Relating Road Dust Emissions Surrogates to Average Daily Traffic and Vehicle Speed in Las Vegas, Nevada

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ABSTRACT

A new approach to estimate particle emissions from roads was developed as part of a road dust study that took place in Las Vegas, NV in 1999. The Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER) method uses the difference in particle concentrations measured behind the front tire and on the hood of a specially instrumented vehicle to infer potential emissions from roads. Because the system uses real-time particle concentration sensors to estimate PM_{10}, large amounts of data can be collected over a short time period when compared with silt loading analyses. The results of the TRAKER study were incorporated into a GIS program for comparison with traffic demand model output. The analysis found that roads with vehicle speeds greater than 45 mph were 20 times cleaner than slower speed roads. In addition, roads with average daily traffic greater than 10,000 vehicles per day per lane were found to be 12 times cleaner than lower average daily traffic roads. These results provide an improved understanding of the factors that control the emissions of dust from roads.

INTRODUCTION

Road dust is the predominant source of primary PM_{10} in many western cities based on existing emissions inventories. In the California South Coast Air Basin, paved road dust accounts for 65% of the PM_{10} emissions (CARB, 1998). Despite the importance of this source, little is known about the major processes that control the reservoir of suspendable particles on the roadways, the physical processes that entrain the dust, and the distance that the dust travels before depositing to the ground. This information is essential for developing effective management practices for this PM_{10} source.

The U.S. E.P.A. paved road dust emissions factor used for the National Trends Inventory and the PART5 mobile source emissions model is shown in equation 1 (U.S. EPA, 1993).

Equation (1) $$R_{pr,size} = k_{size}(sL)^{0.65}(W)^{1.5}$$

where:

$R_{pr,size}$ = PM_{10} or $PM_{2.5}$ road dust emission factor for all vehicle classes combined (grams per mile)
k_{size} = 0.90 g mile^{-1} (1609 m) for PM_{10} or 0.41 g mile^{-1} for $PM_{2.5}$
sL = silt loading on the road (g m^{-2})
W = average weight of all vehicle types combined (short tons (909 kg))

Silt loading is a measure of the mass of particles less than 75 μm in diameter per unit area of road surface. Measurement of silt loading requires the closure of one lane of traffic for a few hours while samples are collected from several test strips that span the width of the lane. Samples are collected by sweeping large debris into a container followed by thoroughly vacuuming the road surface. Silt particles are then extracted from the total sample by dry mechanical sieving. The resulting dry silt fraction is then weighed. The silt loading is calculated as the mass (in grams) of material with diameter less then 75 um divided by the area (in square meters) of the road surface swept.

A new approach has been developed to measure the emissions of particles from roads using onboard particles sensors mounted behind a vehicle's tire and on the hood of the vehicle. The difference in particle concentrations measured at these two points is related to the emissions of particles resulting from the tire's contact with the road. The method is named Testing Re-entrained Aerosol Kinetic Emissions from Roads (Kuhns et al., 2001) and permits sampling on a much larger spatial scale than would be feasible using conventional silt loading methods. When coupled with a GPS, the TRAKER system permits mapping of road dust emissions for every street surveyed by the TRAKER vehicle. Because many measurements of dust emissions potential can be obtained in a relatively short amount of time, the TRAKER system provides data sets that are large enough for the investigation of factors controlling road dust emissions. In this study, the TRAKER data is combined with activity data from a traffic demand forecasting model (TDFM) to explore the relationships between the TRAKER signal, Average Daily Traffic (ADT), and vehicle speed.

EXPERIMENTAL METHODS

The TRAKER vehicle in this experiment was a 1988 Jeep Cherokee and used 2 TSI model #8520 DustTrak's (one mounted on the hood of the vehicle and a second with an inlet mounted behind the vehicle's tire). Measurements took place between September 23 and October 4, 1999 in the greater Las Vegas, Nevada area. Particle concentrations at the two locations were measured every second and joined with positioning data from an onboard GPS unit. The TRAKER system was operated over 19 segments of road in which silt loading measurements were collected. Using linear regression, a mathematical model inferring silt loading from the TRAKER signal (i.e. the difference in PM_{10} concentration measured between the tire and the hood) and vehicle speed was formulated. The TRAKER vehicle was then used to survey over 300 miles of paved and unpaved roads in the Las Vegas Valley. A detailed description of the instrument setup and the relationship between the TRAKER signal and silt loading is provided by Kuhns et al. (2001).

RESULTS

Early in the TRAKER experiment, it was discovered that speed was a significant factor controlling the concentrations of PM_{10} behind the vehicle's tire. When the vehicle was operated over the same road segment at different speeds, the concentrations were observed to increase exponentially with speed. By normalizing all differential PM_{10} concentrations to the concentration measured at 20 mph, a speed curve was assembled from 20 different road segments (see Figure 1). Based on this relationship, the vehicle speed was factored out of the TRAKER signal to produce a corrected signal indicative of the potential of the road to emit PM_{10}. The speed-corrected TRAKER signal is defined as:

Equation (1) $$T^* = C_{diff} e^{(-0.090 \pm 0.009)s}$$

where

C_{diff} = Differential PM_{10} concentration (in mg/m^3) measured between the tire and the hood of the vehicle
s = Vehicle speed (in mph)
T^* = TRAKER signal corrected for speed effects (in mg/m^3)

The corrected TRAKER signal was calculated for the 300 miles of roads in Las Vegas surveyed during the 1999 TRAKER study. Using ArcView GIS software, a map of the TRAKER signal was produced for times in which the vehicle was traveling more than 5 mph. At speeds less than 10 mph, the TRAKER signal was generally very low and more susceptible to interferences from cross winds. An example map is shown in Figure 2. The speed independent TRAKER signals (T^*) were averaged over each road segment. The thickness of the solid black lines scales with the magnitude of the average T^* for that segment.

For all segments surveyed with the TRKAER during the study period an analysis was conducted to evaluate how the road dust emissions potential is dependent on the typical travel speed of the vehicles and the average daily traffic (ADT) per lane.

Travel speeds were calculated from the second by second change of position of the TRAKER vehicle. While these speeds are likely to differ from the daily average vehicle speed over a particular road segment, they approximately represent a vehicle moving with the pace of traffic at the time of the measurement. The ADT per lane data was obtained from TRANSCAD model output. The TRANSCAD model is a traffic demand forecasting model (TDFM) maintained by the Clark County Department of Comprehensive Planning. The model uses a four step process (trip generation, trip distribution, mode split, and traffic assignment) to simulate trips taken on the Clark County roadway network. Real traffic counts were used to adjust the output of the TDFM to more accurately reproduce the flows of traffic on the roadway segments. A plot of the adjusted TDFM output versus the actual traffic counts is shown in Figure 3. Both modeled and measured traffic flows were divided by the total number of lanes on the road segment, thus the data is shown with units of average daily traffic per lane. The slope with zero intercept for this relationship is 0.91 with an r^2 of 0.82 indicating that the TDFM is able to adequately represent traffic volumes on roads in Las Vegas.

The TRAKER signal T^* is compared with the modeled ADT per lane in order to investigate how traffic volume affects dust emissions potential. Figure 4 shows the T^* plotted versus ADT per lane for each road segment in which there were at least 10 TRAKER measurements. There is a great deal of scatter in the data indicating that ADT alone is not the primary factor controlling road dust emissions potential. While the average T^* data is spread over five orders of magnitude, there does appear to be a decreasing trend in T^* with ADT per lane. When traffic volumes are greater than 10,000 vehicles per day, the average and standard deviation of T^* is 0.005 +/- 0.015 mg/m^3 (n = 114). For roads with less than 10,000 vehicles per day the average and standard deviation T^* is 0.06 +/- 0.60 mg/m^3 (n = 375). Note that the high standard deviations represent the spread in the values of emissions potential and not the precision of the TRAKER.

T^* is also compared with the travel speed of the TRAKER vehicle. The relationship shown in Figure 5 between vehicle speed and T^* appears to be stronger than the relationship between ADT and T^*. For speeds greater than 45 mph, the average and standard deviation of T^* is 0.003 +/- 0.008 (n = 104). For speeds less than 45 mph, the average and standard deviation of T^* is 0.06 +/- 0.60 mg/m^3 (n = 385).

DISCUSSION AND CONCLUSIONS

The TRAKER signal T^* is based on the measurement of particles that are either suspended directly from the road surface or are emitted by the vehicle tire. At present, it is unknown whether road dust emissions are dominated by the mechanical interaction between the tire and the road or by the turbulent shear applied to the road by the moving vehicle. The TRAKER method is only a measure of the former mechanism.

The results above indicate that emissions from the tire interacting with the road surface are affected both by ADT and by vehicle speed. Average T^* values for roads with less than 10,000 ADT were 12 times larger than T^* measured on roads with more than 10,000 ADT. Similarly, roads with typical vehicle speeds less than 45 mph were ~20 dirtier than roads with vehicle speeds faster than 45 mph. These results are consistent with observations since busier and faster roads are generally visibly cleaner than less used and slower roads.

A quantitative kinetic mass balance model does not exist for road dust that accounts for the sources depositing material to the roadway, the transformations of coarse material to fine suspendable PM by grinding, and ultimately the removal of these particles from the roads. An understanding of these processes would both improve estimation of road dust emissions on urban and regional scales and provide the basis for developing management practices that can be used to minimize these emissions. The preceding results illustrate that TRAKER provides a method that will be useful for developing such a model. In particular, future TRAKER work can be used to help design strategies that will reduce potential sources of road dust and to quantify the rates at which dust is emitted from roads under various conditions.

REFERENCES

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KEYWORDS

Road Dust
Fugitive Dust
Paved Road Emissions
Unpaved Road Emissions
Particulate Matter

FIGURES

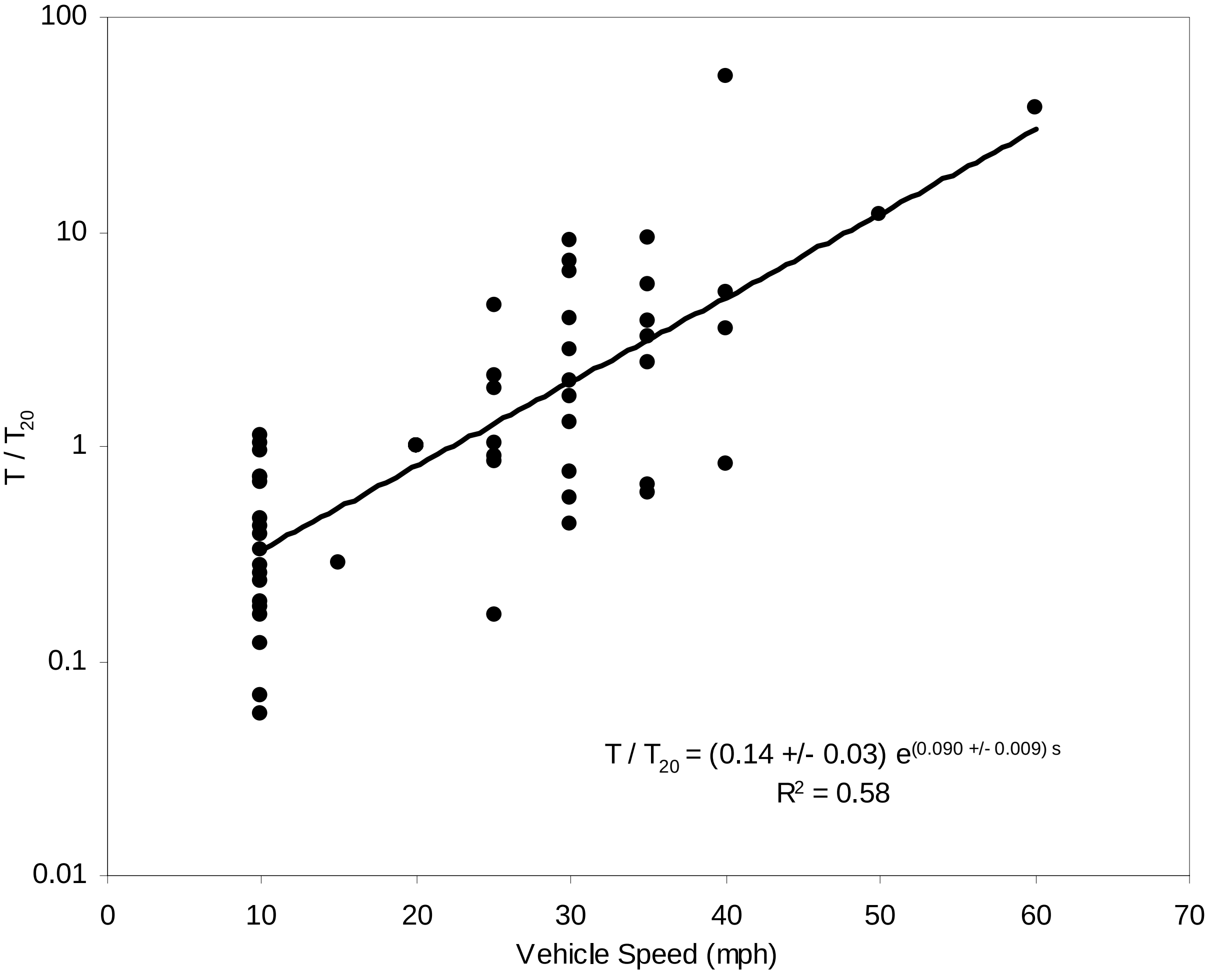

Figure 1. TRAKER signal (i.e. difference between tire PM10 concentrations and hood PM_{10} concentration) normalized to TRAKER signal at 20 mph versus vehicle speed. Data for the figure was obtained from 20 different road segments in the Las Vegas area.

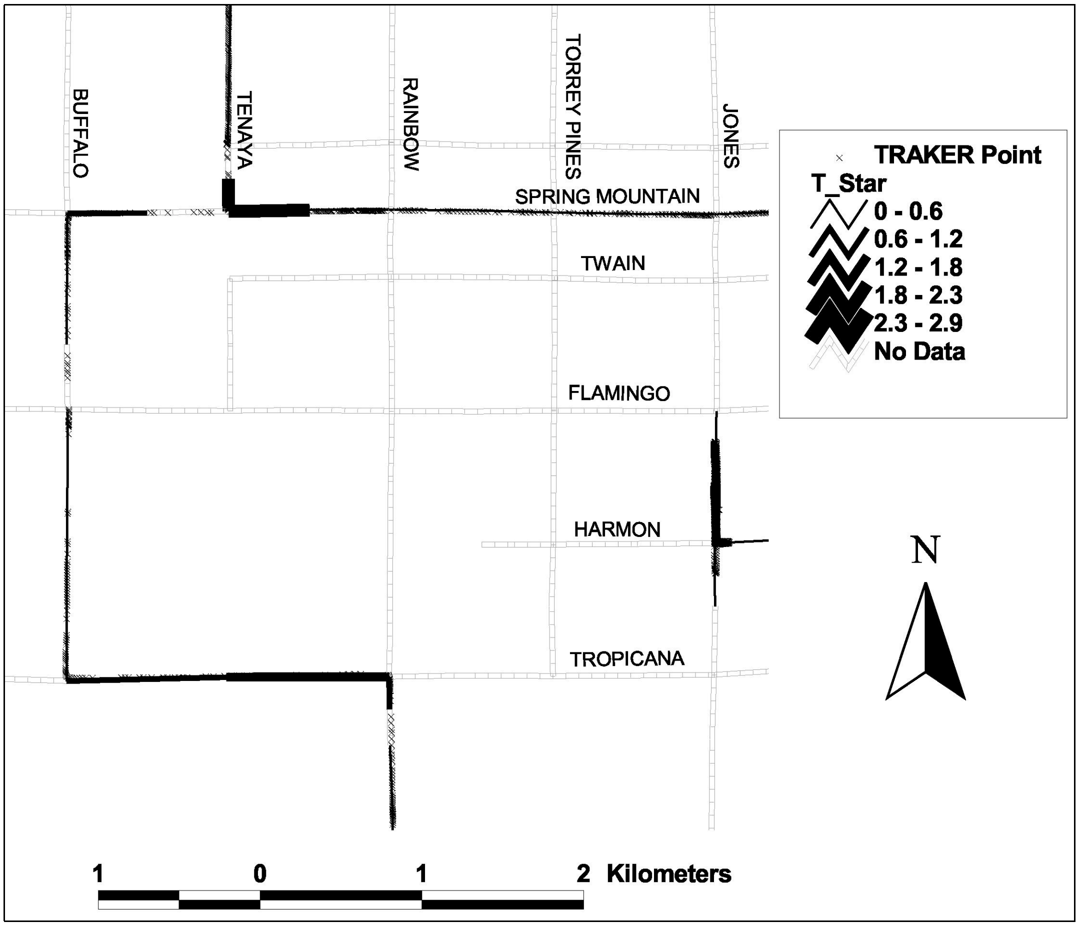

Figure 2. Example map of TRAKER survey data. Circles with white centers are points where TRAKER measurements were collected. Solid black lines indicate street segments on which a minimum of 10 TRAKER measurement were collected. The thickness of the line is proportional to the average TRAKER signal measured on that street. This analysis permits quantitative identification of roads with comparatively high dust loadings. Note that the intersection of Tenaya and Spring Mountain is substantially dirtier than Buffalo between Flamingo and Tropicana.

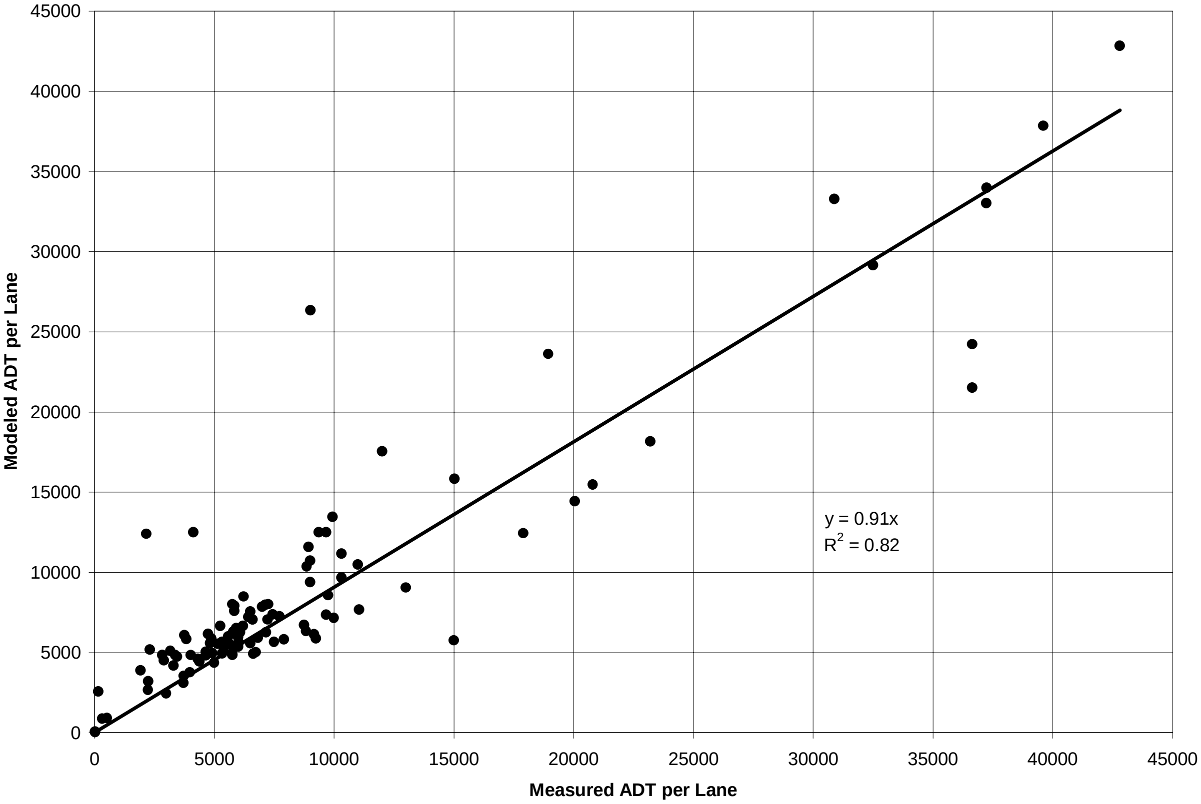

Figure 3. Modeled versus measured average daily traffic per lane. Comparison of traffic demand model output with real traffic counter data.

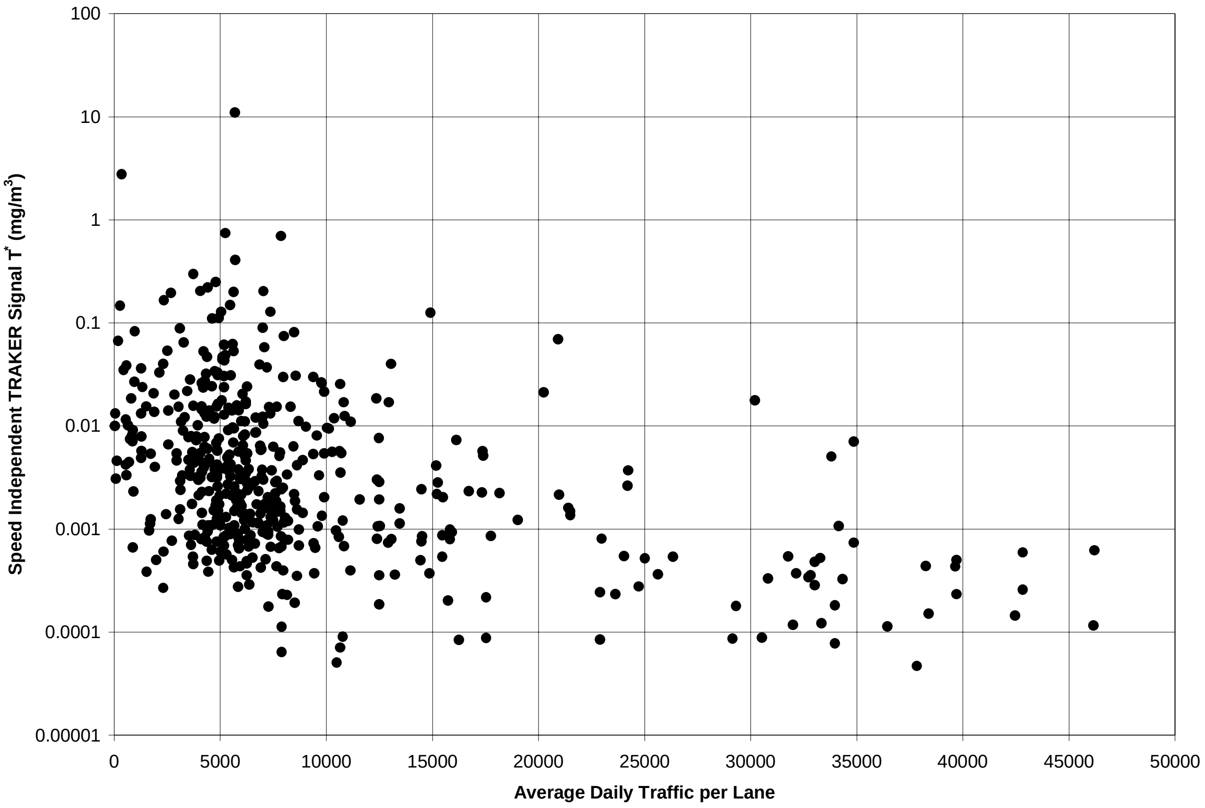

Figure 4. Comparison of the TRAKER signal (T*) with the average daily traffic per lane. Roads tend to be cleaner (T* < 0.01 mg/m^3) when traffic flows are above 10,000 vehicles per day.

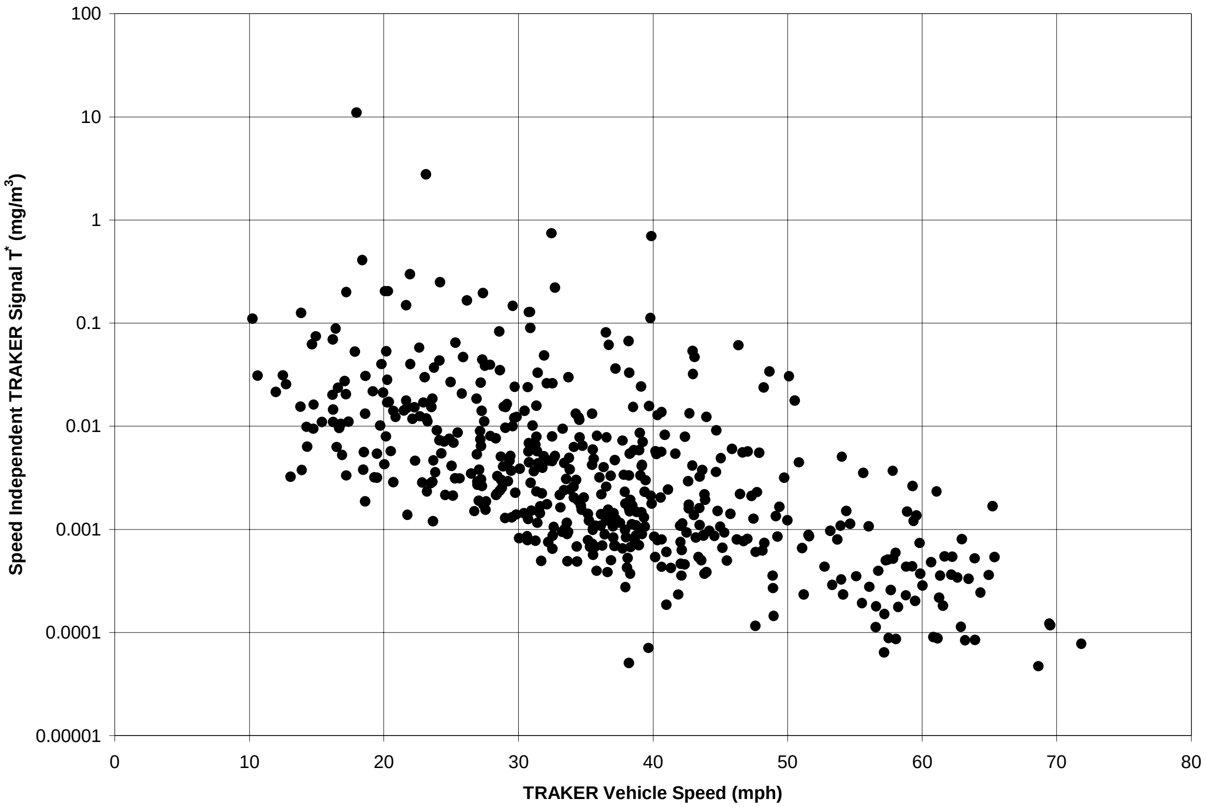

Figure 5. Comparison of the speed independent TRAKER signal (T*) with TRAKER vehicle speed during survey. Roads tend to be clean ($T^* < 0.01$ mg/m^3) when traffic speed is above 45 mph.