Comparisons of Discretionary Passenger Vehicle Idling Behavior by Season and Trip Stage with Global Positioning System and Onboard Diagnostic Devices

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This study addresses the comparisons of discretionary passenger vehicle idling by using field data collected from 20 volunteers in Vermont. Each volunteer participated in two 2-week data collection periods, one in the summer and one in the winter. Overall, 15.6% of vehicle-operating time was spent idling, consistent with the limited existing data on this topic. In addition, the paper describes a processing method used with an in-vehicle Global Positioning System and onboard diagnostic data that allows discretionary idling at the start and end of trips to be separated from the in-travel idling related to traffic or traffic control. Discretionary idling accounted for more than 6.5% of vehicle operating time. Discretionary winter idling events were found to be longer than summer idling events and, for idling events greater than 60 s, trip-start idling was found to be longer than trip-end idling. Both of these results reaffirm previous findings suggesting that there are opportunities for behavioral changes to reduce idling. The method used to extract discretionary idling is promising for widespread use and large sample data collection efforts. This method will be critical for the many communities that lack robust idling data when considering the costs and benefits of idling behavior change initiatives.

Passenger vehicle idling, defined as time periods when the engine is on but the vehicle is not moving, consumes fuel and produces both greenhouse gas (GHG) and criteria pollutant emissions. A 2009 study by Carrico et al. estimated that approximately 1.6% of total U.S. GHG emissions could be attributed to vehicle idling (*1*). Idling increases the cost of vehicle operation and exacerbates negative health and environmental externalities associated with vehicle use. Because this behavior imposes costs to the individual and the larger society but provides limited or no benefits, it is a logical target for efforts to reduce fuel consumption and GHG emissions and to improve air quality.

Most idling reduction efforts to date have focused on large diesel vehicles, usually trucks or buses, which have a tendency to sit idle for long periods of time. Consequently, as of 2012, 21 states have statewide idling laws that cover trucks, with only five states (Connecticut, Hawaii, Maryland, Massachusetts, and Virginia) including all motor vehicles in their idling restrictions (*2*). There is relatively little information, however, about the duration and frequency of idling events for passenger vehicles, especially discretionary idling at the start or end of trips. Additional research in the area of discretionary idling is needed to assess the fuel and emissions gains possible from targeting behavior change and informing programs that target idling-reduction awareness and behavior change.

The data for this paper came from a field study of discretionary passenger vehicle idling in the state of Vermont. With a Global Positioning System and onboard diagnostic (OBD) data loggers, vehicle-speed data were collected from a group of 20 volunteers for two 2-week periods (summer of 2011 and winter of 2012). In addition, an estimate is presented of the total percent of vehicle operating time that is spent at idle, a new method to classify idling events as either discretionary or nondiscretionary according to whether the events occurred at a trip end or in travel. The duration of all idling events and the subset of discretionary idling events were then compared statistically for seasonal differences for the 15 volunteers who participated in both the summer and winter data collection periods. The length of trip-start discretionary idling events was also compared with the length of trip-end idling events.

For this paper, discretionary idling is defined as idling that occurs at either trip starts or trip ends. Trip-start idling occurs after the engine is turned on ("key-on") and before the vehicle moves for the first time. Trip-end idling events occur after a vehicle has arrived at its destination and before the engine has been turned off ("key-off"). In the case of trip chaining, trip-end idling events can occur at intermediate destinations and thus multiple trip-end idling events may occur during a single key-on to key-off operating period. While trip-start and trip-end idling cannot be completely eliminated, the duration of these idling events is controlled largely by the driver and can be considered part of travel or driver behavior. In-travel idling events occur when the vehicle is stopped before reaching its destination because of conditions such as congestion or a red traffic signal that is outside the driver's control. Recent research suggests turning off a vehicle under these circumstances may have adverse safety consequences and, therefore, in-travel idling is considered nondiscretionary (*3*).

The distinction between discretionary and in-travel idling is critical because different interventions may be required to reduce the duration and frequency of each of these types of events. Discretionary idling events, for example, could be reduced with anti-idling ordinances (*2*) and driver education programs such as ecodriving (*4*). Reducing in-travel idling, in contrast, may depend on factors such as retiming signals, reducing congestion, or vehicle routing. Both in-travel and

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discretionary idling can be reduced or eliminated by vehicle technology that automatically shuts off or starts up the engine when the vehicle stops and starts although some research suggests that this approach may have drawbacks in regard to some air pollutants (*5*). This study is focused solely on discretionary idling that may be addressed through behavior change. Following a review of the types of literature that have addressed idling, the data collection and analysis are described, followed by the results of the seasonal and trip-start versus trip-end comparisons.

BACKGROUND AND LITERATURE REVIEW

Although real-time information on the idling behavior of long-haul trucks, motor coaches, and buses has become increasingly available, similar data on the idling behavior of passenger vehicles, including cars and light-duty trucks, are scarce. A recent national survey of 1,300 drivers found drivers spend considerable time idling, on average 16 min per day (*1*). A series of studies for Natural Resources Canada found that drivers self-reported only about 8 min of idling behavior per day, but were observed idling between 1.5 and 3 min per stop (*6, 7*). Robust in-vehicle data collection for idling observation during a multiday study period is an essential complement to self-reported information to accurately estimate behavior change benefits and self-reporting biases.

A significant amount of research during the past decade has been focused on passenger vehicle tailpipe emissions, including those occurring during idling. Many studies have used in-vehicle devices such as those used in this study (*8–13*). Some on-road data collection efforts focus on a controlled specific route to study differences between drivers, road types, and vehicle-operating modes (*8–10*). Focus on a specific test route, even when it represents typical real-world driving conditions, systematically eliminates the ability to study discretionary idling as part of driver and travel behavior. Others are interested in driving style including the interaction of road type and driver attributes (*11–13*). These efforts capture in-travel idling but not discretionary idling at trip ends.

Emissions models, such as EPA's MOVES2010 model, focus on emissions factors for different operating modes and include idling as one vehicle operating mode. Data collection for these models includes the amount of emissions during idle, which is significantly lower per unit time than with other modes such as acceleration and cruise (*14*). Efforts have also been made to understand start emissions that are accounted for in MOVES2010 and other models. Understandably more effort to date has been on the higher-emitting modes such as acceleration. Recently, Papson et al. used MOVES2010 to consider the emissions at intersections under various conditions including consideration of the amount of idling time (*15*). Their results suggest a need for improvements in how in-travel idling is modeled. A large body of previous research has focused on in-travel idling and the traffic control and management strategies that can reduce congestion and thus idling, such as retiming traffic signals and other congestion management techniques [recent examples include Li et al. (*16*) and Lv and Zhang (*17*)].

In 2003 Taylor conducted a review of existing studies of idling in North America and Europe. Of the four studies covering nine or more cities, he found two had been able to estimate the extent of discretionary idling (*18*). All idling was found to be between 13% and 23% of the total vehicle operating time. Extended idle (events longer than 10 min) ranged between 1% and 7% of the total idling time. Pretrip idling ranged between 14% and 15% of total idling time. In one of the data sets reviewed, idling time was found to increase with trip length. A more recent study by Aultman-Hall of more than 250 passenger vehicles and 10 days of routine travel in Lexington, Kentucky, showed vehicles were idle about 24% of total vehicle operating time but no distinction was made between discretionary and nondiscretionary idling (unpublished data). The ranges of estimates for the total amount of idling are large and no doubt vary by region because of congestion. But they also point to the need for more data and indicate that discretionary idling is a meaningful proportion of idling, which merits study.

Few studies have evaluated the effect of countermeasures that attempt to alter discretionary idling behavior. Studies on truck idling have identified different successful approaches to reducing truck queue or congestion idling versus overnight idling (*19, 20*). Beusen et al. found that ecodriving training did not have a long-term effect on the amount of idling but did not distinguish between discretionary and nondiscretionary idling (*21*). Numerous Canadian communities have undertaken awareness and education campaigns (*22*), some in combination with regulation, but behavior change and the actual levels of idling have not been measured (*18*).

In summary, very little comprehensive information exists about the nature of passenger vehicle idling behavior including the distinction between discretionary versus nondiscretionary idling and how each varies by season and trip stage. From a research perspective, a robust method to distinguish between idling behavior that can be prevented through driver behavior (discretionary) and the time a vehicle is idling as a result of queuing or traffic measures beyond the driver's control (nondiscretionary) is needed. This paper describes such a method, which uses synchronous in-vehicle GPS and OBD data, and presents aggregate idling behavior results by season for a sample of 20 volunteers monitored for a total of 4 weeks.

DATA COLLECTION AND PREPARATION

Volunteer Recruitment

Study participants were recruited between March and June of 2011 via advertising placards on gas pumps at three gas stations located in northern, central, and southern Vermont and via a posting on the University of Vermont Transportation Research Center's main web page. To avoid influencing the volunteers' idling patterns, the recruitment materials stated only that the study was intended to characterize driver behavior to improve transportation modeling. Volunteers who drove hybrid vehicles were excluded from the study group since hybrid engines generally do not operate when the vehicles are not in motion and thus do not idle in the traditional sense. In addition, pre-1996 model year vehicles were excluded, since these vehicles are not compatible with the OBD logging device used for this study.

Data collection for summer 2011 was initiated with 26 volunteers. Analysis of the summer data revealed a problem using data from vehicles in which the 12-V adapter did not shut off with the engine. Because of this problem, three volunteers from the summer 2011 period were not asked to participate in the winter 2012 period. Scheduling difficulties also prevented three volunteers from participating in the winter 2012 study period. The winter 2012 data collection period, therefore, included 20 returning volunteers. Following preprocessing, the valid, usable OBD and GPS data for 17 volunteers in the summer group and 18 in the winter group were merged, yielding a total of 8,101 idling events—4,508 in the summer and 3,593 in

the winter. A total of 15 individuals have data in both the summer and winter. The aggregate data set included data from 20 separate volunteers.

Resources for this study were limited; the sample was not intended to be representative, and no effort was made to extrapolate these results to estimate statewide idling. Plans are under way for a second study with a larger sample from which representative results are sought.

Vehicle Instrumentation

To collect second-by-second engine status and vehicle-speed and position data for this study, each volunteer's vehicle was instrumented with two devices, a GPS and an OBD data logger, for a 2-week period in the summer of 2011 and again in the winter of 2012. For each vehicle, a GeoLogger GPS data logger manufactured by GeoStats recorded time-stamped records for latitude and longitude, the vehicle's speed, and the vehicle's heading. The GeoLogger has several features that made it desirable for this study. The device is powered by the vehicle's DC power system via the cigarette lighter or power outlet so that it operates only when the vehicle is turned on. Unlike many commercial vehicle-tracking systems that are hardwired into the vehicle's power system, it is easy to install and remove from a volunteer's vehicle. In addition, it records data on a second-by-second basis and continues to record data even when the vehicle is not moving. The GeoLogger also has adequate memory capacity to record 2 weeks' worth of travel data, and the data are easily downloaded and exported into other programs.

The GeoLogger also had some limitations for this application. It has a cold-start satellite-acquisition time of approximately 45 s, but the actual satellite acquisition time can be considerably longer, meaning that idling events at the trip start may be missed. Similarly, as with all portable GPS devices, obstructions may result in the loss of satellite lock during travel, causing gaps in the GPS data records. Finally, the speeds reported by the GeoLogger are occasionally inconsistent with the speeds apparent from the positional data and thus postprocessing is required to flag problematic speed records.

To compensate for some of the deficiencies in the GPS data, particularly the lag between key-on and satellite acquisition and occasional problematic speed records, speed data were also collected from the vehicle's OBD system by using a MiniDL OBD logger manufactured by EASE Diagnostics. The logger plugs into the vehicle's OBD port and can record a range of information from the vehicle's computer system. In this case, the OBD recorded vehicle speed, engine RPMs, and relative throttle position, although only vehicle speed was used for this study. This device provided uninterrupted, continuous speed data from a few seconds after key-on until key-off. The sampling rate for the OBD logger depends on the number of OBD outputs that the device is recording but was under 1 s for all of the data collected in this study.

METHODS

Data Synchronization

The data were downloaded by using the proprietary software provided by the devices' manufacturers and then exported as comma-separated-value files for synchronization. The OBD logger provides separate data files for each key-on to key-off vehicle operating period. It also provides the start time for each operating period and the elapsed time between each record in an operating period. The OBD logger determined the start time for each operating period from the vehicle clock. Since an operating period lasts from key-on to key-off, it can consist of either a single trip or multiple trips in a trip chain in which the vehicle was not turned off at one or more intermediate destinations.

The GeoLogger outputs a single data file for the entire study period with a flag indicating the first record in each set of continuous GPS data points that constitute a GPS data segment. Because the GPS device sometimes lost satellite lock, several GPS data segments could correspond to a single operating period. Processing of the GPS data included separation of GPS data by day and then by individual GPS data segments. In addition, the change in distance between second-by-second GPS positions was compared with the GPS speed records to identify questionable speed records in which the apparent distance traveled did not match the distance that would have been traveled if the recorded speed was accurate.

Once the GPS data were separated into continuous data segments, the first step in synchronizing data from the two devices was to assign each GPS data segment on a given day to a corresponding operating period from the OBD data for that day. The next step was to match the OBD and GPS records on a second-by-second basis. Because, as discussed previously, the GPS generally took longer to begin recording data than the OBD, the first record in the GPS data rarely corresponded with the first record in the OBD data and matching the two data sets based on their start-time stamps was not sufficiently accurate because of the lack of reliability in the OBD time values. Instead, since both devices stop recording when the ignition is turned off, the program aligned the data sets backward from the final record in each data set. To account for slight discrepancies in the sampling rate, the program automatically adjusted the alignment by a few seconds in either direction and selected the alignment that produced the highest correlation coefficient between the GPS and OBD speed records.

Creation of the Discretionary Idling Event Data Set

Once the OBD and GPS data sets were synchronized and merged, a new data set was created that consisted of all idling events as identified by zero-speed records in the OBD data. This data set contained one record for each idling event including the event duration, the vehicle position, and the cumulative heading change during the 20 s preceding the start of the idling event. When the GPS speed records showed a corresponding set of zero-speed records, the most frequent observation of the latitude and longitude position values from the GPS zero-speed records was recorded to the idling event. If the GPS speed data did not have a corresponding set of zero-speed records, the latitude and longitude that corresponded to the first OBD record in the series was assigned to the idling event. When there was no corresponding GPS data, the event was dropped from the data set.

The discretionary idling events at trip starts and at the final destination trip ends correspond to the first and last sets of zero-speed records in each operating period and are thus easily identified in the OBD data set. Discretionary idling events at intermediate destinations are more difficult to identify. This study combined spatial position and heading change criteria to identify idling events that are likely to correspond to trip ends at intermediate destinations.

To distinguish intermediate trip-end idling events from in-travel idling, the data were imported into a GIS environment that contained

data from the Vermont Center for Geographic Information (VCGI) and Caliper. The VCGI's data included Vermont town boundaries and Vermont town parcel boundaries layers. In addition, a layer of all roads and streets in Vermont, the rest of the New England states, New York, New Jersey, and Pennsylvania was used for the GPS analysis. This layer has exceptional coverage, even for minor roads, lanes, alleys, and some driveways, for the entire United States, based on 2007 Census Bureau files with additional enhancements by Caliper.

On the basis of the spatial criteria, idling events that were outside the traveled way were flagged as potential discretionary idling events. A hierarchical selection process in TransCAD was used to determine which idling events occurred in the traveled way. For the idling events that occurred in a Vermont town with a parcel layer (87% of the idling events), idling events in the public roadway parcel were selected. A section of public roadway parcel layer used in this analysis and example locations for in-travel and discretionary idling events are shown in Figure 1.

For the idling events that occurred outside Vermont or in a Vermont town where no parcel layer was available (13%), all points that were within 25 ft of the centerline of a road or street were considered in-travel and added to the selection set. This estimation method is subject to more error than the identification of idling events within the public roadway parcel. However, only a relatively low number of idling events required this logic (13%). The remaining idling events occurred outside the roadway and were flagged as potentially discretionary idling events.

For the heading change criteria, the cumulative heading changes preceding final trip-end idling events were assumed to be similar to the heading changes that would precede an intermediate destination trip end. On the basis of previous work, the team expected that trip ends would most likely be preceded by a significant heading change, while nondiscretionary idling events would be less likely to be preceded by a significant turn (*23*). With this assumption, the 20-s heading change for this set of final destination trip-end idling events was analyzed to identify a minimum threshold that could be used to distinguish "significant" heading changes. An examination of the distribution of heading changes showed a break point at 88°. Therefore, the heading change method of distinguishing discretionary idling from nondiscretionary idling used a total 20-s heading change of 88° as the cutoff for whether or not an idling event is likely to be discretionary. Idling events with more than 88° of heading change in the 20 s preceding the event were considered discretionary, while those with less than 88° of heading change were considered nondiscretionary.

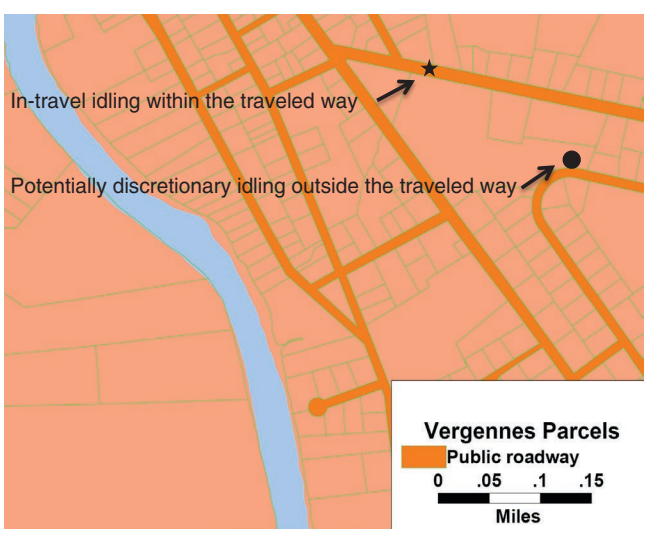

FIGURE 1 Characterization of idling events based on spatial criteria.

The heading change method of distinguishing discretionary idling events yielded a smaller number of events (2,893) than the spatial method (3,627), with 2,316 events in common between the two approaches. The mean length of a discretionary idling event was 19.5 s for the spatial method and 19.3 s for the heading change method, and distributions for the two sets were similar. On the basis of these findings, the idling events identified by both methods were considered the most conservative estimate of discretionary idling and were used for the final analysis of seasonal and trip-stage differences. The final set of discretionary idling events, therefore, consisted of all trip starts and final trip ends as well of those zero-speed segments that took place outside the roadway and were preceded by a heading change in excess of 88°.

Histograms of idle time durations for summer and winter idling events showed that the data are not normal but more closely resemble a lognormal or exponential distribution. Statistical fit testing was performed in MATLAB, and the results indicate that the distribution is best represented by a lognormal function. The fit testing is illustrated in Figure 2.

Two methods were used to compare the summer and winter idling events. First, for each data set, researchers calculated the maximum likelihood parameter estimates of the lognormal distribution that best fit each data set. Then these estimated lognormal distributions were compared by using an *F*-test. Second, each data set was compared by using the two-sample Kolmogorov–Smirnov (KS) goodness-of-fit hypothesis test. The KS test is a nonparametric, distribution-neutral test, with a null hypothesis that the data sets being compared come from the same distribution. This analysis was repeated by using only the 15 drivers that participated in both the summer and winter sessions to ensure that the seasonal findings were not an artifact of the difference in volunteer groups between the two sessions.

RESULTS

Across all volunteers, an average of 15.6% of vehicle operating time was spent at idle. Discretionary idling accounted for at least 6.5% of vehicle operating time, but the exact percentage is uncertain since idling events without GPS data could not be categorized as either discretionary or nondiscretionary. The percent of time at idle for individual operating periods ranged from less than 1% to 100% of the operating period. The median percent time at idle was 10.2% of the operating period. The average percent time at idle for individual volunteers during the study period ranged from as low as 8.2% of operating time to a high of 24.5% of total operating time. These values are within the range of values reported in Taylor (*18*) but lower than those found by Aultman-Hall (unpublished data).

For the 15 volunteers who participated in both the summer and winter study periods, the mean discretionary idling event duration was 18.6 s. The longest discretionary idling event was 738 s (12 min), and the median idling duration was 6 s. The mean duration of the discretionary summer idling events was 16.3 s, while the mean duration of discretionary winter idling events was 21.9 s. Statistical testing indicates that the distributions of winter and summer discretionary idling events differ significantly. The two-sample KS test rejects the

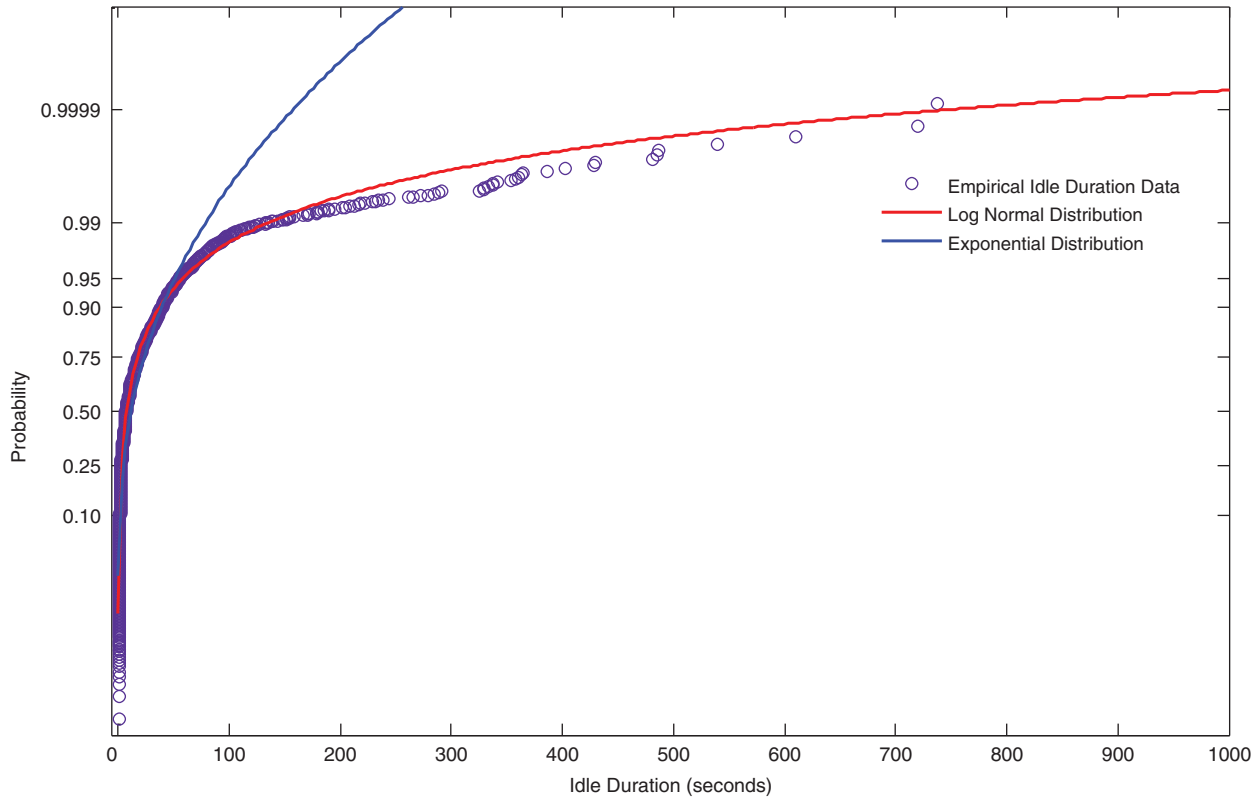

FIGURE 2 Fit testing of cumulative frequency distributions of idling events.

null hypothesis that the distributions are the same at a 0.04 significance level. The sample means for both winter and summer idling duration for all idling events (discretionary and nondiscretionary) are shown on the right-hand side of Table 1. The distribution of all winter and summer idling events is not significantly different, however. The two-sample KS test indicates a 71% significance level for the hypothesis that the distributions are the same.

As noted previously, these distributions fit a lognormal distribution best. Therefore, for each set, the lognormal parameters μ and σ were estimated to fit the lognormal probability density function:

$$y = \frac{1}{x\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(\ln x - \mu)^2}{2\sigma^2}\right]$$

where y is the relative likelihood that a random variable takes on a value, x. Results of the lognormal parameter estimations for μ and σ

TABLE 1 Selected Statistics for Discretionary Idling Events and for All Idling Events

	Discretionary Idling Events			All Idling Events		
Parameter or Statistic	Both Seasons	Winter	Summer	Both Seasons	Winter	Summer
General Characteristics of Durations of Idling Events						
Maximum duration (s)	738	738	720	738	738	720
Total duration (s)	36,620	17,676	18,944	119,268	50,177	69,091
Count	1,968	806	1,162	7,004	2,855	4,149
Sample mean (s)	18.6	21.9	16.3	17.0	17.6	16.7
Assuming a Lognormal Distribution of Durations of Idling Events						
μ	1.95	2.01	1.91	2.05	2.06	2.05
σ	1.20	1.28	1.15	1.22	1.24	1.21
Expected value (s)	14.4	16.9	13.1	16.3	16.9	16.2
Median (s)	7.0	7.5	6.8	7.8	7.8	7.8
Mode (s)	1.7	1.5	1.8	1.8	1.7	1.8

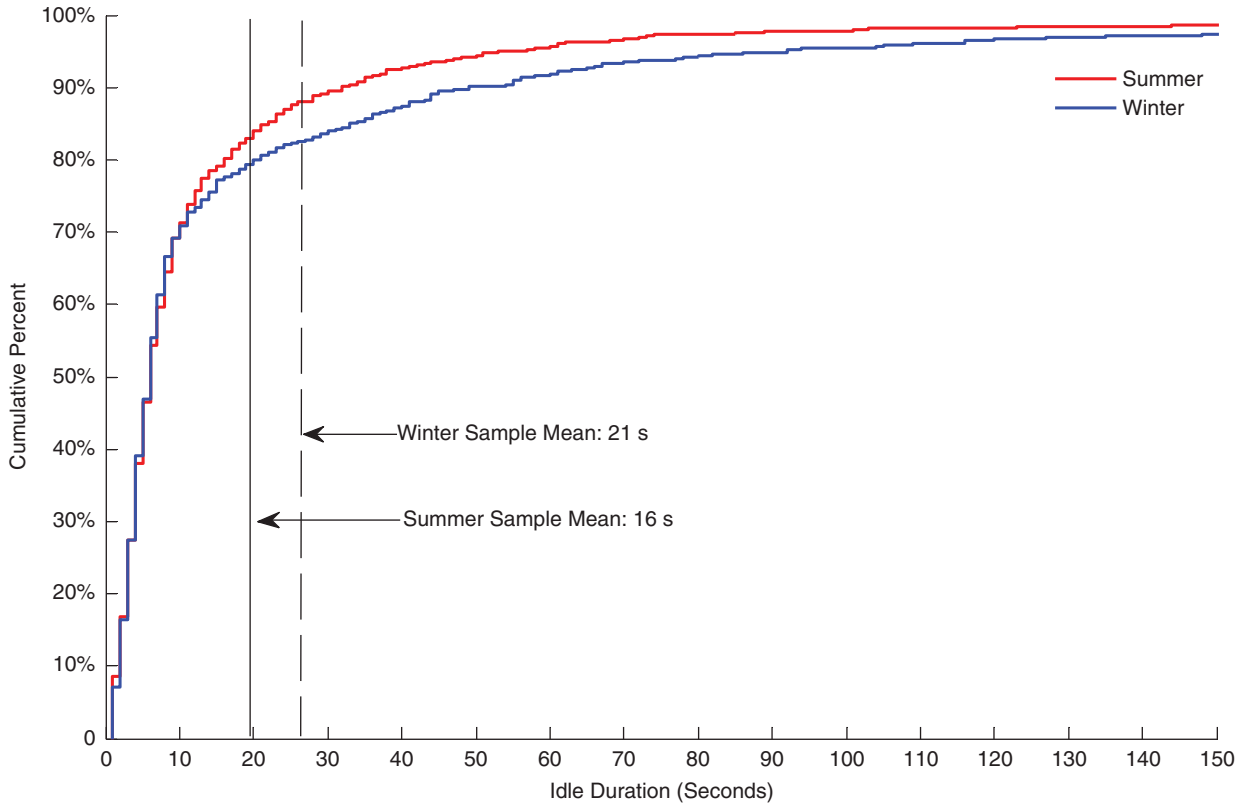

FIGURE 3 Cumulative frequency distributions of discretionary idling events.

and the resulting lognormal distribution descriptive statistics are also shown in Table 1.

A review of the arithmetic sample means and the expected values of these distributions clarifies the importance of the distributional assumption of lognormality. The expected values of the lognormal distribution reflect the true nature of the distribution. That is, the clustering of values nearer to the mode that is consistent with a lognormal distribution brings the expected value down closer to the mode. The cumulative-frequency distributions of the set of discretionary idling events for the 15 volunteers that participated in both study periods are shown in Figure 3, along with the sample means.

The cumulative frequency distributions shown in Figure 3 diverge significantly above 10 s in duration, and particularly between 10 s and 100 s. This divergence is reflected in the expected winter mean, which exceeds the expected summer mean with statistical significance, and in the estimated 85th percentiles of each distribution, which are 33 s and 22 s for winter and summer, respectively.

The trip-start, intermediate trip-end, and final trip-end idling events longer than 60 s for all 20 volunteers were then isolated for comparisons. The 60-s threshold represents the most conservative estimate of the point at which fuel savings from avoiding idling exceed the incremental maintenance costs associated with shutting off and restarting the vehicle (*1*). Idling events longer than 60 s are deemed to represent a clear economic loss for vehicle operators. Of the 8,101 idling events in the data set, 355 events were longer than 60 s. The sample mean, number of events, and lognormal parameters for the events for each trip stage are shown in Table 2. The two-sample KS test showed a significant difference in the distributions of trip starts and intermediate trip ends at the 0.05 significance level and between trip starts and final trip ends at the 0.1 significance level. The test showed no statistically significant differences between the distribution of intermediate and final trip ends.

The longest discretionary idling events follow key-on in the winter, likely reflecting some combination of the driver's desire to warm the interior of the vehicle and the belief that the vehicle's engine needs to be "warmed up" before it will perform well. Unfortunately, the sample size of idling events at this point is low, so this finding should be considered preliminary.

CONCLUSIONS

This research and a method to study discretionary idling are critical for three reasons. First, discretionary idling has distinct countermeasures from in-travel idling, and many communities are currently considering the costs and benefits of such programs. Second, the extent of

TABLE 2 Average Durations of Idling Events Longer Than 60 s, by Trip Stage

	Type of Discretionary Idling Event		
Parameter or Statistic	Trip-Start Idling	Intermediate Trip-End Idling	Final Trip-End Idling
Sample mean (s)	219.2	128.9	125.1
Count	71	125	37
μ	5.05	4.67	4.69
σ	0.78	0.54	0.51

discretionary idling and the GHG and other benefits possible from idling reduction are not well understood. Finally, the geographic distribution and factors associated with extended discretionary idling such as vehicle type or driver attributes have not been documented.

The data collected for this study show that vehicles idle for a considerable portion, 15.6%, of their operating time and that there are significant seasonal differences in discretionary idling events which, on average, represent at least 6.5% of vehicle operating time. Among discretionary idling events longer than 60 s, trip-start idling events are significantly longer than trip-end events and the longest idling events are winter trip starts.

However, since most discretionary idling events are of short duration, unless a pattern in the location of longer discretionary idling can be found, the ability to enforce discretionary idling restrictions may be limited. The education or the awareness effect of an anti-idling law that results in behavior change without enforcement may be the most effective approach. This increased awareness could incrementally improve short and long discretionary idles. These broader patterns can be better understood through the collection of a larger data set.

The promising method using passive in-vehicle devices and spatial analysis for distinguishing between discretionary and non-discretionary idling events demonstrated here will facilitate much larger, more representative samples for idling study in which patterns in idling between vehicle types, driver types, and locations can be sought in addition to season and trip end. Future work should also isolate long-duration discretionary idling events with predictive spatial, temporal, and demographic data.

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REFERENCES

1. Carrico, A. R., P. Padgett, M. P. Vandenbergh, J. Gilligan, and K. A. Wallston. Costly Myths: An Analysis of Idling Beliefs and Behavior in Personal Motor Vehicles. *Energy Policy,* Vol. 37, No. 8, Aug. 2009, pp. 2881–2888.
2. Laws Restrict Vehicle Idling in Vermont and Other States. Idle-Free Vermont. http://www.idlefreevt.org/idling-laws.html. Accessed April 30, 2012.
3. Jou, R.-C., Y.-C. Wu, and K.-H. Chen. Analysis of the Environmental Benefits of a Motorcycle Idling Stop Policy at Urban Intersections. *Transportation,* Vol. 38, No. 6, Jan. 9, 2011, pp. 1017–1033.
4. Barkenbus, J. N. Eco-driving: An Overlooked Climate Change Initiative. *Energy Policy,* Vol. 38, No. 2, Feb. 2010, pp. 762–769.
5. Robinson, M. K., and B. A. Holmén. Onboard, Real-World Second-by-Second Particle Number Emissions from 2010 Hybrid and Comparable Conventional Vehicles. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2233,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 63–71.
6. *Survey of Attitudes, Awareness and Behaviour of Drivers.* Research Report by the Office of Energy Efficiency, Natural Resources Canada, 1998.
7. Mckenzie-Mohr Associates and Lura Consulting. *Turn It Off: Reducing Vehicle Engine Idling.* Research Report by the Office of Energy Efficiency, Natural Resources Canada, 2001.
8. Frey, H. C., K. Zhang, and N. M. Rouphail. Fuel Use and Emissions Comparisons for Alternative Routes, Time of Day, Road Grade, and Vehicles Based on In-Use Measurements. *Environmental Science and Technology,* Vol. 42, No. 7, April 1, 2008, pp. 2483–2489.
9. Holmén, B. A., and D. A. Niemeier. Characterizing the Effects of Driver Variability on Real-World Vehicle Emissions. *Transportation Research Part D: Transport and Environment,* Vol. 3, No. 2, March 1, 1998, pp. 117–128.
10. Jackson, E., and L. Aultman-Hall. Analysis of Real-World Lead Vehicle Operation for Modal Emissions and Traffic Simulation Models. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2158,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 44–53.
11. Brundell-Freij, K., and E. Ericsson. Influence of Street Characteristics, Driver Category and Car Performance on Urban Driving Patterns. *Transportation Research Part D: Transport and Environment,* Vol. 10, No. 3, May 2005, pp. 213–229.
12. Ericsson, E. Independent Driving Pattern Factors and Their Influence on Fuel-Use and Exhaust Emission Factors. *Transportation Research Part D: Transport and Environment,* Vol. 6, No. 5, 2001, pp. 325–345.
13. De Vlieger, I., D. De Keukeleere, and J. G. Kretzschmar. Environmental Effects of Driving Behaviour and Congestion Related to Passenger Cars. *Atmospheric Environment,* Vol. 34, No. 27, 2000, pp. 4649–4655.
14. Barth, M. J., F. An, T. Younglove, G. Scora, C. Levine, M. Ross, and T. Wenzel. *The Development of a Comprehensive Modal Emissions Model.* Final Report for NCHRP Project 25-11. NCHRP, Transportation Research Board of the National Academies, Washington, D.C., 2000.
15. Papson, A., S. Hartley, and K.-L. Kuo. Analysis of Emissions at Congested and Uncongested Intersections with Motor Vehicle Emission Simulation 2010. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2270,* Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 124–131.
16. Li, J.-Q., G. Wu, and N. Zou. Investigation of the Impacts of Signal Timing on Vehicle Emissions at an Isolated Intersection. *Transportation Research Part D: Transport and Environment,* Vol. 16, No. 5, July 2011, pp. 409–414.
17. Lv, J., and Y. Zhang. Effect of Signal Coordination on Traffic Emission. *Transportation Research Part D: Transport and Environment,* Vol. 17, No. 2, 2012, pp. 149–153.
18. Taylor, G. W. R. *Review of the Incidence, Energy Use and Costs of Passenger Vehicle Idling.* Research Report by the Office of Energy Efficiency. Natural Resources Canada, 2003.
19. Thompson, M. R., and C. M. Walton. A Qualitative Review and Comparison of Operational Strategies for Reducing Freight Truck Fuel Consumption and GHG Emissions. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.
20. Lutsey, N., C.-J. Brodrick, D. Sperling, and C. Oglesby. Heavy-Duty Truck Idling Characteristics: Results from a Nationwide Truck Survey. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1880,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 29–38.
21. Beusen, B., S. Broekx, T. Denys, C. Beckx, B. Degraeuwe, M. Gijsbers, K. Scheepers, L. Govaerts, R. Torfs, and L. Int Panis. Using On-Board Logging Devices to Study the Longer-Term Impact of an Eco-Driving Course. *Transportation Research Part D: Transport and Environment,* Vol. 14, No. 7, 2009, pp. 514–520.
22. Lura Consulting. *The Carrot, the Stick, and the Combo: A Recipe for Reducing Vehicle Idling in Canadian Communities.* Research Report by the Office of Energy Efficiency, Natural Resources Canada and the Clean Air Partnership, 2005.
23. Du, J., and L. Aultman-Hall. Increasing the Accuracy of Trip Rate Information from Passive Multi-day GPS Travel Data Sets: Automatic Trip End Identification Issues. *Transportation Research Part A: Policy and Practice,* Vol. 41, No. 3, 2007, pp. 220–232.

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