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A Predictive Model for Vehicle Air Exchange Rates based on a Large, Representative Sample

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Abstract

The in-vehicle microenvironment is an important route of exposure to traffic-related pollutants, particularly ultrafine particles. However, significant particle losses can occur under conditions of low air exchange rate (AER) when windows are closed and air is recirculating. AERs are lower for newer vehicles and at lower speeds. Despite the importance of AER in affecting in-vehicle particle exposures, few studies have characterized AER and all have tested only a small number of cars. One reason for this is the difficulty in measuring AER with tracer gases such as SF_6 the most common method. We developed a simplified yet accurate method for determining AER using the occupants' own production of CO_2 a convenient compound to measure. By measuring initial CO_2 build-up rates and equilibrium values of CO_2 at fixed speeds, AER was calculated for 59 vehicles representative of California's fleet. AER measurements correlated and agreed well with the largest other study conducted (R^2=0.83). Multi-variable models captured 70% of the variability in observed AER using only age, mileage, manufacturer and speed. These results will be useful to exposure and epidemiological studies since all model variable values are easily obtainable through questionnaire.

1. Introduction

The in-vehicle microenvironment is an important route of exposure to traffic-related pollutants, especially ultrafine particles (UFP) (D_p < 0.1μm) (1, 2). In-vehicle exposures are

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Supporting Information

The vehicles tested are compared against the California fleet in terms of vehicle size, manufacturer, age and odometer reading, and the complete list of vehicles tested is provided (S1). Also, information about the instruments used (S2), the consistency of CO_2 build-up rates (S3), the effect of fan setting (S4), results of outside air ventilation setting AER tests (S6), AER predicted distributions for the California fleet (S6), and the results of simulating small sample sizes (S7).

Brief

Passenger car air exchange rates, critical for estimating particle losses inside vehicles, measured for 59 vehicles, produce the literature's first statistically-robust predictive model.

high due to vehicles' frequent proximity to relatively undiluted emissions from other vehicles, particularly in urban areas; the typically rapid air exchange rate (AER) inside vehicles (3–6); and the average 80 min per day spent by people in the U.S. in the in-vehicle microenvironment (7). UFP exposures are of particular concern due to their high enrichment in PAHs and other organics, high oxidative capacity, and their ability to pass directly into the blood stream (8, 9).

Roadway concentrations of traffic-related pollutants are typically an order of magnitude higher than urban ambient concentrations (10, 11). The pollution concentrations inside a vehicle generally match the roadway concentrations when there is sufficiently high air turnover. This occurs whenever windows are open, often when outside air is drawn into the vehicle through the ventilation system, or when the vehicle is sufficiently leaky. However, under conditions of low air exchange rate, i.e., several air changes per hour, there can be significant reductions in particle mass and particle number due to losses to vehicle's internal surfaces (12).

Conditions of low air exchange usually only occur for newer cars, for which door seals and insulation are tightest, and/or at low speeds where air flow dynamics are not producing large differences in pressure around the vehicle. If the air exchange rate (AER) of a vehicle is known, the particle losses can be estimated; however, AERs are usually not known, and are highly variable even for the same vehicle, as they vary widely with speed (3, 4, 6). For example, Knibbs et al. (1) found AERs to vary from 1 to 33 air changes per hour (hr^{-1}) across six cars at a speed of 60 km hr^{-1} (37 mph).

Few studies have characterized AERs. The largest study to date has been Knibbs et al. (1) who measured AER using SF_6 as a tracer gas for six vehicles spanning an age range of 18 years at various speeds and under different ventilation settings. In addition to the findings cited above for speeds of 60 km hr^{-1}, they found AERs to range from 2.6 to 47 hr^{-1} (mean 18) at 110 km hr^{-1} (68 mph). They also tested cars at zero speed and reported AERs within the range 0.1–3.3 hr^{-1} with five cars having AERs <1 hr^{-1}. Ott et al. (4) reported AERs in the range of 1.6 to ~40 hr^{-1} for four vehicles spanning a range of six years covering a speed range from 32 - 116 km hr^{-1} (20 - 72 mph) using CO as a tracer gas. They also provide an excellent review of previous studies on the subject. Beside the work by Ott et al. (4, 12, 13), Knibbs et al. (1), Rhodes et al. (6) and Fletcher and Saunders (14), (a total of 16 cars tested), others have only tested AERs in stationary vehicles.

Under conditions of low AER, in-vehicle particle concentrations are reduced due to losses to surfaces. They are also reduced if air recirculation is used, due to air passing through the in-cabin filter (15, 16). Knibbs et al. (17) tested the same five cars used in previous AER measurements of 2009 and found high correlation between inside-to-outside (I/O) UFP concentration ratios and AER ($r^2 = 0.81$), with somewhat higher losses with the recirculation fan on. They report ratios in the range 0.08–0.47 when recirculation setting was on with low fan and 0.17–0.68 with fan off. Thus, inside-to-outside particle number ratios depend strongly on AER, which varies widely across normal operating speeds and from vehicle to vehicle.

In contrast, AERs observed during conditions that introduce outside air into the cabin (either via ventilation system set to outside air or by opening windows) are much higher than those observed at air recirculation settings. For example, Knibbs et al. (3) conducted experiments for six cars and showed that even at lowest fan settings, AERs were typically a magnitude higher than those at recirculation setting. Ott et al. (6) observed opening the windows by 3 inches increased AERs 8–16 times.

The purpose of this study was to test a sufficiently large number of cars in order to develop robust predictive models of AER during recirculation conditions – the conditions of maximum particle losses – as a simple function of readily-available information, such as vehicle age, mileage, manufacturer, and average speed. One important application of these models is epidemiological studies of particulate matter (PM), especially for UFP, which has high on-road concentrations. For UFP, excluding travel time in exposure assessment introduces large errors in exposure estimates. Furthermore, omitting UFP in-vehicle loss rates in exposure assessment would produce significant errors in exposure estimates for drivers of newer cars and drivers with significant time at slow speeds.

In this study, we measured AERs at three speeds for each of 59 California vehicles, chosen to represent the California fleet with regard to age, vehicle type, and manufacturer. These results more than triple the number of vehicle AERs reported in the literature and provides for the first time a sample of vehicles that is large enough to be considered reasonably representative of the current fleet of California vehicles and/or the U.S. Since vehicle AER varies more than an order of magnitude between vehicles, a large sample number is necessary to fully characterize vehicle AERs.

This study also demonstrated that using CO_2 to calculate vehicle AER is a relatively straightforward and accurate alternative to the use of tracer gases, which requires specialized measurement instruments. The ease of this method was one reason for the large number of vehicles tested.

2. Methods

2.1 Vehicle selection

Vehicles were selected to approximate the distribution of the California fleet in terms of vehicle size type (e.g., subcompact, compact, midsize, etc.), mileage, and age. Vehicle size data were based on the dataset of the 2002 report by the California Department of Motor Vehicles to the California Air Resources Board in support of their mobile source Emission Factors model (EMFAC) database), the latest available at the time of initial study design (18). Data on fleet mileage and age were based on 2009 data. Target numbers of test vehicles for each size category were calculated based on the frequency of these size categories multiplied by the fraction of the fleet that was five years old or newer (30%), 6 to 14 years (53%), and 15 years or older (17%) (18). Within these categories, an attempt was also made to select vehicles from the manufacturers having the largest sales in California (e.g., Toyota Corolla, Honda Civic, etc.) but there were no specific requirements by manufacturer. All vehicles tested are listed in the Supporting Information, S1.

2.2 Instruments

CO_2 was measured both inside and outside the vehicle simultaneously using two or more TSI Q-Traks, Model 7565 (TSI Inc., MN, USA) and one or more LI-COR Li-820 units (LI-COR Biosciences, NE, USA). Both units use a non-dispersive infrared (NDIR) detection technique, but the LI-820 unit is pump driven, thus allowing a faster response time than the Q-Trak unit, e.g., several seconds versus 20 seconds. Table S2 in the Supporting Information provides more details about the instruments and their settings. All instruments used for a given vehicle test were run simultaneously and ambient concentrations before and after a run were checked for consistency. An on-board GPS device (Garmin GPSMAP 76CSC) recorded the location and speed of the car at 1-second intervals. All instruments were synced to within 1 second of the time recorded by GPS.

2.3 CO_2 as a Tracer Gas

Carbon dioxide was chosen as an AER indicator for its low toxicity, ease of measurement, and its ready availability when using car occupants as the source. At a fixed vehicle speed (and hence fixed AER), in-vehicle CO_2 concentrations change until an equilibrium concentration is reached whereby the source of CO_2 from vehicle occupants is balanced by the losses of CO_2 due to exchange of low CO_2 concentration outside air with high CO_2 concentration inside air. This difference is typically hundreds or thousands of parts per million (ppm) of CO_2 so it is easy to measure with high relative accuracy. We achieved well-mixed conditions with a fan inside the vehicle, verified for each test by checking agreement with Q-Trak and Li-820 instruments placed in different locations within the car.

2.4 Mathematical Equation and Assumptions

AER increases with increasing vehicle speed due to pressure differences and/or turbulence around the vehicle. However, for a given vehicle speed (strictly-speaking, the vehicle air speed), the AER is nearly constant and the CO_2 concentrations inside the car will eventually reach an equilibrium value. But until the equilibrium is reached, the mass balance Equation 1 applies:

$$dT = S/V + C_{\mathrm{amb}} - C_{\mathrm{in}} AER_s \quad \text{Equation 1}$$

where, S/V is the vehicle-volume-specific source strength in ppm per hour, C_{amb} and C_{in} the outdoor and in-vehicle CO_2 concentrations (ppm), respectively, and AER_s is the speed- and vehicle-specific air exchange rate (hr^{-1}).

At equilibrium, Equation 1 becomes

$$dT = 0 = S/V + C_{\mathrm{amb}} - C_{\mathrm{eq}} AER_s \quad \text{Equation 2}$$

which can be re-written as:

$$AER_s = (S/V) / C_{\mathrm{amb}} - C_{\mathrm{eq}} \quad \text{Equation 3}$$

Assuming a small air exchange rate when the car is stationary, with interior air well mixed, the vehicle-specific source term can be determined by the initial build-up rate of CO_2 when inside and outside CO_2 concentrations are similar, i.e., the $((C_{amb} - C_{in}) * AER)$ term in Equation 1 is much smaller than the S/V term. For example, for <10 ppm difference in inside versus outside CO_2 and an AER of 2 hr^{-1}, the $((C_{amb} - C_{in}) * AER)$ term is 20 ppm per hour per unit volume change, compared to a typical build-up rate of 15000 ppm per hour per unit volume for two occupants, or less than one per cent. Under these conditions, Equation 1 becomes:

$$dT \cong S/V \quad \text{Equation 4}$$

2.4.1 Determination of Source Strength—The CO_2 source strength was determined by measuring the build-up rate of CO_2 from two occupants inside the vehicle when the vehicle was first sealed and the inside CO_2 concentrations were close to ambient concentrations. At the start of the test, any small rates of air exchange had little effect on inside CO_2 concentrations since the inside and outside CO_2 concentrations were similar. At the beginning of these tests, the CO_2 concentration build-up is very linear and it is easy to determine the build-up rate accurately as the slope of the CO_2 concentration versus time. Eventually, as the inside CO_2 concentrations reach high levels, the exchange of small amounts of inside air with outside air causes the build-up rate to slow and become non-linear, but this typically requires at least several minutes.

Since physical activity before, during, and after the runs were minimal, the CO_2 source strength reflected the resting (inactive) metabolism rates of the occupants and was therefore constant for the hour or two of the measurements. This was demonstrated in repeated measures of CO_2 build-up after the run for 10 vehicles. Results are presented in Supporting Information S3.

2.4.2 Determination of Equilibrium Concentration—Equilibrium CO_2 concentrations were determined for constant speeds of 32, 56, and 89 km hr^{-1} (20, 35 and 55 mph) with windows closed, ventilation set to air recirculation, and the fan setting set to either 50% or the closest possible to a midway setting. For a smaller subset of vehicles, AER was also determined for stationary vehicles and speeds exceeding 100 km hr^{-1} (62 mph). Equilibrium CO_2 concentrations were determined when the criterion was met of a maximum fluctuation of 50 ppm for at least the last 10 minutes at each speed. For the median equilibrium value recorded in this study, 50 ppm fluctuation translated to 2.1%. For conditions of closed windows and recirculating air, the fan setting was also observed to affect AER, although the effect was minor compared to that of speed. Fan setting effects on AER were tested for a subset of nine vehicles at several speeds and results are presented in the Supporting Information, S4.

Early in the testing, we consistently observed that when the ventilation was set to outside air condition or the windows were open, AER was extremely high. To characterize the high end of AER conditions, we estimated AER at outside air ventilation settings for 8 stationary vehicles. The vehicles tested, testing methods and AERs measured are listed in Supporting Information, S5.

2.4.3 Speed and Routes Driven—Routes were carefully chosen to allow nearly constant speeds. To achieve constant speeds of 89 km hr^{-1}, freeways were driven during conditions of free-flowing traffic. To achieve constant speeds of 32 and 56 km hr^{-1}, runs were either made in a large cemetery or a continuous loop around the Rose Bowl in Pasadena, depending on the source location of the car being tested. Both of these routes allowed fairly short laps to prevent long duration in one direction, thus canceling any effect of wind direction and velocity on AER. Furthermore, there was minimal vehicular traffic on the roads at both locations during the times the tests were conducted. This minimized changes in outside CO_2 due to the presence of exhaust plumes from other vehicles.

2.4.4 CO_2 Criteria—Time series plots of speed, CO_2 particle number, and fine particulate mass ($PM_{2.5}$ $D_p < 2.5$ μm) were aligned and adjusted to take into account any differences in instrument clock time or response time. Alignments were made based on events that caused a rapid concentration change, such as a window opening that rapidly reducing in-vehicle CO_2.

Where the in-vehicle CO_2 concentration met the <50 ppm change criterion for a given speed, the exact equilibrium concentration was determined at the time where CO_2 concentrations showed a less than 2% standard deviation for at least 20 data points (i.e., > 3 minutes of data). Concurrent outside CO_2 concentration was then subtracted. For the 32 and 56 km hr^{-1} speeds, the outside CO_2 concentrations at both the Rose Bowl and the cemetery were very stable, but the outside CO_2 concentrations on freeways for the 89 km hr^{-1} condition were not. Therefore, freeway CO_2 concentrations were averaged over the previous two minutes for each equilibrium value chosen.

2.4.5 Predictive Model—As it is not feasible to test AERs in large numbers of vehicles, such as might be required in an epidemiological study, predictive models are needed for estimating AER. Preliminary multiple linear regression models showed that AER was well predicted using a combination of vehicle age, mileage, speed, and manufacturer. The AER was strongly related to speed in particular. However, even after adjusting for speed, repeated measurements of AER on the same vehicle have some degree of correlation. For example, a leaky vehicle will consistently show higher AERs than average across all speeds. This violates the assumption of independent observations in multiple linear regression (MLR) models. To account for the presence of unknown within-vehicle correlation, Generalized Estimating Equation (GEE) models (19) were used. MLR models were also fit to compare results across modeling techniques.

The results for the 59 vehicles tested, generally three AERs per vehicle (i.e., at three different speeds), were modeled to test the predictive power of vehicle characteristics such as vehicle mileage, age, and manufacturer. Squared and cubed terms for mileage, age, and speed were included to account for any non-linear effects. Vehicle characteristics such as interior vehicle volume and frontal area, and fan setting were also included. Manufacturer variables included specific vehicle manufacturer categories such as Ford, GM, Toyota, Nissan, Honda, and ‘other’ as well as broader categories such as U.S. and non-U.S. or U.S., Japan, and ‘other.’ Vehicles were also grouped by the source of the vehicle (i.e., CARB, rental agency, or student volunteers) and tested for differences. Speed was included; both as a predictive variable and as a stratifying variable, i.e., data were analyzed separately for a given speed. Since AER results had a strong rightward skew, a natural log transformation was used.

Parsimonious GEE and MLR models were obtained by backwards step-wise selection in which variables were retained if they improved R^2 (MLR) or were statistically significant (GEE) at p=0.05 value. Residuals from both models were inspected to check model assumptions. R^2 was calculated for the GEE model by taking the square of the Pearson correlation coefficient between observed and model-predicted values of natural log transformed AER.

3. Results and Discussion

3.1 Vehicles Tested

Achieving a representative sample of vehicles for testing was a primary objective of this study since representativeness enhances the utility of predictive models of AER. We selected 59 vehicles to represent the California fleet in terms of vehicle age and size type based on EPA classes as shown in Table S1 in the Supporting Information. The age distribution of the cars tested is presented in Figure S1 against a background of the age distribution of the California fleet.

3.2 AER Results and Uncertainties

A typical time-series plot of in-vehicle and outside CO_2 concentration and speed is shown in Figure 1. As shown in this plot, the CO_2 build-up rate at the beginning of the test is quite linear. Figure 1 also shows how the various in-vehicle CO_2 concentrations at different speeds show an underlying logarithmic change that eventually reaches a steady equilibrium concentration despite the small irregularities in speed. In Figure 1, the % standard deviations of the in-vehicle CO_2 concentration were 1.0, 1.5 and 1.1% at 32, 56, and 89 km hr^{-1}, respectively, while the outside CO_2 concentration standard deviations were 4, 7 and 1.4%, respectively. The resulting AER at 89 km hr^{-1} was 13.6 hr^{-1}. If the in-vehicle CO_2 concentration deviated by the 1.1% (13 ppm) standard deviation observed, for example, the AER values ranged from 13.4 and 13.8, or ±1.5%. Similarly, the change in AER values for 56 and 32 km hr^{-1} due to observed deviations in inside CO2 concentrations were ± 2% and 1%, respectively.

The equilibrium CO_2 concentrations were repeatable to within 2%, and the CO_2 build-up rates were repeatable to within 1% based on 4 and 10 repeated tests of equilibrium concentration and build-up rate, respectively. We assumed these values were good estimates of the uncertainty in these variables, and combined them with manufacturer estimates of instrument precision in a root-mean-square error propagation, to arrive at a total AER uncertainty. The Q-Trak and Li-820 manufacturer stated accuracies were ±3% and 4%, respectively, in the range of measurements taken. The resulting root-mean-square error propagation resulted in a maximum CO_2 build-up rate uncertainty of 5.2%, an equilibrium concentration maximum uncertainty of 4.5%, and an AER maximum uncertainty of 7.5%. The highest uncertainty was for 56 km hr^{-1}, due to challenges in maintaining this speed on arterial roads.

Figure 2 shows the results for all cars tested at each speed. Under recirculation conditions, the large vehicle-to-vehicle differences are readily apparent, as is the strong dependence of AER on speed for a given vehicle. Under outside air settings, AERs were uniformly higher, and showed a strong positive correlation with the fan setting (average $R^2 = 0.99$). There were no observed associations between AER and the manufacturer or the age of the eight vehicles.

3.3 GEE Model Results

The Generalized Estimating Equation (GEE) model gave the following predictive equation for AER under recirculating conditions as a function of easily-obtainable parameters related to each vehicle:

$$Ln(AER) - 0.63 - (age*0.066)+(age^2*0.0058)+(kilometers *0.016) - (kilometers^2 *7.8*10^{-5})+(speed*0.029)+Manuf\ \ Adjustment \quad \text{Equation 5}$$

Where ‘age’ is in years, ‘kilometers’ is vehicle lifetime mileage in thousands of kilometers, and ‘speed’ is in kilometers per hour. The manufacturer’s adjustment (‘Manuf Adjustment’) is given in the last four rows of Table 1, with Japanese manufacturers being the base case (i.e., no adjustment needed). Fan setting, although observed to slightly increase AER, was not significant, nor were vehicle size characteristics such as frontal area. The GEE model R^2 was 0.70. In general, GEE and MLR coefficients matched closely, but the GEE coefficients had wider confidence intervals, due to the within-vehicle correlation.

AER is a non-linear function of speed and mileage/age and Figure 3 shows how the model-predicted AER strongly increases with speed for the median age and mileage in the study test fleet (8 years old and with 138,000 kilometers (about 86,000 miles), respectively. Figure 3 also shows how the model predicts AER to increase with each additional year of age assuming 23,000 kilometers per year (about 14,000 miles), the study average mileage change per year. An AER prediction for vehicles having an age-mileage distribution equal to the average for California vehicles (as reported in EMFAC (18)) at three speeds 10, 35 and 65 miles hr^{-1} (16, 56 and 105 km h^{-1}) are presented as Figure S5 in the Supporting Information.

Figure 4 shows the model predictions versus actual measurements, and the normality of the residuals. The model predictions, when grouped by source of vehicle (ARB, rental or volunteer), did not show any difference in the pattern of residuals.

As a test of our experimentally-derived and modeled results against other studies, our Equation 5 was used to predict the AER of the vehicles tested in the study by Knibbs et al.

(1), the largest AER study conducted before the present study, and agreement was good. The slope of our results versus predicted was 0.7 and was 0.6 for the Knibbs et al. results. The respective intercepts were 0.6 and 0.8, respectively. Both R^2s were good, 0.7 and 0.8, respectively. To test how good this agreement was for a comparison sample size of six vehicles (with two speeds), we took 10,000 samples of six cars of our measurements results, each with the two speeds closest to the Knibbs et al. speeds, and produced distributions of slope and R^2. The median slope and R^2 was 0.56 and 0.75, respectively. Therefore, our model predictions for the vehicles used in the Knibbs et al. (3) study were indistinguishable from our own results. The distributions are shown in S7 in Supporting Information.

3.4 Implications for Exposure Assessment and Epidemiology

The AERs measured during recirculation conditions in this study were in the range where significant particle number losses would be expected to occur. For example, Figure 3 shows that for the median age study vehicle, the speed range from 32 to 105 km hr^{-1} (20 to 65 miles hr^{-1}) would cause AERs to range from about 4 to 9 hr^{-1}, respectively. Our recent (unpublished) measurements of particle number attenuation in these vehicles show that this air exchange rate typically produces 70 to 90% particle number reductions at steady state. Therefore, vehicle-specific estimates of AER are necessary for accurate assessment of in-vehicle UFP exposure, as these loss factors would produce exposures that vary three fold, i.e., 10 to 30% of on-road concentrations.

Our predictive model explained 70% of the variation in the observed AERs under recirculation conditions, from <2 hr^{-1} to >50 hr^{-1}, but only requires variables that are easily obtainable through questionnaire or survey. AER was found to be a predictable function of vehicle age and mileage, speed, and to a lesser extent, manufacturer, while fan speed setting was relatively unimportant. Average speed can also be estimated by survey for typical commutes to work, and from city averages for other trips based on home location. However, ventilation setting would also be a necessary survey component as driving with ventilation set to outside air or with windows open generally produces AERs that are an order of magnitude higher, with correspondingly low particle loss rates.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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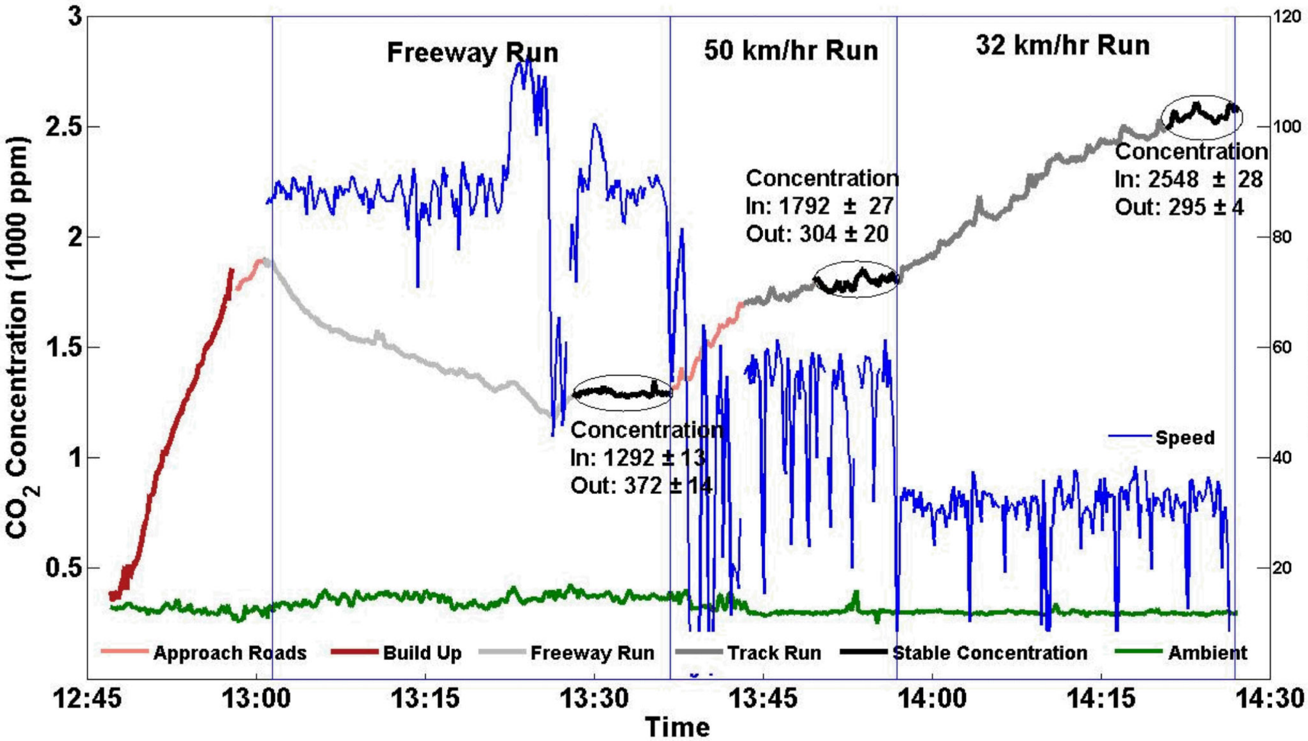

Figure 1.

Typical time-series plot for runs conducted at the cemetery along with the initial build up and freeway run. Average speed during freeway run was 89 ± 10 km hr^{-1} (average ± standard deviation) for stable CO_2 portion highlighted in black. The second black highlight corresponds to stable CO_2 values during 51 ± 9.4 km hr^{-1} and 31 ± 5.5 km hr^{-1} speeds.

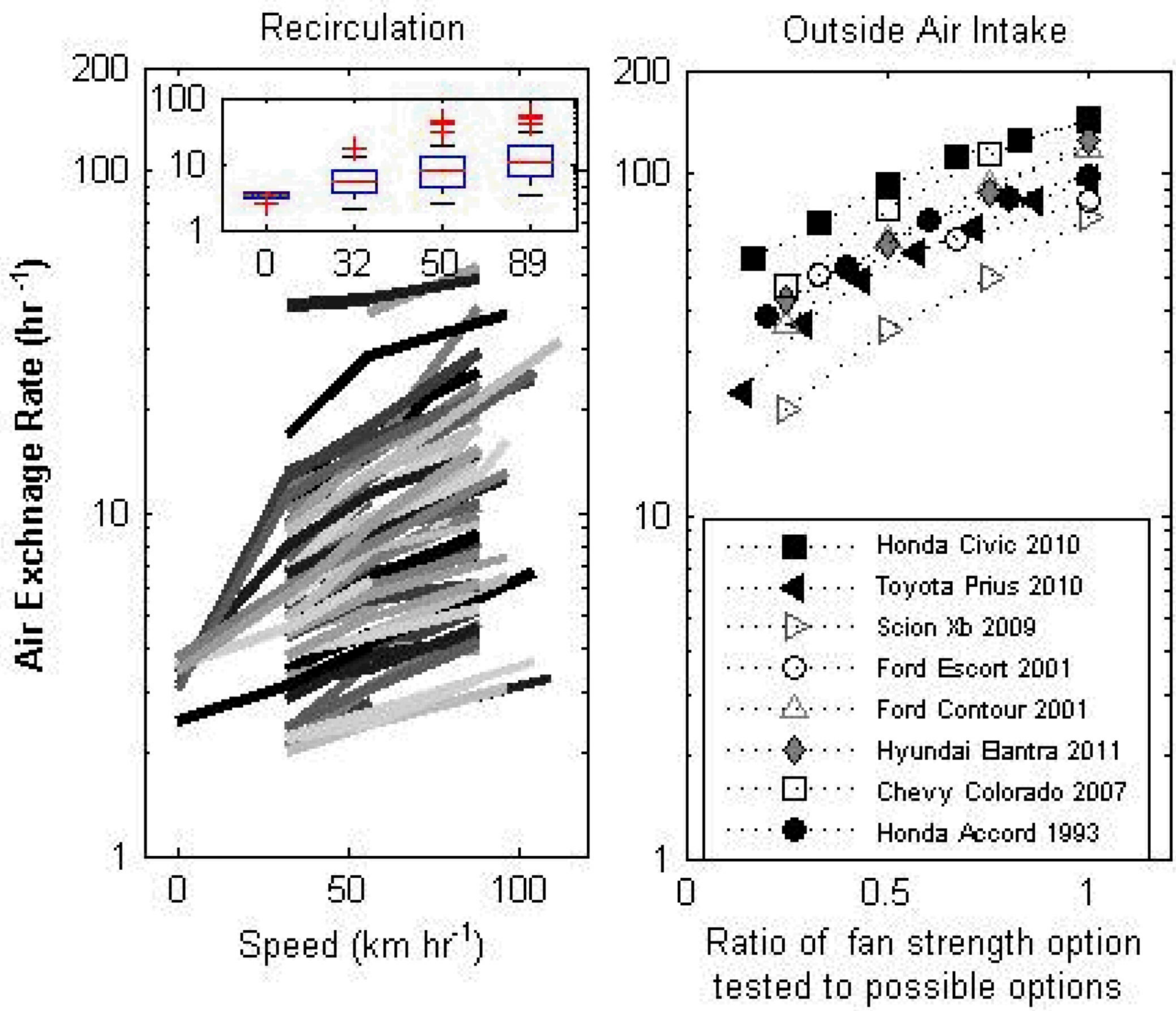

Figure 2.

AER results for all vehicles tested. For the box plot inset, the red line in the middle of the box is the median and the box bounds the 25th and 75th percentiles of the data.

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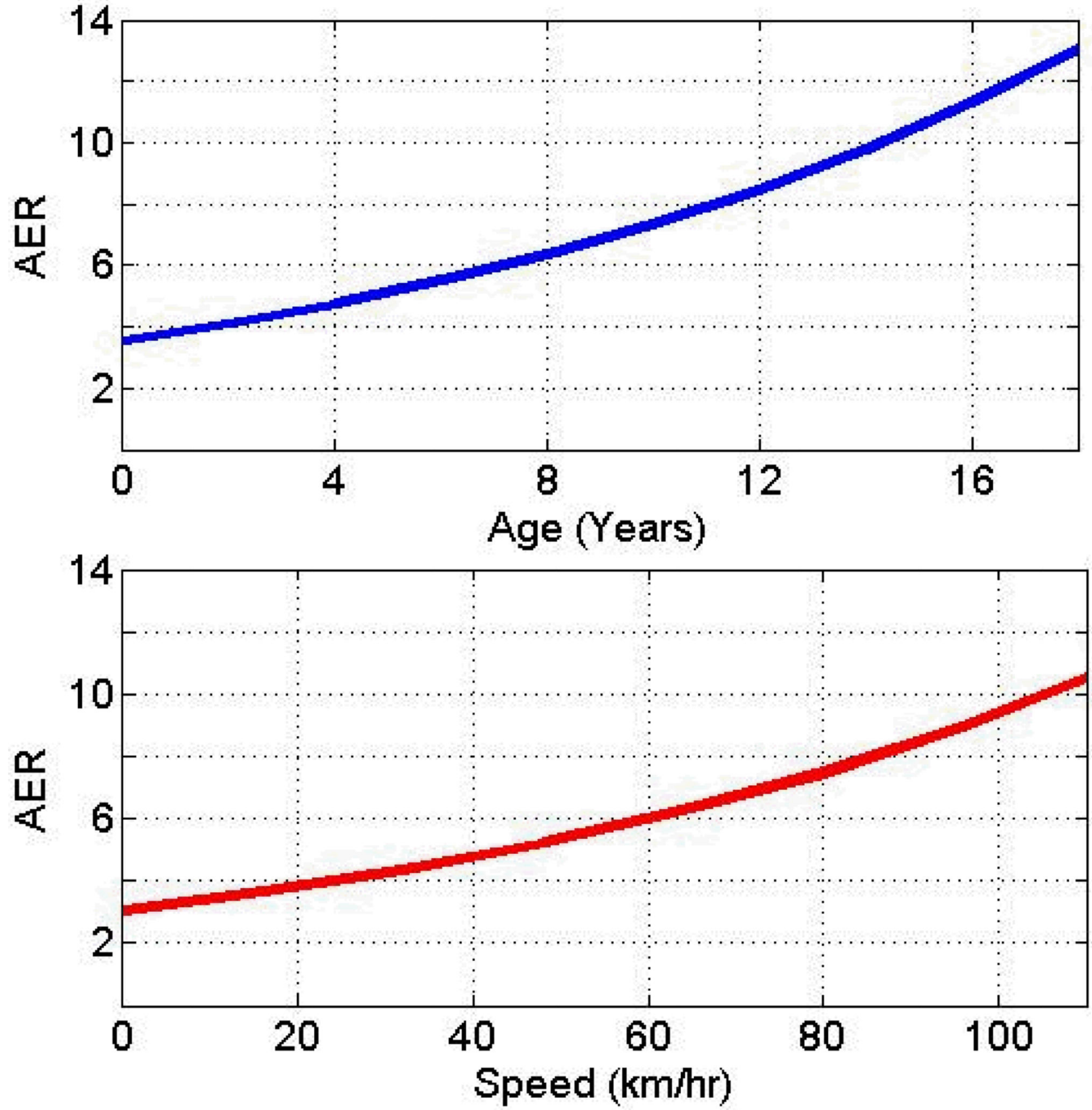

Figure 3.
Model-predicted AER increase with age and speed for median age study vehicle.

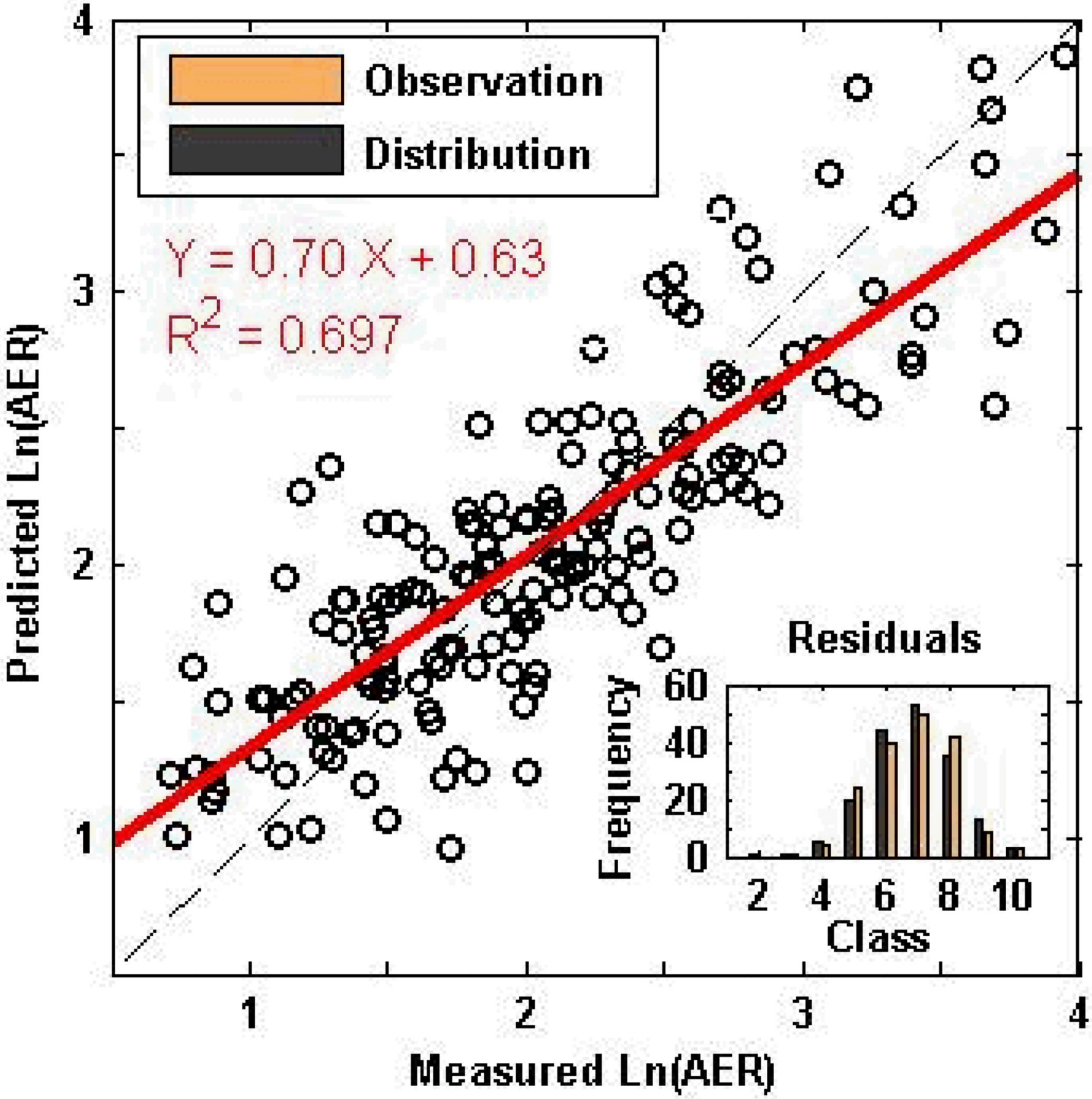

Figure 4.

Model predictions versus actual measurements, and the normality of the residuals. Each data point represents a measured AER used to populate the predictive model. The solid line is the linear fit line and the dashed line is the 1:1 fit line. The class boundary for residuals is defined as bins of Ln(AER) being −2.00, −1.68, −1.36, −1.04, −0.73, −0.41, −0.088, 0.23, 0.55, 0.87 and 1.19.

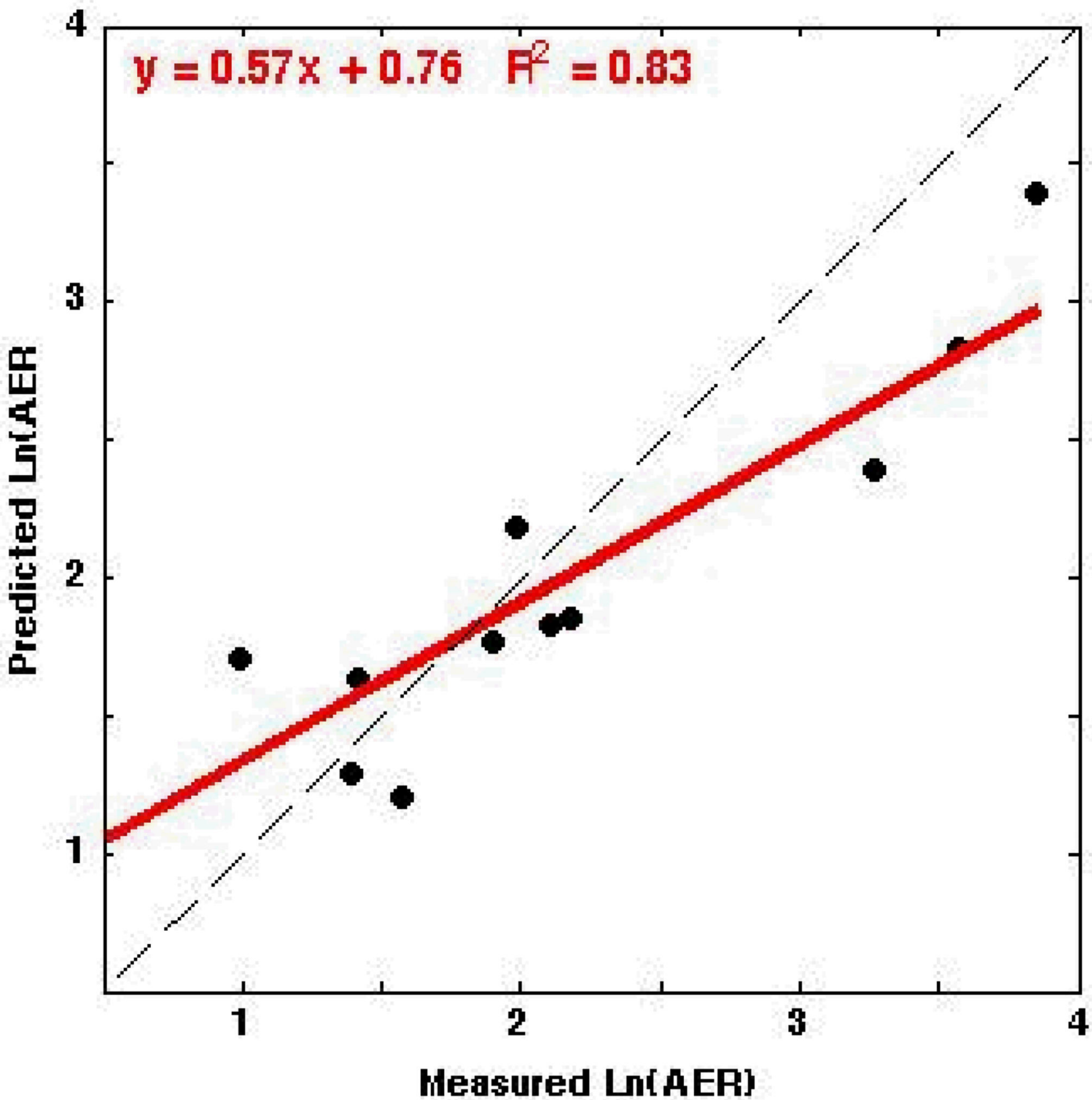

Figure 5.
Comparison of model predictions and results from Knibbs et al., 2009.

Table 1

AER model coefficients, 95% confidence intervals, and P values.

Source	Value	Standard Error	z	Pr > |t|	95% Confidence Interval	
Intercept	0.63	0.124	5.1	0.000	0.390	0.876
Age (years)	−0.066	0.043	−1.6	0.12	−0.15	0.018
Age^2	0.0058	0.0020	3.0	0.003	0.0020	0.0096
Kilometers (thousands)	0.016	0.0076	2.2	0.025	0.0021	0.032
$Kilometers^2$	−0.000078	0.000044	−1.7	0.082	−0.000167	−0.000010
Speed ($km\ hr^{-1}$)	0.029	0.00152	19	0.000	0.026	0.032
Manuf-Japan	0.000	0.000				
Manuf-GM	0.55	0.15	3.7	0.000	0.26	0.85
Manuf-Ford	0.25	0.12	2.0	0.042	0.0085	0.48
Manuf-other	−0.051	0.20	−0.25	0.80	−0.45	0.34