off (these averages are based directly on driver responses). The number of drivers who idle less than 1 h a day, at about 10%, is approximately equal to the number of drivers who idle 10 h or more. Using responses for driving hours per day and idle hours per day, it is estimated that idling accounted for 34% of total engine run time. The distribution presented in Figure 1 shows that there are approximately the same number of trucks that idle 10% or less of engine run time as those that idle at least 55% of the time. Multiplying each driver's average daily idle duration (h/day) by annual truck operation (day/year) revealed an average of 1,700 h at idle per year per truck. Annual idle time is relatively evenly distributed across the range of 500 to 2,500 h/year.

The reported values for daily time spent driving and idling were erroneous. Drivers were asked to divide their average 24-h day into time spent each day with their engines off, driving, and idling. They were explicitly told this should add up to 24 h. The average sum of these three daily values was only 19.6 h. One plausible explanation for this error was the drivers' concern that their actual driving hours (which often exceeded the legal limit) would be reported to authorities. In fact, one common question was whether the hours of service would be viewed by law enforcement or other government agencies.

It is not clear how best to correct the discrepancy in hours reported. Some drivers admitted to intentionally underestimating their driving. Assuming that to be the case, it would be logical to add the 4.4 unaccounted-for hours into the driving category, and idling time would remain at the 5.9 h reported. Alternatively, it is possible the drivers misunderstood that three possible activities should sum to 24 h. In scaling up the three daily values to sum to a full day (i.e., multiplying by 24 and dividing by 19.6), the average daily breakdown of long-haul time would be 12.7 h driving, 7.2 h idling, and 4.1 h with the main engine off. Further complicating this discrepancy, the inclusion of team drivers could account for the driving average being higher than hours of service rules allow. Because there is not an obvious rationale for selecting which correction to apply to which survey, it is possible to generalize only that the average daily idling time is likely to be from 6 to 7 h.

Accessory Use

The earlier 2001 pilot survey, conducted during the summer in northern California, indicated that climate control is the primary motivation

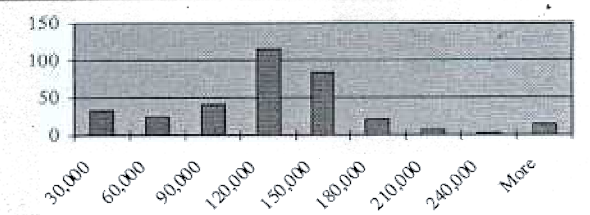
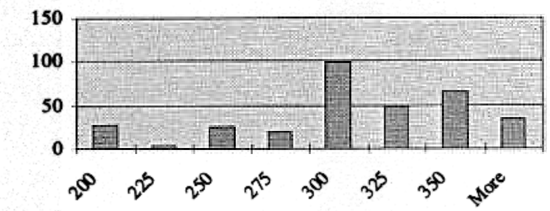
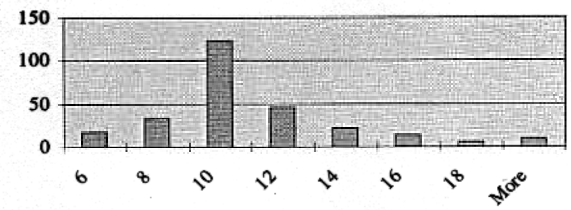
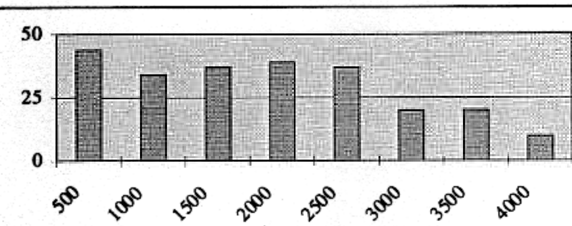
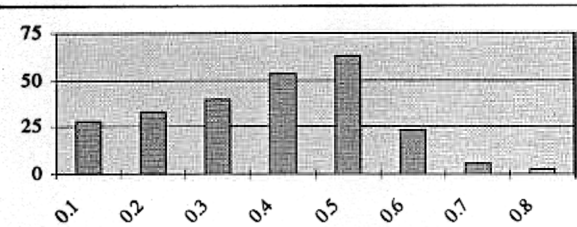
Variable	Number of Driver Responses	Mean (st. dev.)	Distribution of Responses
Annual driving distance (mi/yr)	345	111,631 (61,870)	
Annual operation (day/yr)	329	292 (68)	
Daily driving time (hr/day)	269	10.4 (3.3)	
Daily idle time (hr/day)	273	5.9 (3.9)	
Annual idle time (hr/yr)	250	1,744 (1,199)	
Fraction of engine run-time at idle	250	0.34 (0.18)	

FIGURE 1 Survey responses for long-haul truck use and idling characteristics.

for truck idling during the course of the year, with air-conditioning being cited more frequently than heating by drivers (*16*). The nationwide survey reported here similarly shows climate control to be the most important reason for idling. However, responses from this survey ranked heating higher (81% of drivers) than air-conditioning (73%). This differing result from the two surveys could be due to the more representative national sampling of drivers for the larger survey or it could indicate a faulty memory of drivers in the nationwide survey, trying to remember summertime behavior while filling out surveys in the winter. Drivers were allowed to select multiple motivations for idling. Powering accessories was checked as a reason for idling by 35% of respondents; accessories used by drivers are shown

TABLE 4 Long-Haul Truck Accessories

Cabin Accessory	Percentage of Trucks with the Given Accessory		
	2001 Pilot Survey[a]	2002 Pilot Survey[b]	This Survey
Stereo	96%	86%	66%
TV	60%	21%	74%
Computer	35%[c]	28%[d]	23%
CB radio	90%	86%	88%
Lamp (built-in)	84%	66%	NA
AC light bulb	N/A	41%	46%
Refrigerator	52%	48%	59%
Coffee maker	14%	7%	15%
Microwave	12%	10%	19%
A/C powered by engine	92%	93%	90%
VCR	9%	N/A	53%
Cell phones	N/A	28%	62%
"Other"	5%	N/A	11%
Power-take-off	13%	N/A	22%[e]

[a] Brodrick et al. 2001 (*14*)
[b] Lutsey et al. 2003 (*17*)
[c] No distinction between PC and dash-readout/company computer was made.
[d] Dash-readout/company computer percentage is given; 10.3% of trucks had personal computers.
[e] Includes trailer refrigeration.

in Table 4. Avoiding start-up problems (13%), drowning out other noise (9%), and reducing engine maintenance (4%) were also cited by drivers as reasons for idling.

Idle Duration Variation

The effect of season on idle duration appears to be quite clear, as shown in Table 5. Drivers indicated they idled about 5 h per day during the more moderate seasons of spring and fall and about 7 h during winter and summer. The differences in idle duration averages by season were statistically significant with a *t*-test for paired observations at a 90% confidence interval when compared with values for the rest of the year. Values for fall and spring vary more with respect to their means, with higher coefficients of variation (about 0.9) than those for winter and summer (between 0.6 and 0.7). This difference could be a result of more severe weather seasons resulting in more unavoidable or inflexible periods of idling, whereas idling during the more moderate seasons could be more discretionary.

Along with varying by season of operation, the amount of daily idling appears to have some relation to truck ownership, driver's company size, idling policies, and driver traits. In Table 6, average idling duration is analyzed as a function of truck ownership, company idling policies, and driver traits, with those that have statistically significant differences from the rest of the population highlighted in bold. The differences between the means were tested at the 90% confidence interval.

Owner-operators, those who own the vehicles they drive, tended to have lower average daily idling duration: 5.1 versus 6.1 h for all company fleet drivers. This difference may be due to the owner-operators' better understanding and greater responsiveness to the higher operating costs (e.g., fuel and engine maintenance) associated with idling. Indeed, attitudinal Likert-type questions indicated that to be the case. Of owner-operators, 71% either agreed or strongly agreed that they were concerned that idling led to increased expense because of higher fuel consumption, and 57% either agreed or strongly agreed that idling leads to significantly higher engine maintenance and oil change costs. These percentages reported by owner-operators are both higher than those reported by company drivers, who responded with 47% for fuel consumption and 51% for oil and maintenance costs.

Companies' policies or actions with regard to idling appear to have some effect on idling duration. Drivers for companies with no formal program, method, or strategy to reduce idling idled about 1 h more per day (6.4 h) than did those who were affected by any of the methods listed. Those drivers with companies that implemented some form of idling training had the lowest average idle time, 3.7 h/day. Idling training was the only idle reduction method that resulted in a statistically significant difference in average daily idle duration. Other methods, including financial incentives and the use of automatic engine shutoff or start-up devices, resulted in idling times of 5.3 to 5.5 h/day. Drivers from companies that issued some form of punishments for excessive idling had slightly lower idling durations of about 5.1 h/day.

As indicated in Table 6, idling time also varies somewhat with company size, though these differences were not found to be statis-

TABLE 5 Reported Seasonal Daily Idling Duration

Seasonal	Average Daily Idle Duration During Season (hr/day)	Standard Deviation	Coefficient of Variance	Idling Percentage of Total Engine Run-Time
Winter	7.3	4.4	0.61	39%
Spring	5.1	4.6	0.90	29%
Summer	6.7	4.6	0.69	36%
Fall	5.1	4.5	0.88	29%

TABLE 6 Average Daily Idle Duration for Selected Subsets of Survey Population

Criterion	Subset of Sample	Average Idle Duration[a] (hr/day)
Ownership	Owner-Operator	5.12
	Leasing company	6.33
	Fleet	6.05
Company size (number of tractors)	1	5.41
	2-24	6.54
	25-99	5.74
	100-999	5.92
	1000+	5.84
Methods taken to reduce idling	None	6.39
	Financial incentive for reduced fuel usage	5.47
	Automatic engine shutoff	5.38
	Automatic engine start-up	5.30
	Punishments for excessive idle	5.12
	Training on decreasing idling	3.73
Driver age	<30	5.87
	30-39	6.05
	40-49	6.40
	50+	4.96
Driving experience (yrs)	<5	6.30
	5-9	5.32
	10-19	6.41
	20-29	6.06
	30+	3.55
Education	Some high school	5.59
	High school diploma	6.06
	Some college	5.97
	College degree	5.72

[a] The differences between the numbers in bold from the rest of the sample are statistically significant at a 90% confidence interval.

tically significant. Among companies with 25 or more tractors, the average idling duration was about the same or slightly lower than the survey average of approximately 6 h/day. However, the average for the small fleets of 2 to 24 tractors was higher (6.5) than the survey average (5.9). This result hints that larger firms may be more successful at implementing formal strategies (e.g., fuel economy bonus, automatic idling shutoff) to reduce idling. Some evidence for this is seen in Table 7, which catalogs the methods taken by different size fleets to reduce idling. Small fleets of 2 to 24 tractors were the most likely (with 58% of responses) of any company size group to offer no program or strategy to reduce idling. Owner-operators are most likely to pursue no idle reduction strategies, with 62% of responses. The largest companies, with more than 1,000 tractors, were most likely to have some program or strategy to reduce idling among their

TABLE 7 Truck Company Efforts to Reduce Idling

Method or Strategy to Reduce Idling	Percentage of Responses from Given Groups That Reported That Their Company Utilized Each Idle Reduction Method						
	Owner-Operators	Leasing Company	Company Size (# trucks)				All Drivers
			2-24	25-99	100-999	1000+	
None	62%	24%	58%	35%	33%	25%	41%
Financial incentive for reduced fuel usage	9%	28%	16%	27%	26%	39%	24%
Automatic engine shutoff	7%	40%	20%	35%	23%	28%	24%
Automatic engine start-up	2%	20%	10%	12%	7%	15%	11%
Punishments for excessive idle	0%	0%	4%	12%	7%	11%	6%
Training on decreasing idling	4%	16%	8%	4%	5%	16%	9%
Other	9%	12%	8%	19%	11%	21%	13%

drivers, with higher percentages than the average for all drivers in all strategy categories (i.e., financial incentives, automatic shutoff, etc.).

The oldest and most experienced drivers (more than 50 years old, more than 30 years of professional driving) had notably lower idling durations. These two driver trait subgroups were the only ones with statistically significant differences in idling patterns from the rest of the sample. Compared with the overall average of about 6 h spent at idle per day, drivers who were 50 years or older averaged only 5.0 h per day, and those that had professionally driven for at least 30 years averaged about 3.6 h. The nature of this trend is unclear, but possible factors could be the increased experience these drivers had with the long-term costs of idling, their higher likelihood of owning their trucks, their decreased overall workload in older age (their average daily driving times were also lower), or their increased sensitivity to idling-related sleep discomfort.

Engine Operation at Idle

Engine speed, measured in revolutions per minute (rpm), has a substantial effect on fuel consumption and emissions of heavy-duty trucks at idle (*7, 10, 12, 19*). Because drivers can adjust the setting for engine speed, information was requested about the engine revolutions per minute setting and whether and for what reason drivers change that setting. Generally, factory default settings for engines are lower than those that drivers reported to us, ranging from 600 to 700 rpm. When respondents were asked the idle speed of their engines, the average response was about 870 rpm, with responses fairly evenly distributed from 600 to 1,200 rpm and small peaks around 650 and 1,000 rpm (see Figure 2). While responses might have been biased by wintertime interviewing, similar responses were received in the summer 2001 California pilot survey, with a mean accessory loading engine speed of 850 rpm and peaks in the distribution of responses greater and less than the mean (*16*). About 33% of drivers reported that they periodically change their engine speed from their more usual setting. Drivers offered many different explanations for changing their engine speed, including increased power for air-conditioning, increased electric power for accessories, reduced engine vibration, reduced engine noise, reduced problems with respect to oil (maintain oil pressure, circulation), and ability to maintain sufficiently high engine temperature in the winter. It should be noted that drivers do not always adjust to the same speed or for the same time duration. For example, some drivers indicated increasing engine speed for increased power for a particular accessory for several hours, while others increased engine speed for consecutive months while driving in northern winter climates.

Fuel Consumption

Figure 3 shows the distribution of reported fuel economy values. The responses were fairly evenly distributed from 6 to 6.5 mi/gal. Dividing the reported annual miles driven by the reported annual fuel economy gives an estimate of the total diesel fuel consumption per vehicle. Using this method of approximating total annual fuel use, it is found that 70% of driver respondents consumed between about 10,000 and 24,000 gal of diesel per year, with a mean of about 19,000 gal.

The amount of fuel consumed while the vehicle is at idle was estimated from the reported engine speed at idle. As stated above, engine speed (rpm) has a substantial effect on fuel consumption of heavy-duty trucks at idle (*7, 10, 12, 19*). Although accessory loading from the alternator electric loads and the air-conditioning compressor consumes substantial energy, engine speed appears to be much more important. A strong relationship was found between idle fuel consumption and engine speed by using data from an EPA study with 42 different tests on nine idling trucks of different model years with different loading conditions (*10*). A linear regression model ($r^2 = 0.81$) was used. This general regression, including results for all idling conditions in the EPA report, was used to derive the idling fuel consumption, in gallons of diesel fuel per hour, from the idle engine speeds reported for each driver.

On the basis of survey data about engine speed at idle, the annual idling fuel consumption and the associated cost for each driver were estimated. As shown in Figure 4 the mean result for instantaneous idling fuel consumption is 0.85 gal/h. Ninety percent of respondent cases fall between 0.5 and 1.5 gal/h. Annual idled fuel consumption in gallons per truck per year was estimated by multiplying these results by each driver response for daily idle duration (h/day) and annual truck operation (day/year) (see Figure 4). The mean annual fuel used during idle is 1,600 gal, but the standard deviation of about 1,300 indicates that the values vary widely. More than 25% of responses for idled fuel are more than 2,300 gal of fuel per year, and 10% are more than 3,400 gal per year. In turn, these values were translated into the total cost of the idled fuel for each driver using the Energy Information Administration's data on spot diesel prices (*21*). The average U.S. diesel price during the period from January 21, 2002, to January 13, 2003 (the year directly preceding the administration of the survey), was $1.33/gal. At those prices the average truck idled about $2,000 per year worth of fuel, but an estimated 25% of drivers used more than $3,000 per year of fuel during idle, and 10% of drivers spent more than $4,500 per year.

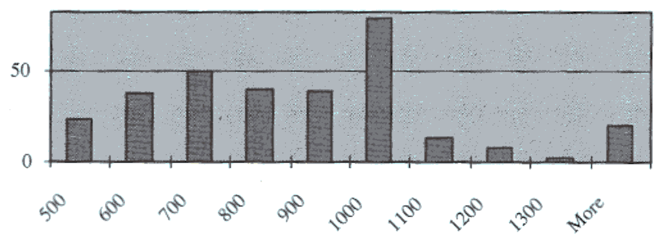
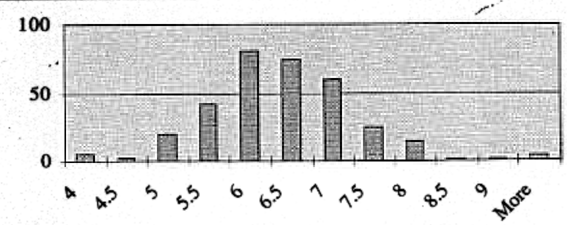
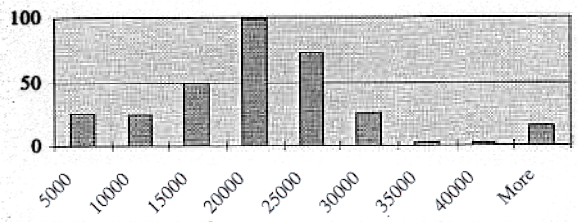
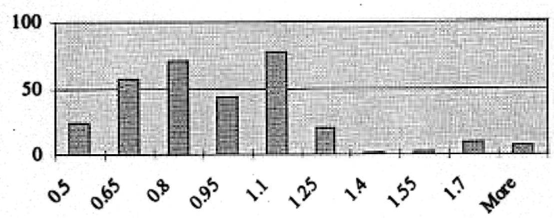
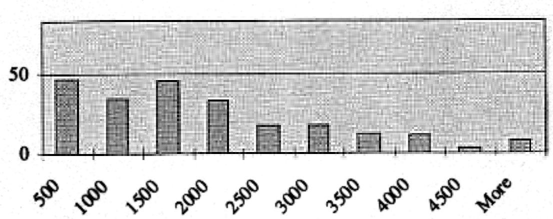
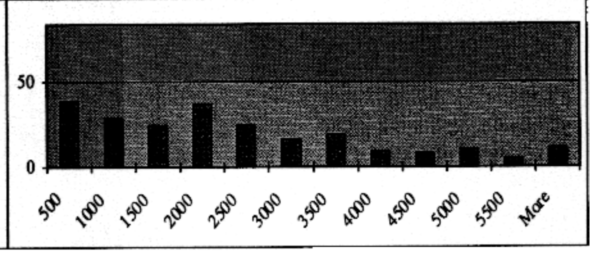
Variable	Number of Driver Responses	Mean (st. dev.)	Distribution of Responses
Idle engine speed (rpm)	315	866 (280)	

FIGURE 2 Engine speed (rpm) settings at idle.

Variable	Number of Driver Responses	Mean (st. dev.)	Distribution
Fuel economy (mpg)	329	6.3 (0.9)	
Total annual fuel consumption[a] (gal/yr)	320	18,846 (11,245)	

[a] This distribution was not directly reported on by surveyors and was calculated as (annual miles driven) / (mpg).

FIGURE 3 Reported and calculated fuel consumption characteristics of long-haul trucks.

Variable	Number of Driver Responses	Mean (st. dev.)	75th %-tile, 90th %-tile	Distribution
Fuel consumption at idle[a] (gal/hr)	316	0.85 (0.30)	1.0, 1.2	
Annual idled fuel[b] (gal/hr)	229	1636 (1274)	2,370, 3,440	
Annual cost of fuel consumed at idle[c] ($/yr)	229	2,178 (1,697)	3,170, 4,580	

These distributions were not directly reported by surveyors, but were calculated as indicated by the footnotes to this table.
[a] Derived from EPA test data on idle engine speed (rpm) and fuel use. Linear regression model generated the following relationship with $r^2 = 0.81$: (gal/h) = 0.0011 (rpm) – 0.0099 [for test data see Lim, 2000 (*10*)].
[b] Calculated as (gal/h idled) (h idled/day) (days/yr operation).
[c] Calculated as (annual idled fuel gal/yr) (diesel $/gal), diesel price is average from 1/21/02 to 1/13/03, $1.33 per gallon, the year directly preceding the survey (*21*).

FIGURE 4 Cost and quantity of idling fuel consumption for long-haul trucks.

CONCLUSIONS

This study provides an enhanced understanding of long-haul truck idling behavior and activities. Long-haul trucks are idled for extended periods on a daily basis although idling behavior varies widely with respect to a variety of factors. The survey found that the average idling duration was about 6 h per day and about 1,700 h per year per truck. Because there are so many of these trucks and they are used so extensively, the emissions, fuel, and cost consequences are substantial. On average, these trucks consume about 1,600 gal/year for idling, though this varies widely, with about 10% of trucks annually consuming more than 3,400 gal.

These research findings have repercussions for air quality planners, the trucking industry, and developers of advanced idling-reduction technologies. They are important for air quality agencies because many drivers routinely set their engine speeds higher with higher accessory loads than is assumed by regulatory agencies in the derivation of emission factors. Thus, emissions are being significantly underestimated. The findings are important for trucking companies attempting to educate their drivers on the negative consequences of idling. Although most companies have implemented some strategy or policy to reduce idling, it was found that most of these efforts, including punishments for excessive idling or incentives for decreased fuel use, are not well correlated with reduced idling duration. And finally these findings are key to developing advanced technology alternatives, such as APUs and grid-connection services, to provide heating, cooling, and electricity for various in-cabin accessories. The more extreme idlers, with annual idling losses of several thousand dollars, are attractive early adopters of APUs and grid-connection services.

ACKNOWLEDGMENTS

The authors are grateful to the many people who contributed to this project. Patricia Mokhtarian helped with survey design, wording, and analysis. S. William Gouse III of the American Trucking Associations helped refine questions. George Strickland and the general managers at the six TravelCenters of America survey locations provided permission and access to the truck stops. Graduate students from the Institute of Transportation Studies at the University of California, Davis (ITS-Davis)—David Grupp, Jonathan Weinert, Dan Rubins, Ryan Hammond, Thomas Barron, Ethan Abeles, Sondra Rosenberg, Michael Nicholas, Belinda Chen, and Ryan McCarthy—interviewed truck drivers at truck stops around the country. UC-Davis student Shonket Ray proficiently aided in analyzing the survey data. The U.S. Department of Energy and Freightliner LLC provided funds for this study, with additional student funding support provided by the National Science Foundation's IGERT grant to ITS-Davis.

REFERENCES

1. *Vehicle Inventory and Use Survey* (CD-ROM CD-EC97-VIUS). U.S. Department of Commerce, Feb. 2000.
2. Levinson, T. Anti-Idling Laws and Regulations. The Maintenance Council Annual Meeting, Nashville, Tenn., March 15, 2001. www.transportation.anl.gov/ttrdc/pdfs/TA/73.pdf. Accessed Aug. 5, 2002.
3. Texas Administrative Code. *Control Requirements for Motor Vehicle Idling, Rule §114.502.* Jan. 18, 2001.
4. *National Energy Policy: Reliable, Affordable, and Environmentally Sound Energy for America's Future.* Report of the National Energy Policy Development Group. U.S. Office of the Vice President, Washington, D.C., 2001.
5. Stodolsky, F., L. Gaines, and A. Vyas. *Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks.* ANL/ESD-43. Argonne National Laboratory, Argonne, Ill., 2000.
6. McCormick, R. L., M. S. Graboski, T. L. Alleman, and J. Yanowitz. Idle Emissions from Heavy-Duty Diesel and Natural Gas Vehicles at High Altitude. *Journal of the Air and Waste Management Association,* Vol. 50, 2000, pp. 1992–1998.
7. Brodrick, C. J., M. Farshchi, H. A. Dwyer, D. B. Harris, F. G. King, Jr. Gaseous Emissions from Idling of Heavy-Duty Diesel Truck Engines. *Journal of the Air and Waste Management Association,* Vol. 52, Sept. 2002, pp. 174–185.
8. Gautam, M., N. N. Clark, W. S. Wayne, G. Thompson, D. W. Lyons, W. C. Riddle, and R. D. Nine. Qualification of the Heavy Heavy-Duty Diesel Truck Schedule and Development of Test Procedures. Final Report, CRC Project No. E-55-2. Prepared for California Environmental Protection Agency, Air Resources Board and Coordinating Research Council, Inc. March 2002. www.crcao.com/reports/recentstudies00-02/e-55-59/The%20Final%20Report_E55-2.pdf. Accessed Aug. 11, 2002.
9. Traver, M. L. Interlaboratory Crosscheck of Heavy-Duty Vehicle Chassis Dynamometers. Final Report, CRC Project No. E-55-1. Prepared for California Environmental Protection Agency, Air Resources Board and Coordinating Research Council, Inc. Automotive Testing Laboratories, Inc. 2002. www.crcao.com/reports/recentstudies00-02/e-55-59/E-55-1%20Interlaboratory%20Crosscheck%20of%20Heavy-Duty%20Vehicle%20Dynamometers%20(Final%20 Report).pdf. Accessed Aug. 11, 2002.
10. Lim, H. *Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices.* EPA420-R-02-025. U.S. Environmental Protection Agency, Oct. 2002.
11. Storey, J., J. F. Thomas, S. A. Lewis, Sr., T. Q. Dam, K. D. Edwards, G. L. DeVault, and D. J. Retrossa. Particulate Matter and Aldehyde Emissions from Idling Heavy-Duty Diesel Trucks Oak Ridge National Laboratory. *SAE Technical Paper Series* 2003-01-0289, SAE, Warrendale, Pa., 2003.
12. Pekula, N., B. Kuritz, J. Hearne, A. J. Marchese, and R. P. Hesketh. The Effect of Ambient Temperature, Humidity, and Engine Speed on Idling Emissions from Heavy-Duty Diesel Trucks. *SAE Technical Paper Series* 2003-01-0290, SAE, Warrendale, Pa., 2003.
13. Brodrick, C. J., M. Farshchi, H. A. Dwyer, S. W. Gouse III, M. Mayenburg, and J. Martin. Demonstration of a Proton Exchange Membrane Fuel Cell as an Auxiliary Power Source for Heavy Trucks. *SAE Technical Paper Series* 2000-01-3488, SAE, Warrendale, Pa., 2000.
14. Brodrick, C. J., N. P. Lutsey, Q. A. Keen, D. I. Rubins, J. P. Wallace, H. A. Dwyer, D. Sperling, D., and S. W. Gouse III. Truck Idling Trends: Results of a Northern California Pilot Study. *SAE Technical Paper Series* 2001-01-2828, SAE, Warrendale, Pa., 2001.
15. Brodrick, C. J., T. Lipman, M. Farshchi, N. Lutsey, H. A. Dwyer, D. Sperling, S. W. Gouse III., B. Harris, and F. King, Jr. Evaluation of Fuel Cell Auxiliary Power Units for Heavy-Duty Diesel Trucks. *Transportation Research, Part D,* Vol. 7, 2002, pp. 303–315.
16. Lutsey, N., C. J. Brodrick, D. Sperling, and H. A. Dwyer. Markets for Fuel-Cell Auxiliary Power Units in Vehicles: Preliminary Assessment. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1842,* TRB, National Research Council, Washington, D.C., 2003, pp. 118–126.
17. Lutsey, N., J. Wallace, C. J. Brodrick, H. A. Dwyer, and D. Sperling. Modeling Stationary Power for Heavy-Duty Trucks: Engine Idling Versus Fuel Cell APUs. *SAE Technical Paper Series* 2004-01-1479, SAE, Warrendale, Pa., 2004.
18. Antares Group, Inc. *Truck Stop Electrification (TSE) Market Study and Preliminary Design.* Prepared for Niagara Mohawk Power Corporation, Jan. 2001.
19. Tario, J. D. *Truck Stop Electrification in New York State.* New York State Energy Research and Development Authority, Feb. 2003.
20. Maldonado, H. Development of Heavy Duty Truck Chassis Dynamometer Driving Cycles for Source Testing for Emissions Modeling. 12th CRC On-Road Vehicle Emissions Workshop, April 15–17, 2002.
21. Weekly On-Highway Diesel Prices. Energy Information Administration, U.S. Department of Energy, 2003. tonto.eia.doe.gov/oog/ftparea/wogirs/xls/psw18vwall.xls. Accessed April 17.

Publication of this paper sponsored by Transportation and Air Quality Committee.