A Report from the University of Vermont Transportation Research Center

Passenger Vehicle Idling in Vermont Phase II

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Passenger Vehicle Idling in Vermont
Phase II, Final Report

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UVM Transportation Research Center
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A Report for the Vermont Agency of Transportation

Executive Summary

While trip-start and trip-end idling, including idling at intermediary stops along a route, cannot be completely eliminated, the duration of these discretionary idling events is largely controlled by the driver and can be considered part of travel or driver behavior. In contrast, in-travel idling events (i.e. non-discretionary) occur when the vehicle is stopped prior to reaching its destination due to conditions such as congestion or a red traffic signal that are outside the driver's control. 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 and driver education programs such as eco-driving. Reducing in-travel idling, in contrast, may depend on factors such as retiming signals, reducing congestion or vehicle routing. Both in-travel and discretionary idling can be reduced or eliminated by vehicle technology which automatically shuts-off or starts-up the engine when the vehicle stops.

This study is solely focused on discretionary idling that may be addressed through behavior change. In this phase of the project, in-vehicle data collection was undertaken for 10-days each with 86 volunteers in Addison County Vermont between January and July 2013. The location and duration of each discretionary idling event was extracted from on-board instruments. The duration of discretionary idling was analyzed as a function of area type, weather, individual, household and vehicle variables.

The final aligned dataset covered 785.8 hours (2,828,890 seconds) of in-state vehicle operating time (VHT). These data included 15,484 separate zero speed events lasting nearly 79 hours (284,233 seconds). A total of 46% of the idling events was determined to meet the discretionary idling criteria. More than 55% of the total discretionary idling time occurred during events that lasted over 1 minute. In total, approximately 1% of greenhouse gas (GHG) emissions from passenger vehicles in this sample were associated with discretionary idling.

No relationship between idling duration and residential or retail density was found though more total idling events were recorded in built-up areas such as metropolitan areas than in open spaces and rural areas. More idling takes place on weekdays and during daytime hours. This is not unexpected as these times correspond to more travel and the types of locations where more trip ends occur. Women and drivers of older vehicles are most likely to be longer idlers. This provides limited guidance with which to identify targets for future programs for idling limitations, education and enforcement. However, discretionary idling was present for a significant portion of the sample suggesting that overall general education is critical.

No association between daily high or low temperature was found for discretionary idling in this sample of volunteers. This is in contrast to the phase I of this study where paired analysis was possible because given individuals were sampled twice, once in the summer

and once in the winter. Together this suggests that while small differences exist between seasons, larger differences exist between individuals, which likely related to knowledge level or travel patterns/needs.

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Introduction

The transportation sector in Vermont is the largest user of energy and the largest contributor to greenhouse gas (GHG) emissions in the state. The combination of rural land use patterns and limited public transit result in longer distances traveled and heavy reliance on automobile transport. The large percentage of GHG emissions being generated by the transportation sector makes it an important focus within the state for emissions-reduction targets and provided the original motivation for this study.

There are a number of behavior-based strategies that have been used to reduce GHG emissions by drivers. These strategies together are referred to as "eco-driving" and they include reducing idling, reducing rapid acceleration and deceleration, reducing speed on highways, keeping tires inflated, keeping engines tuned, and removing excess heavy cargo.

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 attribution to vehicle idling[1]. Idling increases the cost of vehicle operation and exacerbates negative health and environmental externalities associated with passenger vehicle use. Because this behavior imposes costs both 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 the 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 as well as to inform programs that target idling reduction awareness and behavior change.

For this project, 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

[1] Carrico, Amanda, Paul Padgett, Michael Vandenbergh, Jonathan Gilligan, Kenneth Wallston (2009). Costly Myths: An Analysis of Idling Beliefs and Behavior in Personal Motor Vehicles. *Energy Policy*. 37-8.
[2] Idle Free Vermont. (2012). Laws Restrict Vehicle Idling in Vermont and Other States. Accessed at http://www.idlefreevt.org/idling-laws.html on April 30, 2012.

events is largely controlled by the driver and can be considered part of travel or driver behavior. In contrast, in-travel idling events (i.e. non-discretionary) occur when the vehicle is stopped prior to reaching its destination due to conditions such as congestion or a red traffic signal that are outside the driver's control. Recent research suggests turning off a vehicle under these circumstances may have adverse safety consequences[3] and, therefore, in-travel idling is considered non-discretionary.

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[1] and driver education programs, such as eco-driving[4]. Reducing in-travel idling, in contrast, may depend on factors such as retiming signals, reducing congestion or vehicle routing. Both in-travel and 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 though some research suggests that this approach may have drawbacks in terms of some air pollutants[5]. This study is solely focused on discretionary idling that may be addressed through driver behavior change.

This study is part of a three-year joint research endeavor between the Vermont Agency of Transportation (VTrans) and the University of Vermont (UVM) Transportation Research Center (TRC). Field-based data was collected to advance our understanding of how discretionary driver behavior change can reduce passenger vehicle GHG emissions in Vermont. The primary goal of this project is to improve our understanding of discretionary idling behavior including the variations in passenger vehicle idling behavior in urban and rural towns, between demographic groups, and by season. The first phase of the project was completed in 2012 and included a pilot-test of a new comprehensive data collection method and spatial analysis techniques. The results of the phase I analysis were focused on an initial understanding of the seasonal differences in idling behavior. The pilot-scale results indicated that differences in discretionary idling behavior exist in Vermont between seasons. Vermonters tend to idle longer, as measured by individual zero speed events and total daily idling, in winter than in summer. Additionally, these results indicate that the additional winter idling may be attributable to the initial car "warming" event when the key is turned on for the first time each day.

Phase II of the project used the same field-based data collection methods developed in phase I. Using Global Positioning System (GPS) and onboard diagnostic (OBD) loggers, vehicle-speed data were collected from a group of 86 volunteers for 10-day periods between January and July 2013. Valid GPS and OBD data were recorded for 70 of these volunteers and combined with the data from 16 volunteers in phase I. In addition to calculating the total percent of vehicle operating time that is spent at idle, idling events

[3] Jou, Rong-Chang, Yuan-Chan Wu, and Ke-Hong Chen. (2011). "Analysis of the Environmental Benefits of a Motorcycle Idling Stop Policy at Urban Intersections." *Transportation* 38-6.
[4] Barkenbus, J. N. (2010). "Eco-Driving: An overlooked climate change initiative." *Energy Policy* 38.
[5] Robinson, Mitchell and Britt Holmen (2011). "Onboard, Real-World Second-by-Second Particle Number Emissions from 2010 Hybrid and Comparable Conventional Vehicles." *Transportation Research Record*, 2233.

were classified as either discretionary or non-discretionary based on whether the events occurred at a trip end or during travel.

The following research questions were examined for phase II of the project:

1. What are the most common locations and who are the most likely perpetrators of long discretionary-idling events? This was intended to try to identify targets for future programs for idling limitations, education and enforcement.
2. What are the temporal patterns of discretionary idling, including the impact of outdoor temperature, that will help develop targeted strategies to reduce or eliminate idling behavior? This use of actual daily temperatures was intended to advance findings from phase I where differences between winter and summer idling were found.
3. What amount of passenger vehicle GHG emissions result from discretionary idling statewide? This data will help policymakers understand the urgency of the problem as well as the GHG benefits that will accrue to program success.

On May 30, 2013, during the data collection on this project, Vermont Governor Peter Shumlin signed into law Act 57 (S.150)[6], which prohibits the idling of stationary motor vehicles for more than 5 minutes out of every 60 minutes[7]. Exceptions to the law are included for emergency vehicles during official operation, motor vehicles subject to highway traffic conditions or signalization, work vehicles requiring power for operation of auxiliary equipment, and when idling is necessary for the health or safety of an occupant. Penalties of $10, $50, and $100 for first, second, and third or subsequent violations, respectively, will be assessed. Driver education courses will be amended to include information on the effects of idling (environmental, economic, and otherwise), laws prohibiting idling, and associated penalties. The law went into effect on May 1, 2014.

[6] "The Vermont Legislative Bill Tracking System." 2013. *Vermont State Legislature*. Accessed September 27. http://www.leg.state.vt.us/database/status/summary.cfm?Bill=S.0150&Session=2014.

[7] Senate Committee on Transportation. *Act 57. An Act Relating to Miscellaneous Amendments to Laws Related to Motor Vehicles. Sec. 28. 23 V.S.A. § 1110*.

Previous Research and Background

While real-time information on idling behavior of long-haul trucks, motor coaches and buses has become increasingly available, similar data on idling behavior of passenger-vehicles, including cars and light-duty trucks, are scarce. A recent national survey of 1,300 drivers[8] found drivers spend considerable time idling, on average 16 minutes per day. A series of studies for Natural Resources Canada (NRC) found that drivers self-reported only about 8 minutes of idling behavior per day, but were observed idling between 1.5 and 3 minutes per stop[9],[10]. Robust in-vehicle data collection for idling observation over a multi-day study period is an essential complement to self-reported information in order to accurately estimate behavior change benefits and self-reporting biases.

A significant amount of research over the last decade has been focused on passenger vehicle tailpipe emissions, including those occurring during idling[11,12,13,14,15,16]. Many studies have used in-vehicle devices such as those used in this study. Some on-road data collection efforts focus on a controlled specific route in order to study differences between drivers, road types and vehicle operating modes. 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. These efforts capture in-travel idling but not discretionary idling at trip ends.

Emissions models, such the 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 include the amount of emissions during idle which are significantly lower per unit time than other modes such as acceleration and cruise[17]. 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

[8] Carrico, Amanda, Paul Padgett, Michael Vandenbergh, Jonathan Gilligan, Kenneth Wallston (2009). Costly Myths: An Analysis of Idling Beliefs and Behavior in Personal Motor Vehicles. *Energy Policy*. 37-8.
[9] Natural Resources Canada. (1998). *Survey of Drivers Attitudes Awareness and Behaviour*. December. Accessed at http://oee.nrcan.gc.ca/transportation/business/reports/14926 April 2012.
[10] Mckenzie-Mohr Associates and Lura Consulting (2001). *Turn It Off: Reducing Vehicle Engine Idling* Natural Resources Canada, January.
[11] Frey, H. C., K. Zhang, and N. M. Rouphail. (2008) "Fuel Use and Emissions Comparisons for Alternative Routes, Time of Day, Road Grade, and Vehicles Based on In-Use Measurements." *Environmental Science & Technology,* 42-7.
[12] Holmen, Britt, and Debbie Niemeier. (1998). "Charactering the effects of driver variability on real-world vehicle emissions". *Transportation Research Part D* 3.
[13] Jackson, Eric and Lisa Aultman-Hall (2010). "Analysis of Real-World Lead Vehicle Operation for Integration of Modal Emissions and Traffic Simulation." *Transportation Research Record* 2128.
[14] Brundell-Freij, Karin, and Eva Ericsson. (2005). "Influence of Street Characteristics, Driver Category and Car Performance on Urban Driving Patterns. *Transportation Research Part D* 10-3.
[15] Ericsson, Eva. (2000). "Independent Driving Pattern Factors and their Influence on Fuel-Use and Exhaust Emissions Factors." *Transportation Research, Part D* 6.
[16] De Vlieger, I. D. De Keukeleere, J.G. Kretzschmar. (2000). "Environmental Effects of Driving Behaviour and Congestion Related to Passenger Cars." *Atmospheric Environment.* 34.
[17] Barth, Matthew, Feng An, Theodore Younglove, George Scora, Carrie Levine, Marc Ross, Thomas Wenzel (2000). *The Development of a Comprehensive Modal Emissions Model.* NCHRP Project 25-11 Final Report.

emitting modes such as acceleration. Recently, Papson et al.[18] used MOVES2010 to consider the emissions at intersections under various conditions including consideration of the amount of idling time. His results suggest a need for improvements in how in-travel idling is modeled. A large body of prior research has focused on in-travel idling and the traffic control and management strategies that can reduce congestion and thus idling such as re-timing traffic signals and other congestion management techniques.

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[19]. All idling was found to be between 13 and 23 percent of the total vehicle operating time. Extended idle (events over 10 minutes) ranged between 1 and 7 percent of the total idling time. Pre-trip idling ranged between 14 and 15 percent of total idling time. In one of the datasets reviewed, idling time was found to increase with trip length. A more recent study of over 250 passenger vehicles and 10-days of routine travel in Lexington, Kentucky showed vehicles were idle about 24% of total vehicle running time but no distinction was made between discretionary and non-discretionary idling[20]. The ranges of estimates for the amount of total idling are large and no doubt vary by region due to congestion. But they also point to the need for more data and indicate discretionary idling is a meaningful proportion of idling which merits study.

Few studies have evaluated the impact 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[21,22]. Although Beusen et al.[23] found that eco-driving training did not have a long-term impact on the amount of idling, their study did not distinguish between discretionary and non-discretionary idling. Numerous Canadian communities have undertaken awareness and education campaigns[24] some in combination with regulation but behavior change and the actual levels of idling have not been measured.

In summary, very little comprehensive information exists about the nature of passenger vehicle idling behavior including the distinction between discretionary versus non-discretionary idling and how each varies by season, trip stage, different drivers or in different locations. Phase I of this research resulted in a robust method to distinguish

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18 Papson, Andrew, Seth Hartley, Kai-Ling Kuo. (2012). "Analysis of Emissions at Congested and Uncongested Intersections Using MOVES2010." *Transportation Research Board Annual Meeting DVD Compendium*, Paper 12-0684.

19 Taylor, G.W.R. (2003). *Review of the Incidence, Energy Use and Costs of Passenger Vehicle Idling.* Natural Resources Canada, Office of Energy Efficiency, March.

20 Aultman-Hall, Lisa, and Britt Holmen. (2010). *Modeling the Spatial Distribution of Fine Particulate Matter Emissions from Transportation Vehicles.* National Science Foundation, February.

21 Thompson, Melissa and C. Michael Walton. (2011). "A Qualitative Review and Comparison of Operational Strategies for Reducing Freight Truck Fuel Consumption and GHG Emissions." *Transportation Research Board Annual Meeting DVD Compendium*, Paper 11-3817.

22 Lutsey, Nicholas, Christine-Joy Brodrick, Daniel Sperling and Carollyn Oglesby. (2004). "Heavy Duty Truck Idling Characteristics, Results form a Nationwide Survey." *Transportation Research Record* 1880.

23 Beusen, B. Broekx, Denys, Beckx, Degraeuwe, Gijsbers, Scheepers, Govaerts, Torfs, Panis (2009). "Using On-board Logging Devices to Study the Longer-term Impact of an Eco-Driving Course." *Transportation Part D* 14.

24 Lura Consulting (2005). *The Carrot, the Stick, and the Combo: A Recipe for Reducing Vehicle Idling in Canadian Communities.* Natural Resources Canada and the Clean Air Partnership.

between idling behavior that can be prevented through driver behavior (discretionary) and the time a vehicle is idling due to queuing or traffic measures beyond the driver's control (non-discretionary). Phase II of the project describes application of this method using synchronous in-vehicle GPS and OBD data to identify discretionary idling events by length and locations for a sample of 86 volunteers monitored for a total of 10 days each.

Data Collection

Addison County Vermont (Figure 1) was selected as the study site for this phase of the project. Addision County has a population of 37,000 and includes both rural areas and the small urban community of Middlebury (population 8,000). Volunteer drivers were recruited for this study via postings at gas stations and advertisements on a community-based online email forum, Front Porch Forum. Drivers were excluded from the study if their primary vehicle was (1) a hybrid vehicle, as conventional methods of vehicle idling were critical to other study objectives, or (2) a pre-model year 1996 vehicle, as compatibility with onboard diagnostics (OBD) was essential to retrieving data directly from each vehicle's computer during operation.

During data collection for a 10-day data period, the 86 volunteer drivers were asked to drive their vehicles as they normally would and were informed only that the study was targeting data collection on general travel behavior (i.e. origins and destinations, number of trips, etc.) to improve the statewide travel demand model (Appendix A contains the informed consent form approved by the University of Vermont Institutional Review Board). Each volunteer's own vehicle was instrumented with an EASE Diagnostics MiniDL Onboard Diagnostics (OBD) logger to collect operation data (vehicle speed, engine speed, etc.) directly from the vehicle's engine control unit (ECU) and a GeoStats GeoLogger Global Positioning System (GPS) to collect spatial location (latitude, longitude, speed, quality assurance parameters) during operation of the vehicle. In addition to the data collected directly from each volunteer's vehicle during operation, a questionnaire was used to collect information on vehicle age, make, model, and type; individual driver age, gender, education, and employment status; and household size, number of vehicles, and income (Appendix B). A $25 gas card was provided to study participants. After a 10-day data collection period, the volunteers received an email reminder to remove the two devices from their vehicles and return them in a pre-paid mailer. Volunteers were sampled between January and July 2013.

The final data set included 70 phase II and 16 phase I volunteers with valid OBD and GPS data. Five of these individuals did not have discretionary idling events but this likely reflects a lack of valid data for these volunteers as they made only 1-3 trips each. Demographics for the 81 drivers with discretionary idling events as well as information about these volunteers' primary vehicles are provided in Table 1. The majority of volunteers were employed and income levels were higher than would be representative of the state as a whole. More women than men were included in the study. However, a good range of age, education, vehicle ages and vehicle types were obtained.

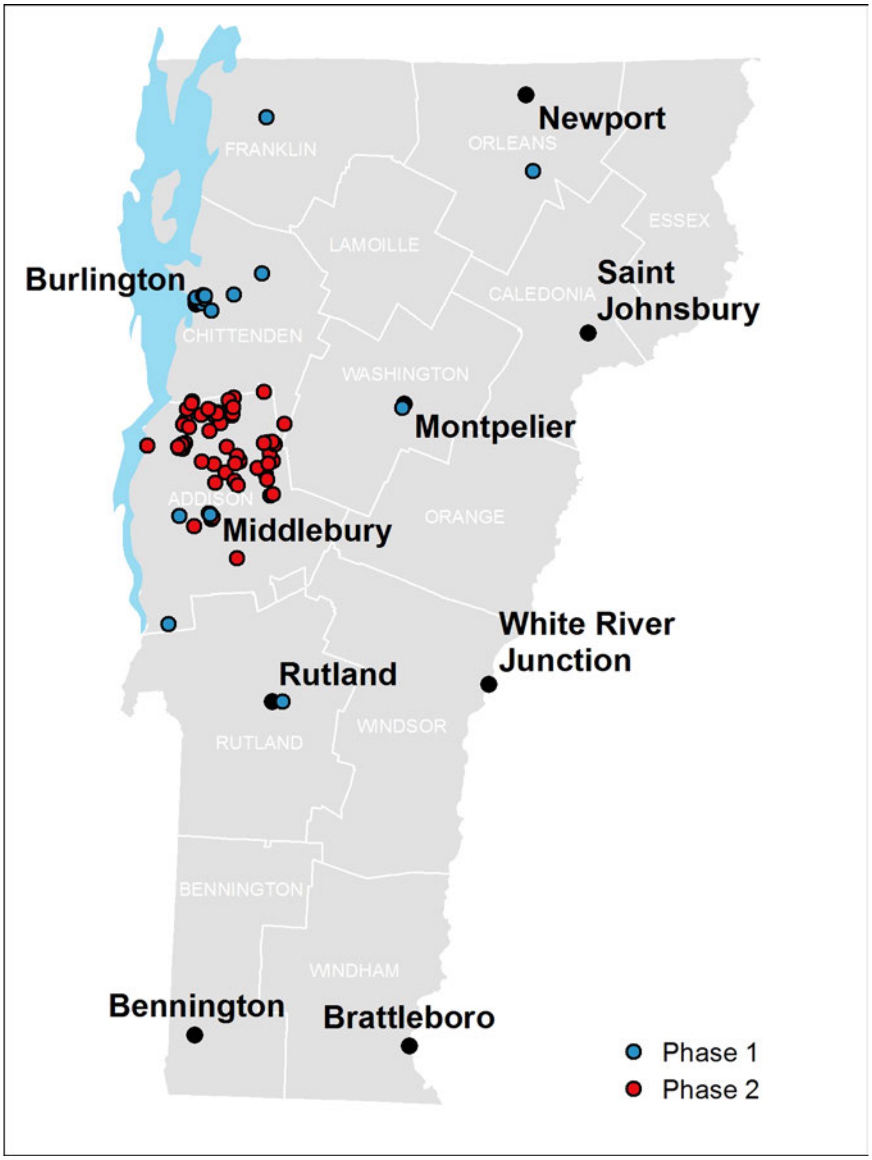

Figure 1: Home Locations of Study Participants

Table 1: Sample Characteristics

	Number of Volunteers	Percent of Total
Employment		
Employed Full Time	53	65.4%
Employed Part Time	20	24.7%
Not Employed	5	6.2%
No Response	3	3.7%
Age		
Twenties	13	16.0%
Thirties	12	14.8%
Forties	22	27.2%
Fifties	23	28.4%
Sixties, Seventies	8	9.8%
No Response	3	3.7%
Gender		
Female	54	66.7%
Male	22	27.2%
No Response	5	6.2%
Education		
At least Bachelors	51	63.0%
Less than Bachelors	24	29.6%
No Response	6	7.4%
Household Size		
1	12	14.8%
2	30	37.0%
3	14	17.3%
>4	21	25.9%
No Response	4	4.9%
Number of Vehicles in Household		
1	22	27.2%
2	32	39.5%
3	19	23.5%
4	4	4.9%
5 or more	3	3.7%
No Response	1	1.2%
Household Income		
Less than $10,000	2	2.5%
$10,000 to $30,000	8	9.8%
$30,000 to $50,000	15	18.5%
$50,000 to $70,000	14	17.3%
$70,000 to $100,000	25	30.9%
$100,000 or more	11	13.6%
No Response	6	7.4%
Vehicle Type		
automobile/car/station wagon	51	63.0%
sport utility vehicle (SUV)	19	23.5%
truck	4	4.9%
van (mini, cargo, or passenger)	2	2.5%
No Response	5	6.2%
Vehicle Age (years)		
9 +	23	28.4%
4 - 8	34	42.0%
0 - 3	19	23.5%
No Response	5	6.2%

Tabulation of Idling Events

The GPS and OBD data logger data were downloaded 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 within 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 of multiple trips within a trip-chain where the vehicle was not turned off at one or more intermediate destinations.

The GPS 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 which 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 to the GPS speed records to identify questionable speed records where 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, all GPS segments on a given day were merged into a single continuous, second-by-second 24 hour record with blank rows for periods without GPS data (either because the vehicle was off or the GPS was not recording). Next the GPS and OBD records were aligned based on their time stamps. Since the OBD time stamp is derived from the vehicle clock it does not always match the GPS time stamp precisely. To ensure that the alignment was accurate the alignment algorithm adjusted the OBD time stamp in 1 second increments from +60 seconds through -60 seconds. The alignment with the highest correlation between the OBD and GPS speeds was used for the final alignment. The aligned OBD and GPS data for all 86 volunteers included approximately 26,659 miles of travel across 3,291 engine operating (key-on to key-off) periods.

Once the OBD and GPS datasets were synchronized and merged, a new dataset was created that consisted of all idling events (both discretionary and non-discretionary) as identified by zero-speed records in the OBD data. This dataset contained one record for each idling event including the event duration, the vehicle position, and the cumulative heading change over the 20 seconds 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 were 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 dataset.

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 dataset. Discretionary idling events at intermediate destinations are more difficult to identify and distinguish from the en-route non-discretionary idling. As documented in detail elsewhere[25], this study combined spatial position and heading change criteria to identify idling events that are likely to correspond to trip-ends at intermediate destinations. In addition, because some idling at key-on and key-off is unavoidable, key-on idling events of 5 seconds or less and key-off idling events of 2 seconds or less were dropped from the final discretionary idling data set. Table 2 outlines the number of discretionary idling events and their average duration. The number of key-on and key-off idles are not equal because not all operating periods included both of these discretionary events. In addition, because of the lag time for the GPS device to acquire a satellite signal there is a slightly higher likelihood that key-on idling events will be missing GPS data. Note the standard deviations are very high indicating significant variation in discretionary idle event length as one might expect. As illustrated by Figure 2, there is also considerable variation between individuals. While most individuals' idling events were about 20 seconds in duration, others have much longer average discretionary idling times. Figure 2 illustrates that individuals had a considerable number of discretionary idling events during the 10 days. The ratio of discretionary idling events to trips over the sample of volunteers is approximately 1.4:1. Keep in mind discretionary idling might occur at trip start, engine off and at intermediate destinations. Discretionary idling is estimated to be 45% of time of total idling (discretionary and non-discretionary).

Table 2: Length of Discretionary Idling Events (81 volunteers, 10-days)

	Number of Observations	Mean Duration (seconds)	Standard Deviation
Key-On	1633	45.5	93.7
Key-Off	2212	12.5	28.1
Intermediate Destinations	789	34.0	69.1

[25] Dowds, Jonathan, James Sullivan and Lisa Aultman-Hall. (2013) Seasonal Comparison of Discretionary Passenger Vehicle Idling Behavior using GPS and OBD Devices. *Transportation Research Record*.

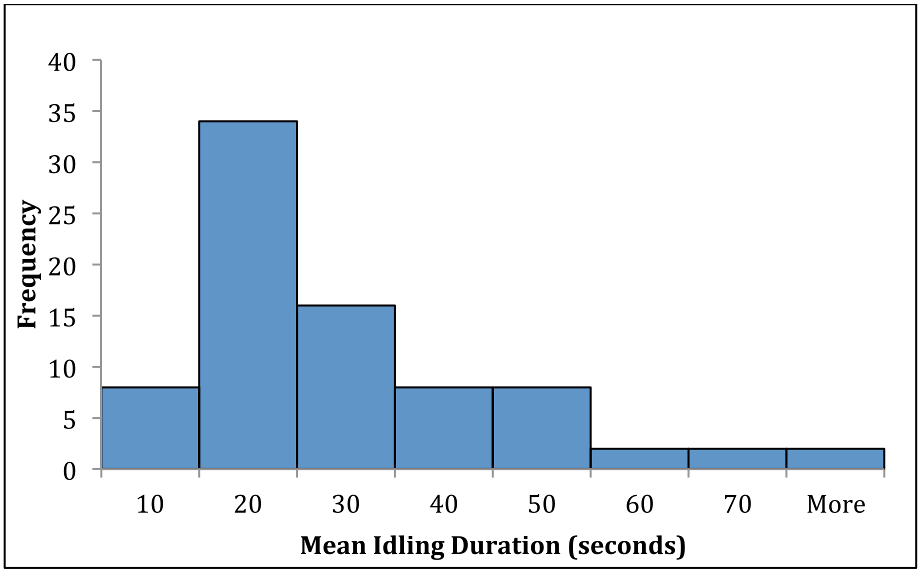

Figure 2: Mean Idling Duration per Volunteer

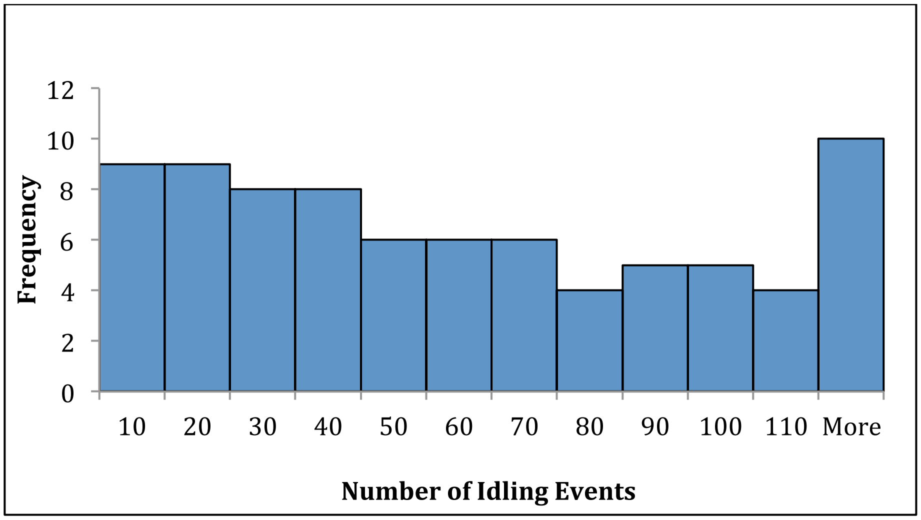

Figure 3: Number of Discretionary Idling Events per Individual

Tables 4-6 outline the average discretionary idling duration and events for different subsets of individuals, households and vehicles. Considering that individuals drove different numbers of trips of different lengths and in different locations, the only notable difference in these tables is that van drivers had considerably more idling events than others.

Table 3: Mean Discretionary Idling by Individual Variables

	Mean Duration of Idling Events	Number of Volunteers	Number of Idling Events	Average Idling Events per Volunteer
Employment Status				
Employed Full Time	26.3	53	3281	61.9
Employed Part Time	34.8	20	1074	53.7
Not Employed	19.1	5	201	40.2
No Response	15.4	3	78	26.0
Age				
Twenties	38.4	13	877	67.5
Thirties	28.9	12	599	49.9
Forties	17.4	22	1169	53.1
Fifties	28	23	1401	60.9
Sixties	34.9	7	473	67.6
Seventies	12.2	1	37	37.0
No Response	15.4	3	78	26.0
Gender				
Female	29.3	54	3267	60.5
Male	26	22	1133	51.5
No Response	15	5	234	46.8
Education				
At least Bachelors	26.6	51	2923	57.3
Less than Bachelor	33.1	24	1378	57.4
No Response	15.9	6	333	55.5

Table 4: Mean Discretionary Idling by Household Variables

	Mean Duration of Idling Events	Number of Volunteers	Number of Idling Events	Average Idling Events per Volunteer
Household Size				
1	28	12	777	64.8
2	29.7	30	1625	54.2
3	31.3	14	929	66.4
4	20.1	15	949	63.3
5	43.2	6	190	31.7
No Response	13.9	4	164	41.0
Household Vehicles				
1	28.1	22	1379	62.7
2	28.7	32	1790	55.9
3	23.3	19	1042	54.8
4	18.8	4	135	33.8
5 or more	47.6	3	226	75.3
No Response	18.7	1	62	62.0
Household Income				
Less than $10,000	16.3	2	97	48.5
$10,000 to $20,000	30	7	557	64.8
$20,000 to $30,000	26.5	1	70	70.0
$30,000 to $40,000	41.8	6	201	33.5
$40,000 to $50,000	41.9	9	434	48.2
$50,000 to $60,000	33.3	8	496	62.0
$60,000 to $70,000	27.1	6	471	78.5
$70,000 to $80,000	23.5	11	717	65.2
$80,000 to $100,000	24.8	14	619	44.2
$100,000 or more	26.5	11	486	44.2
No Response	15.7	6	486	81.0

Table 5: Mean Discretionary Idling by Vehicle Variables

	Mean Duration of Idling Events	Number of Volunteers	Number of Idling Events	Average Idling Events per Volunteer
Vehicle Type				
automobile/car/station wagon	31.2	51	2943	57.7
sport utility vehicle (SUV)	20.5	19	1045	55.0
truck	33	4	93	23.3
van (mini, cargo, or passenger)	26.1	2	224	112.0
No Response	20.3	5	329	65.8
Vehicle Age (Years)				
9 +	37.6	23	1327	57.7
4 - 8	23.6	34	1895	55.7
0 - 3	25.3	19	1083	57.0
No Response	20.3	5	329	65.8

Estimating Total Passenger Vehicle Idling in Vermont

The final aligned dataset covered 785.8 hours (2,828,890 seconds) of in-state vehicle operating time (VHT) with valid vehicle speed and vehicle location information. These data included 15,484 separate zero speed events lasting nearly 79 hours (284,233 seconds). Of these zero speed events, 4,634 events meet the discretionary idling criteria described previously. Cumulatively, the discretionary idling events lasted for approximately 36 hours (128,733 seconds). More than 55% of the total discretionary idling time in this study was the result of 431 idling events that lasted for longer than 60 seconds, accounting for just over 20 hours of discretionary idling time. Overall, for this sample, 10% of VHT was spent at zero speed and discretionary idling consumed 4.6% of total VHT. Study participants traveled 26,659 miles in the nearly 707 hours of vehicle operation during which the vehicles were not at zero speed. Vermont's VMT in 2011 totaled 7.14 billion miles (FHWA, 2011).

Assuming that the ratio of discretionary idling in the study sample to idling in Vermont is equal to the ratio of VMT in the sample to total Vermont VMT, these results suggest that the total duration of in-state, discretionary idling is on the order of 9.6 million hours.

$$\frac{Sample\ VMT}{Total\ State\ VMT} = \frac{Sample\ Discretionary\ Idling}{Total\ VT\ Discrectionary\ Idling}$$

Based on emissions coefficients and fleet composition assumptions in the EPA's MOVES model, 9.6 million hours of discretionary idling would result in 36,500 metric tons of CO_2e. For comparison purposes, the Vermont Agency of Natural Resources estimated total 2009 statewide GHG emissions from on-road vehicles at 3.65 million metric tons of CO_2e (ANR, 2013). Therefore approximately 1% of GHG from all vehicles may be associated with discretionary idling. This is consistent with limited prior studies.

Generation of the Land use and Weather Variables

Using the latitude and longitude of the discretionary idling events allowed generation of additional variables based on the National Land Cover Database[26], the RUCA[27] rural area type classification system and the GIS building location and type from the E911 system of Vermont. These variables are listed in Table 6-9 together with idling event data. Idling events that took place between 6:00 AM and 6:00 PM where considered daytime idling events and all others nighttime idling. The retail and residential density within 500 meters of the idling location were calculated with the E911 building data and allowed generation of Figures 5 and 6. Figure 7 was generated by calculating the shortest path distance between the idling event and the nearest retail establishment.

Table 6: Average Duration of Discretionary Idling Events (secs) by Land Use Class

Landuse	MeanDuration	NumberofVolunteers	NumberofIdlingEvents
1. Developed High Intensity	26.3	72	1351
2. Developed Med Intensity	29.1	75	1461
3. Developed Low Intensity	26.1	59	412
4. Developed Open Space	23.1	40	208
5. Non-developed	29.2	72	1202

Table 7: Average Duration of Discretionary Idling Events (secs) by RUCA Class

RUCA	MeanDuration	NumberofVolunteers	NumberofIdlingEvents
1. Metropolitan	27.8	67	2243
2. Micropolitan	27.4	15	144
3. Small Town	31.2	58	1249
4. Rural Area	23.6	49	998

Table 8: Average Duration of Discretionary Idling Events (secs) by Day of Week and Day/Night

	MeanDuration	NumberofVolunteers	NumberofIdlingEvents
Weekday	28.1	81	3563
Weekend	26.7	66	1071
Day	27.7	79	3677
Night	27.9	70	957

[26] National Land Cover Database 2011, Multi-Resolution Land Characteristics Consortium. http://www.mrlc.gov/nlcd2011.php accessed July 2013

[27] Rural Health Research Center, University of Washington. http://depts.washington.edu/uwruca/ accessed July 2013.

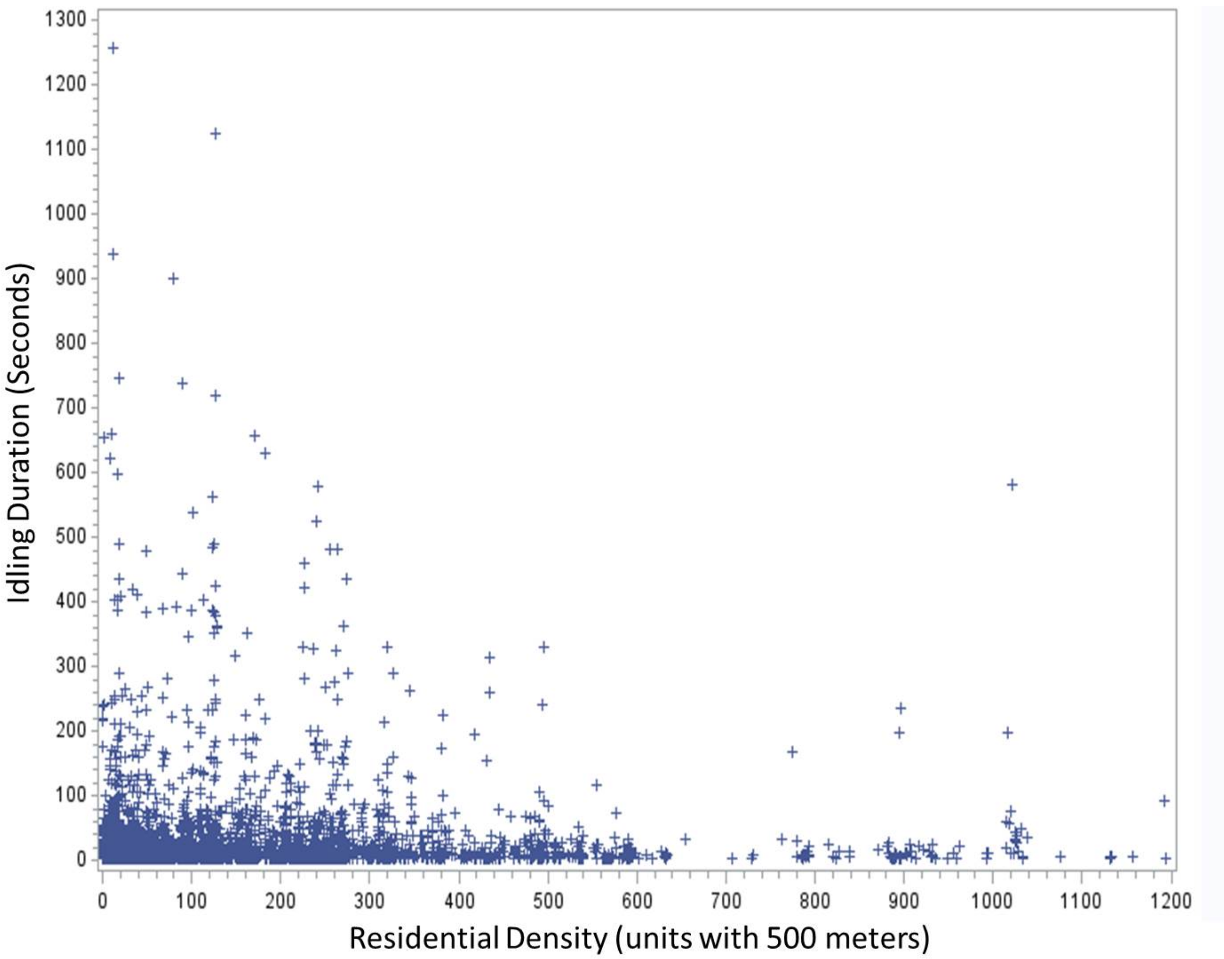

Figure 4 Idling Duration vs. Residential Density

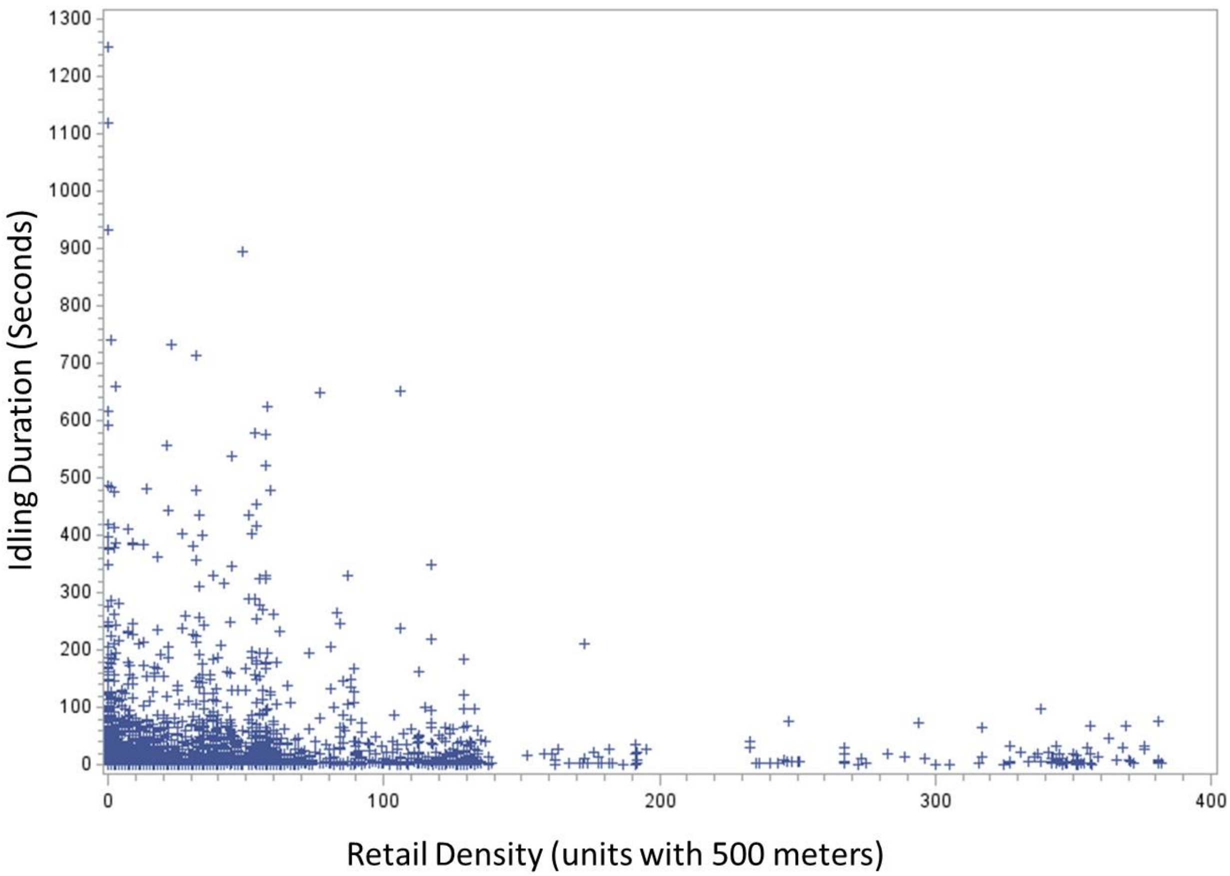

Figure 5 Idling Duration vs Retail Density

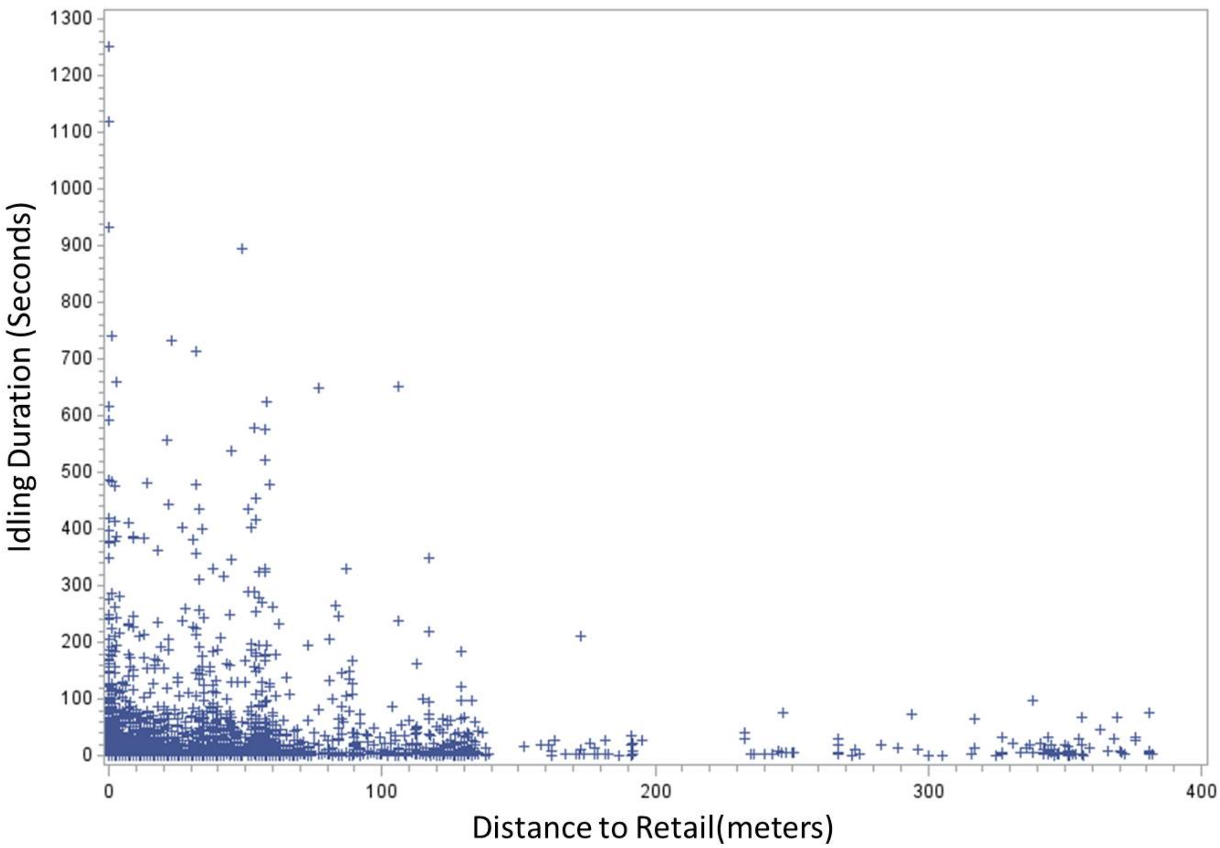

Figure 6 Idling Duration vs Distance to Nearest Retail Location

Weather data from 58 Vermont weather stations was obtained from the National Climatic Data Center.[28] Each idling event was linked to the nearest weather station to find the daily high and prior night low temperature for that location (Table 9). A series of plots of idling duration with daily high and low temperatures is contained in Appendix C. No patterns in idling duration as a function of temperature were noted. Recall, this phase II experiment differs from the phase I experiment in that different volunteers were sampled during single 10-day periods. In phase I, the same volunteers were sampled twice, once in the winter and once in the summer.

[28] National Climatic Data Center. http://www.ncdc.noaa.gov/ accessed August 2013.

Table 9: Temperature Characteristics on Sampling Days

	Minimum	Maximum	Mean	Standard Deviation
Daily High Temperature (ºC)	-11.1	36.7	14.7	11.6
Daily Low Temperature (ºC)	-26.1	24.4	4.5	10.5

Modeling Spatial and Temporal Patterns of Idling

Two types of models were estimated to assess the impact of the individual, vehicle and location on idling. The first models use each volunteer as the unit of observation and they are labeled long idlers (having at least one discretionary idle of more than 60 seconds – 79% of volunteers) and as longest idlers (having at least one discretionary idle of more than 300 seconds – 36% of volunteers). The binary logistic regression results for whether or not a volunteer was a long idler revealed only one significant variable: vehicle age. Based on the odds ratio output, every year of vehicle age corresponds to an increase likelihood of 3% that a volunteer will have a discretionary idling event over 60 second in length. Note that the model has limited predictive power (quasi R2 = 0.075). However in general, the data suggests drivers of older vehicles are more likely to be long idlers.

A binary logistic regression was also used to estimate a model for longest idlers with results in Table 10. Recall longest idlers correspond to volunteers with a discretionary idle of more than 5 minutes in length. These results suggest women are 10 times more likely than men to be the longest idlers, and that car drivers are 2.6 times as likely to be longest idlers. While older vehicles are again associated with increased idling, higher income households are less likely to be longest idlers. However, longest idlers have more vehicles in the household. Several models were estimated and gender and vehicle age remained consistently significant.

Table 10: Binary Logistic Regression for Discretionary Idling at least once for more than 5 minutes

	Parameter Estimate	SE	Wald Chi-Square	P	Odds Ratio Point Estimate	95% Confidence Interval
Gender (Female vs. Male)	2.34	0.82	8.21	0.004	10.41	2.10 - 51.69
Vehicle Type (Cars vs. Other)	0.98	0.64	2.30	0.129	2.65	0.75 - 9.35
Vehicle Age (yrs)	0.14	0.07	3.55	0.060	1.15	0.99 - 1.33
Income (80k+ vs. <80k)	-2.41	0.96	6.24	0.013	0.09	0.01 - 0.60
Number of Vehicles in the Household	0.52	0.34	2.38	0.123	1.68	0.87 - 3.24

R-Square 0.2597 Max-rescaled R-Square 0.3540

In order to model the duration of discretionary idling events, it was necessary to account for the repeated observations from different volunteers. We tested several versions of a repeated, mixed linear model with the log of idling duration as the continuous independent variable. Unfortunately, even after transforming idling duration to the log of idling duration, the residuals of this model are not normally distributed which violates the assumptions for this procedure.

The dependent variable was transformed to “Idle class” with the 0-1 minute, 1-2 minute, 2-5 minute and 5+ minute categories. This allowed estimation of a multinomial logistic regression with a generalizing estimating procedure (GEE) accounting for repeated measures (Table 11). Employment and Trip Status were significant in all model combinations tested. Trip Status was always significant at the .01 level. Age was also significant in almost all models though has a fairly small impact relative to some of the other factors. The interaction Vehicle Age*Trip Stage as well as the variable Education and Income hovered around / just outside the 0.1 significance level in most models. We tried eliminating each individually (there is a clear trade off in the significance between Education and Income) but the model fit, as measured by QIC, was best with all three in the model. In the final model, individuals with incomes between $40,000 and $50,000 were found to idle more than individuals in other income brackets. The model suggests older and more educated individuals idle less time. Part time workers in the sample idle more than full-time employees and unemployed idle less but the difference between unemployed and full-time workers was not significant. Vans are most likely to idle among vehicle types. However, SUVs and trucks are less likely to idle than cars. Idling at key-off is of the shortest duration. There are significant interactions between key-on and key-off and the length of the discretionary idle.

Table 11: Multinomial Logistic Model Results

	Parameter Estimate	Standard Error	Z	P Value	Odds Ratio Point Estimate
Age	-0.02	0.01	-1.95	0.05	0.98
Education (At least Bachelors vs. less than Bachelors)	-0.34	0.20	-1.67	0.10	0.71
Income (All other categories vs. $40,000 to $50,000)	-0.69	0.24	-2.89	0.00	0.50
Employment (Employed Part Time vs. Full Time)	0.65	0.18	3.68	0.00	1.50
Employment (Not Employed vs. Full Time)	-0.21	0.37	-0.58	0.56	0.57
Vehicle Type (SUV vs. Car)	-0.41	0.19	-2.10	0.04	0.74
Vehicle Type (Truck vs. Car)	-0.81	0.68	-1.19	0.23	0.57
Vehicle Type (Van vs. Car)	0.86	0.30	2.84	0.00	2.32
Trip Stage (Key-on vs. key-off)	1.77	0.25	7.00	<.0001	5.86
Trip Stage (Other vs. key-off)	1.69	0.23	7.33	<.0001	5.44
Vehicle Age*Key-on	0.07	0.03	2.40	0.02	1.07
Vehicle Age*Other	-0.01	0.03	-0.24	0.81	0.99
Vehicle Age*Key-off	0.13	0.05	2.30	0.02	1.13

Conclusions

Within the admittedly small data collection, few common locations for discretionary vehicle idling were found. No relationship between idling duration and residential or retail density was found. A total of more idling events were recorded in built-up areas such as metropolitan areas compared to open space and rural. More idling takes place on weekdays and during daytime hours. This is not unexpected as these are the times that correspond to more travel and the types of locations where more trip ends occur. Women and drivers of older vehicles are most likely to be longer idlers. This provides limited guidance with which to identify targets for future programs for idling limitations, education and enforcement. However, discretionary idling was present for a significant portion of the sample suggesting that overall general education is needed.

No association between daily high or low temperature was found for discretionary idling in this sample of volunteers. This is in contrast to the phase I of this study where paired analysis was possible because given individuals were sample twice, once in the summer and once in the winter. Together this suggests that while small differences exist between seasons, larger differences exist between individuals, which likely related to knowledge level or travel patterns/needs.

Based on this admitted non-random and small sample of volunteers, it is possible to estimate passenger vehicle GHG emissions resulting from discretionary idling statewide. This estimate corresponds to approximately 1% of the total GHG emissions from passenger vehicles. Recall, non-discretionary idling is not included in the 1%, so this reduction could be achieved through behavior change, awareness and action. This 1% may be considered the upper limit of the GHG reductions possible from the new Vermont statute. While 1% may seem insignificant, on the contrary this real benefit can be achieved without cost either financial or mobility related.

Discretionary idling is a large enough percent of all idling in Vermont (approximately half) to suggest policies to pursue behavior change over purely vehicle technologies which eliminate all idling emissions by turning off during travel and at stops. Moreover, because a change in new vehicle technology can take years to penetrate the whole fleet, pursuing behavior change to limit idling has important value.

Acknowledgments

The authors acknowledge funding from the Vermont Agency of Transportation and the US DOT through the UTC program at the University of Vermont. The contents of this report reflect the positions of the authors and their interpretation of the data. They do not reflect the position or policy of the funding agencies. The authors appreciated the hard work of Thomas McGrath and his contributions to collecting this dataset. The assistance of Justine Sears is gratefully acknowledged.

Appendix A: Informed Consent Form

TITLE: Privately-Owned Vehicle Driving Behavior in Vermont **PRINCIPAL INVESTIGATOR:** Lisa Aultman-Hall

SPONSOR: Vermont Agency of Transportation and US DOT through the UVM Transportation Research Center

This study is being conducted by the University of Vermont Transportation Research Center. You are being invited to take part in this research study because you have presented a valid Vermont driver's license, are 18 years of age or older, and deem yourself of sufficient capacity to drive with a small piece of monitoring equipment in your vehicle. The manufacture date of your vehicle is 1996 or later and you are willing to have your vehicle instrumented with an OBD logger and GPS device for a period of ten days.

Why is this research being conducted?
The purpose of this study is to gather second-by-second data of an individuals' driving behavior (number of trips per day, destinations, etc.) in order to more accurately reflect driving behavior in computer simulation modeling.

How many people will take part in this study? A total of 150 individuals will take part in the study.

What is involved in the study?
You are being asked to use your vehicle to travel as you normally would for a period of ten days. A small piece of monitoring equipment will be placed in your vehicle and plugged into the 12V cigarette lighter outlet. A research staff member will install the instrument and remove it after ten days of driving has been recorded. During the ten-day period, your vehicle will be monitored to record its speed and location.

What are the risks of the study? Risks in the study are minimal. Physical risks are no more than they would be in your normal driving. Security risk includes the breach of the confidentiality of personal information.

What are the benefits of participating in the study? There is no direct benefit to you for your participation. However, by participating in this study you are helping to further advance transportation research in Vermont and create better computer models to support transportation infrastructure.

Are there any costs? The only associated cost with participating in the study is your time to meet with our staff member, have your vehicle outfitted, and then meet again to drop off the instrument. You will not be expected to make extra trips beyond your routine travel course.

What is the compensation? You will be compensated for your participation with a $25 gas card after the ten-day study period.

Can you withdraw or be withdrawn from this study? Your participation is voluntary and you may refuse to participate or withdraw at any time without penalty or prejudice. If you wish to discontinue during the monitoring period is taking place, notify the research staff of your decision and return the monitoring equipment in the packaging provided as you would if you had finished the monitoring period. You may be withdrawn from the study if it becomes clear that your driving behavior during the monitoring period was not routine.

What about confidentiality?
The behavior that is monitored and recorded will remain confidential and will only be used for the purpose of this research. At no time during the study will your driving actions be reported to the authorities.
Data pertaining to your driving will be coded and kept locked with only authorized personnel able to access the data. The security of your record will be maintained by the Principal Investigator. The

aggregate results of this study may eventually be published but your identity will remain confidential, as only an ID number will be associated with your specific data. Representatives from the University of Vermont Institutional Review Board and regulatory authorities will verify that research procedures have been followed and that the data has been kept secure.

Contact Information If you have any questions about your rights as a participant in a research project or for more information on how to proceed should you believe that you have been injured as a result of your participation in this study you should contact Nancy Stalnaker, the Director of the Research Protections Office, at the University of Vermont at 802-656-5040. You may contact Lisa Aultman-Hall, the Investigator in charge of this study, at 802-656-1312 for more information.

Statement of Consent
You have been given and have read or have had read to you a summary of this research study. Should you have any further questions about the research, you may contact the person conducting the study at the address and telephone number given below. Your participation is voluntary and you may refuse to participate or withdraw at any time without penalty or prejudice.
You agree to participate in this study and you understand that you will receive a signed copy of this form.

_______________________________________ _________________________
Signature of Subject Date

____
Name of Subject Printed

____
Signature of Principal Investigator or Designee Date

____
Name of Principal Investigator or Designee

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Appendix B: Participant Survey

1. Information about you:

1. Contact information is being collected to help us contact you for the study; it will not be kept in the project data.

Name (first name only is ok):

Email Address:

Phone Number:

2. Home locations will help us map your travel.

Home Street Address (not P.O. Box):

Nearest Intersecting Street:

City/Town:

State:

ZIP:

3. Work locations will help us map your travel.

Work Street Address (not P.O. Box):

Nearest Intersecting Street:

City/Town:

State:

ZIP:

4. How many vehicles are owned, leased, or available for regular use by people who currently live in your household ((do NOT include bicycles, scooters, mopeds or ATVs)?

Number of vehicles:

Information about you and your entire household:

5. What is your employment status?

Select one:

6. Including yourself, how many people live in your household? Please do not include anyone who usually lives somewhere else or is just visiting, such as a college student away at school.

Number of People:

7. Year of Birth

You

Member 1

Member 2

Member 3

Member 4

8. Including yourself, how many people in your household have a driver's license?

9. Including yourself, how many people in your household:

Are employed full time?

Are employed part time?

Information about you and your vehicle:

10. What is the make of the vehicle you drive most regularly (Ford, Toyota, etc.)?

11. What is the model of the vehicle you drive most regularly (Taurus, 4Runner, etc.)?

12. What model year is this vehicle?

13. What year did you obtain this vehicle?

14. Does anyone else drive this vehicle regularly? Check as many answers as apply.

- ☐ No
- ☐ Spouse/Unmarried Partner
- ☐ Child
- ☐ Parent
- ☐ Brother
- ☐ Sister
- ☐ Other Relative
- ☐ Non-relative

15. What is the approximate number of miles per year this vehicle is driven?

Miles:

16. What is the current odometer reading of the vehicle?

Odometer Reading:

17. What is your gender?

Select one:

18. What is the highest level of school you have completed or the highest degree you have received?

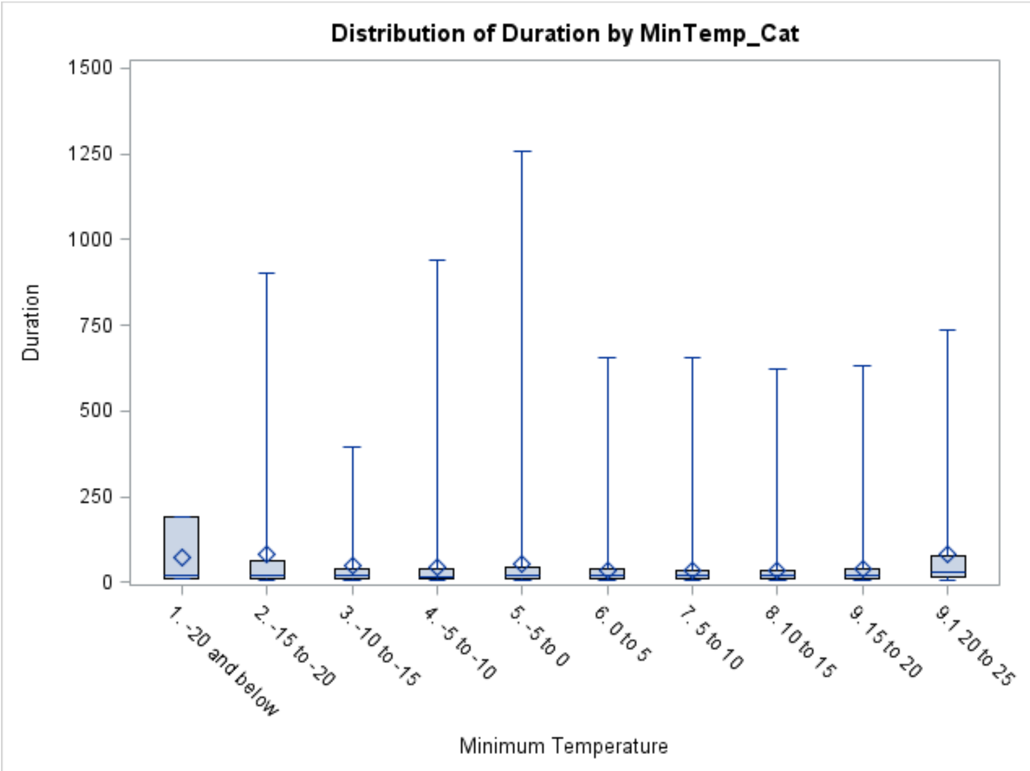
- ○ Less than high school degree
- ○ High school degree or equivalent (e.g., GED)
- ○ Some college but no degree
- ○ Associate degree
- ○ Bachelor degree
- ○ Graduate degree

19. In surveys like these, households are sometimes grouped according to income. Please tell us which category best describes your household income, before taxes, in the past 12 months.

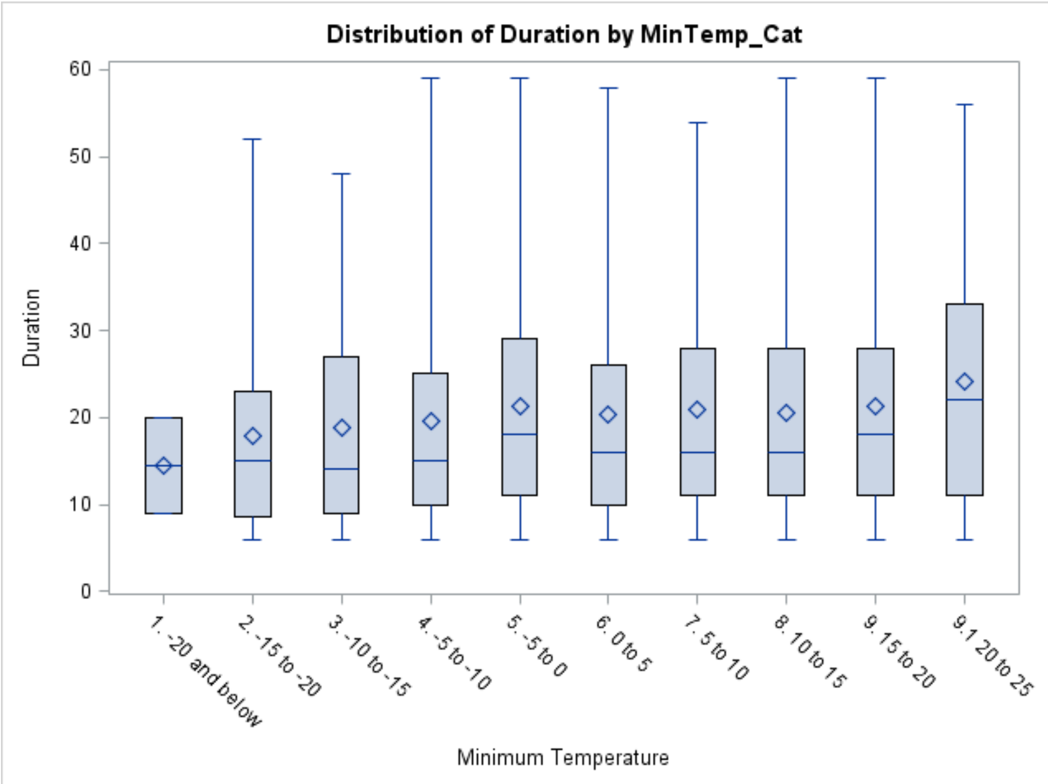
- ◯ Less than $10,000
- ◯ $10,000 to $20,000
- ◯ $20,000 to $30,000
- ◯ $30,000 to $50,000
- ◯ $40,000 to $50,000
- ◯ $50,000 to $60,000
- ◯ $70,000 to $80,000
- ◯ $80,000 to $100,000
- ◯ $100,00 or more

Appendix C: Plots of Idling Duration and Temperature

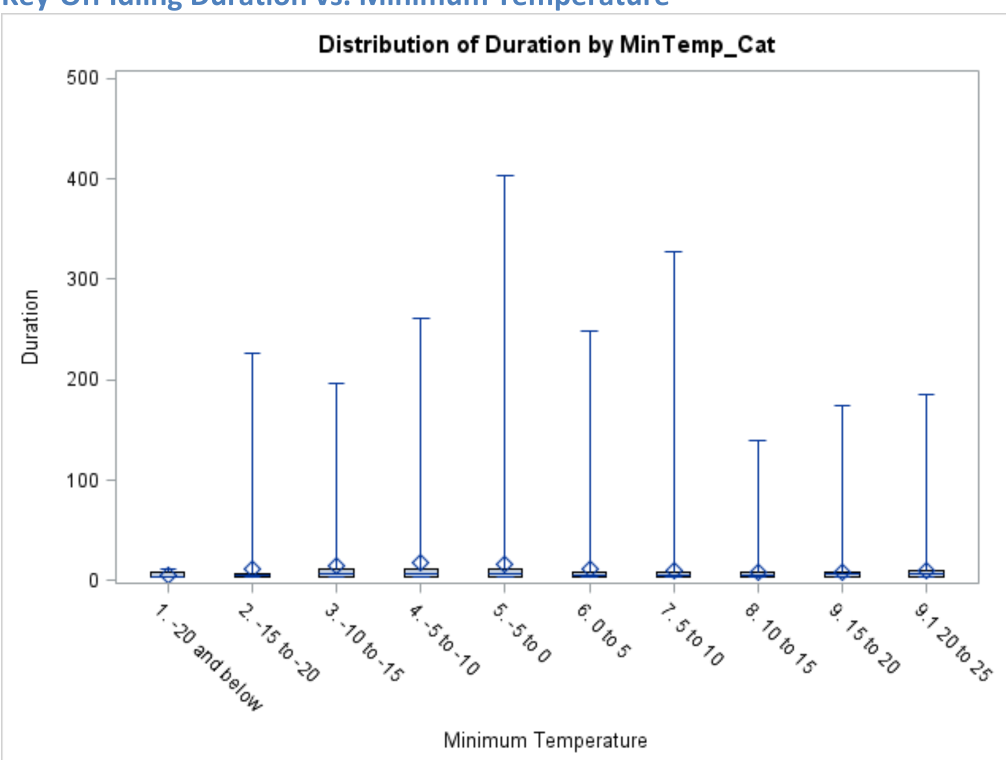
Key-On Idling Duration vs. Minimum Temperature



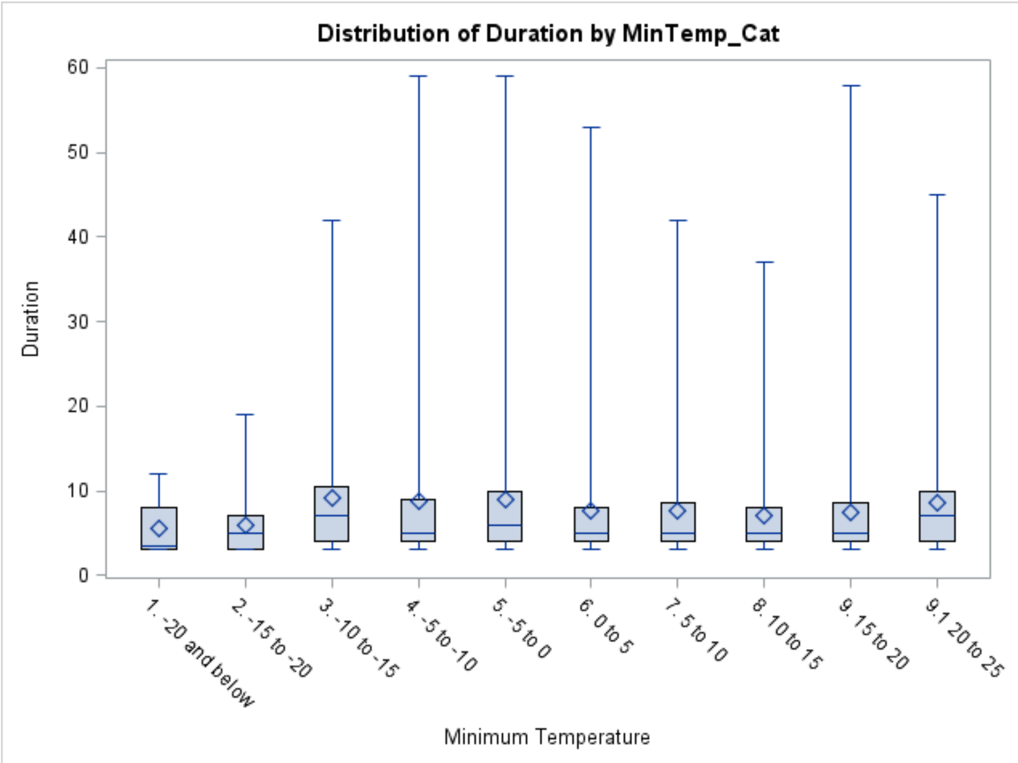
Short Key-On Idling Duration vs. Minimum Temperature



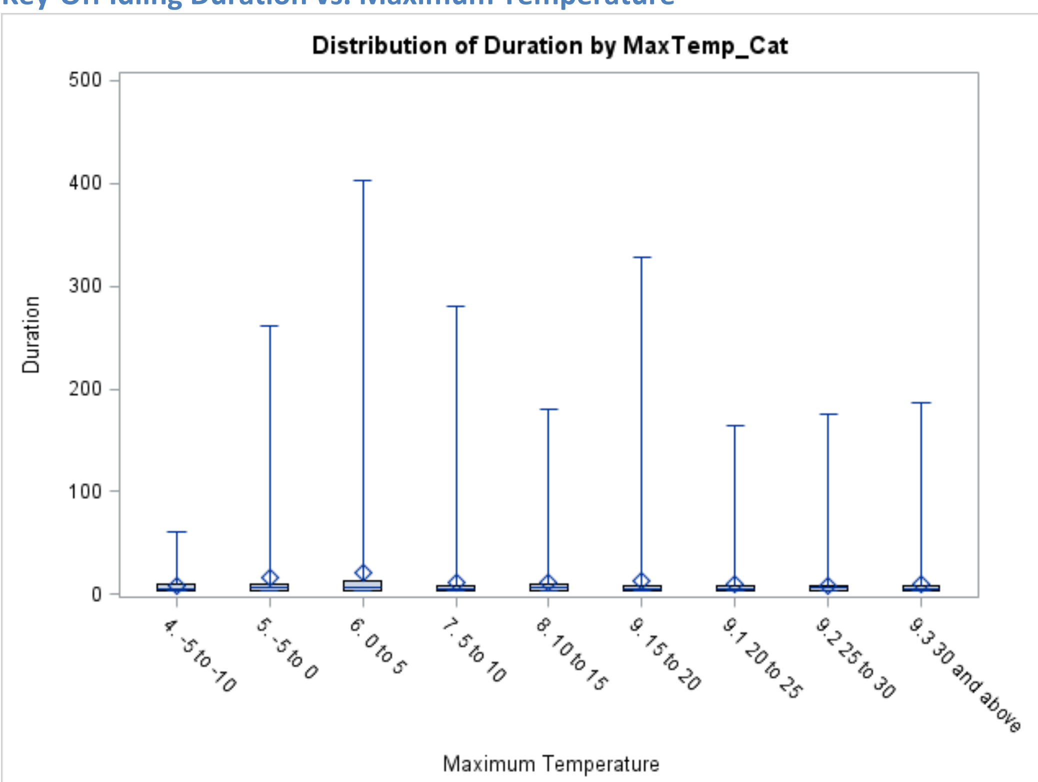
Key-Off Idling Duration vs. Minimum Temperature



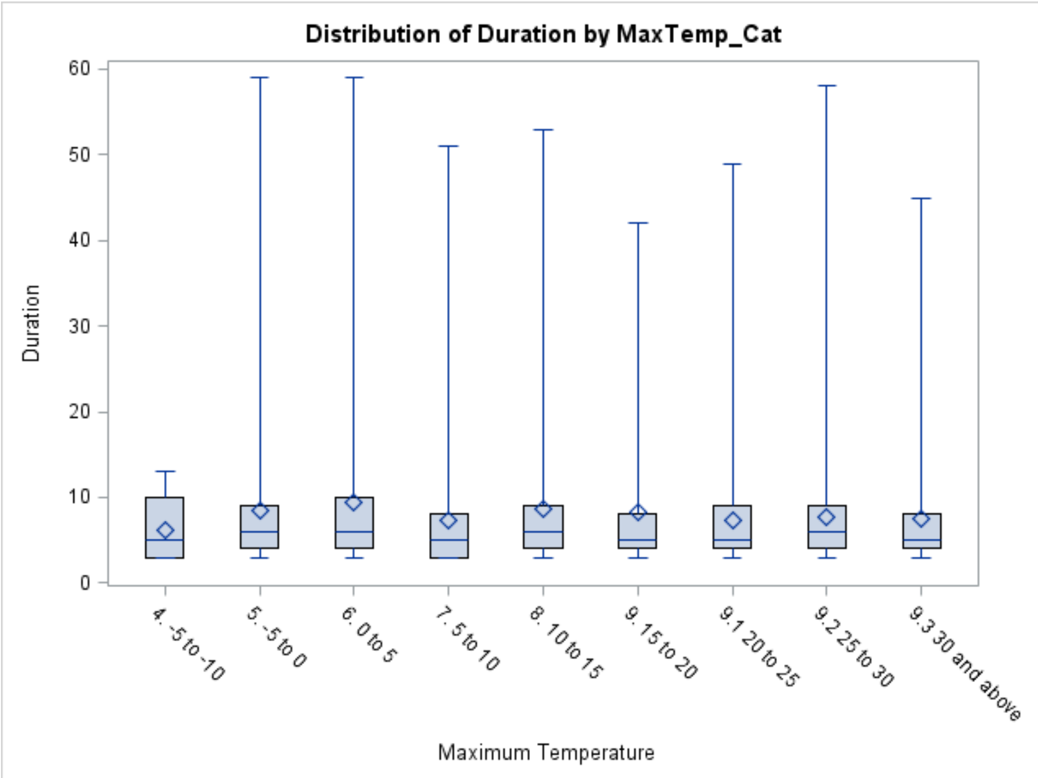
Short Key-Off Idling Duration vs. Minimum Temperature



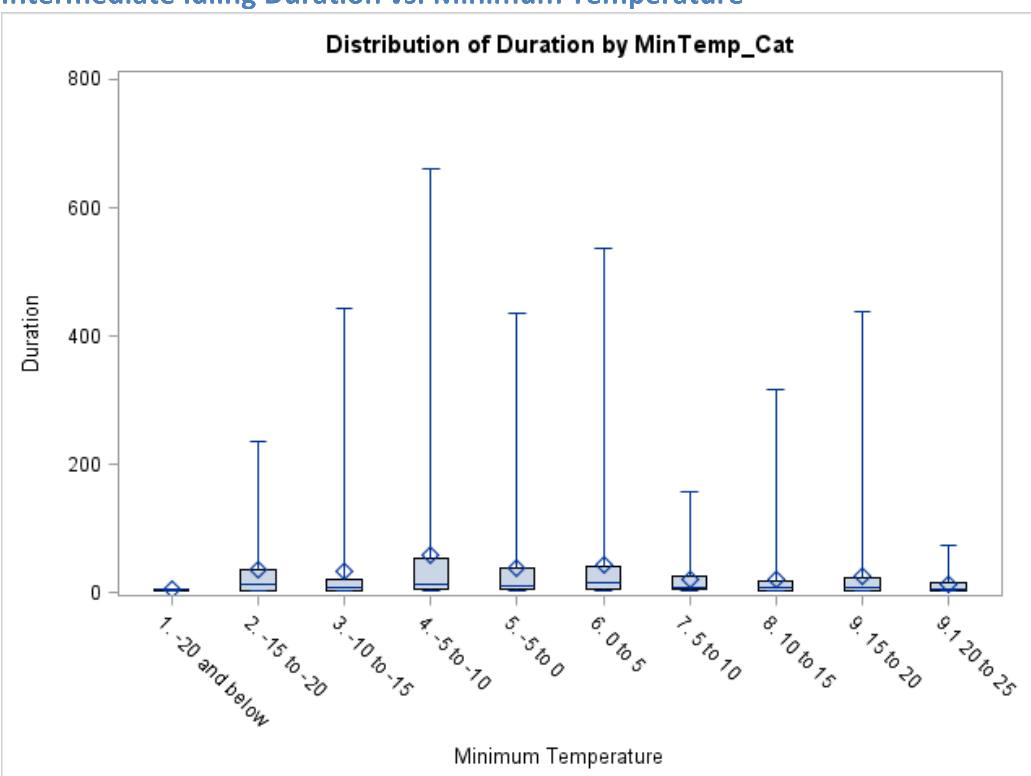
Key-Off Idling Duration vs. Maximum Temperature



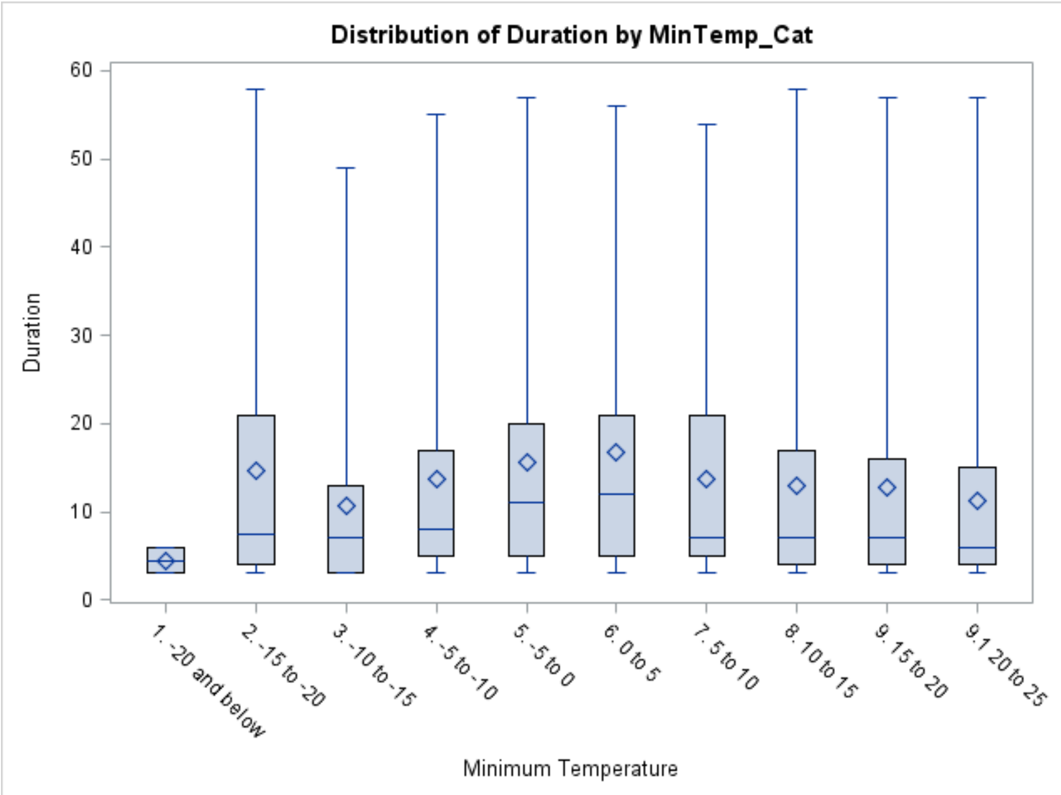
Short Key-Off Idling Duration vs. Maximum Temperature



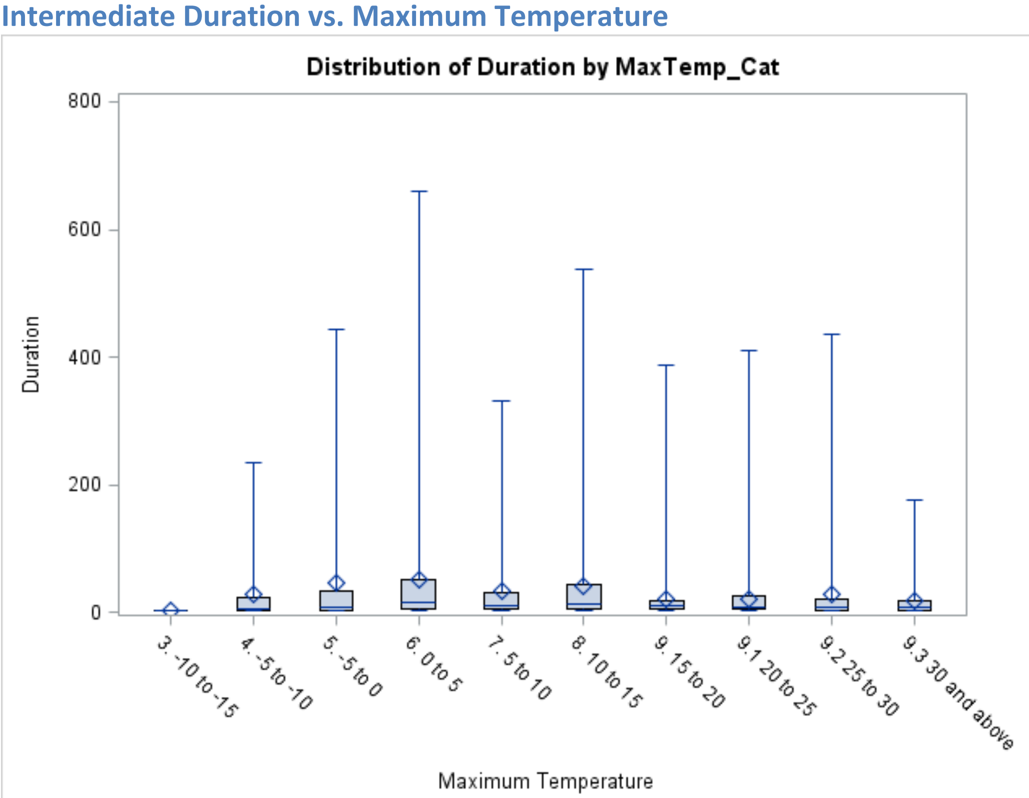
Intermediate Idling Duration vs. Minimum Temperature



Short Intermediate Idling Duration vs. Minimum Temperature



Intermediate Duration vs. Maximum Temperature



Short Intermediate Idling Duration vs. Maximum Temperature