TRAKER: A Method for Fast Assembly and Update of Paved and Unpaved Road Dust Emission Inventories

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ABSTRACT

The broad goal of this study was to assess the state of vehicle-based technologies for measurement of road dust emission potential as a possible alternative to inferring emission factors from silt loading measurements.

A set of roads with a combined length of 150 km was pre-selected for the purpose of PM_{10} road dust emission measurement on two consecutive days. The “loop” formed by these roads covered a variety of street types including freeway, arterial, and residential roads from several geographic locations within the Las Vegas Valley. Overall, analysis of TRAKER (Testing Re-entrained Aerosol Kinetic Emissions from Roads) results showed that emission factors in grams per vehicle kilometer traveled were generally higher for low speed roads such as residential streets than for high speed roads such as freeways.

On a road link basis, the percent deviation between the first and second day followed a roughly normal distribution with an average near zero and a standard deviation of 10%. This indicated that, at least for the two sampling days considered, the day-to-day precision of the TRAKER measurement is reasonably good. It was hypothesized that this was in part because winds were generally low (< 4 m/s) during both sampling days.

In addition to the DRI-developed TRAKER, the University of California in Riverside (UCR) demonstrated a technology (SCAMPER) that is similar in concept. A comparison of results obtained by the TRAKER and SCAMPER systems will be conducted in future work.

INTRODUCTION

Dust emissions originating from motor vehicle travel on paved and unpaved roads constitutes a significant fraction of the PM_{10} (airborne particulate matter with aerodynamic diameter less than 10 microns) in many areas of the western United States[1]. For the purposes of estimating emission inventories of PM_{10} road dust, the AP-42[2] guidance document suggests using silt content and silt loading measurements to estimate emissions from unpaved and paved roads, respectively. Silt measurements are time consuming and frequently require the alteration of roadway traffic patterns while samples are being vacuumed or swept from the roadways. After collection road material samples are mechanically sieved to extract the size fraction with physical diameter less than 75 μm.

The objective of this study was to measure PM_{10} paved road dust emissions over a series of contiguous roads in the Las Vegas Valley that constitute a closed loop. The purpose of this work was to provide the Clark County Department of Air Quality Management with hands-on experience with the nature of the TRAKER vehicle-based road dust emission measurement method and to collect data that would be directly comparable to measurements made by a similar system (SCAMPER) developed by the University of California, Riverside (UCR). In this paper we report on the results of TRAKER measurements completed in the summer of 2004. In future work, measurements collected with TRAKER and SCAMPER will be compared.

BACKGROUND

Inhalable dust emissions from paved and unpaved roads are frequently estimated by measuring airborne concentrations of PM_{10} upwind and downwind of a road[3,4]. Combined with measurements of wind speed and direction, the differences between the downwind and upwind concentrations can be used to estimate the horizontal flux of PM_{10} dust across the plane that is parallel to the road and perpendicular to the ground. The horizontal flux can in turn be translated into an emission factor. The emission factor is an estimate of the amount of PM emissions that result from incremental levels of a certain activity and, in the case of road dust, is expressed as the mass of particles in a given size range emitted as a result of a unit of vehicle travel (e.g., grams per vehicle kilometers traveled or g/vkt).

The upwind/downwind technique is not practicable for measurement of emission factors on the scale of an entire airshed because of the costs involved. A more common practice is to measure a surrogate for emission factors. In the AP-42[2] guidance document, the US EPA suggests collecting loose debris from roads by vacuuming and subsequently analyzing the vacuumed material for silt content. Silt, in this case, is defined operationally as the portion of material that passes through a 200 mesh sieve, corresponding roughly to particles having geometric diameters less than 75 microns. For paved roads, the loading of silt on a per unit area basis (g/m^2) is used to infer emission factors:

$$EF_{10} = k\,(sL/2)^{0.65}(W/3)^{1.5} - C \qquad (1)$$

where k is the paved road dust emission factor multiplier for PM_{10} (4.6 g/vkt), sL is the silt loading of the surface material (g/m^2), W is the mean vehicle weight (tons), and C is the emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

Kuhns et al. (2001)[5] and Etyemezian et al. (2003)[6] have described a vehicle-based alternative to silt measurements. The TRAKER (Testing Re-entrained Aerosol Kinetic Emissions from Roads) is a cargo van that measures road dust PM concentrations by sampling air through three inlets, two that are behind each of the front tires and one that extends through the front bumper in front of the vehicle. As the TRAKER is driven on a road, air that is laden with particles suspended behind the front tires and background air sampled ahead of the front bumper are analyzed by nephelometer-style instruments (TSI, DustTrak model 5820) located inside the vehicle. The instruments record PM_{10} concentrations in one-second intervals. An onboard GPS logs the location of each one-second measurement as well as other parameters such as the speed, acceleration, and heading of the TRAKER. The background-corrected concentration behind the tire varies with speed so that:

$$T = T_T - T_B = a\, s_T^b \qquad (2)$$

where T is the background-corrected TRAKER signal (mg/m^3), T_T is the PM_{10} concentration measured behind the tire (mg/m^3), T_B is the PM_{10} concentration measured ahead of the front bumper (mg/m^3), s_T is the speed of the TRAKER (m/s), and a and b are fitted constants. Both T_T and T_B represent concentrations (measured with DustTraks) that are corrected for particle losses within the TRAKER inlet lines. Based on tests conducted in the Treasure Valley (in and around Boise, ID) and at the Ft. Bliss military installation near El Paso, TX, Etyemezian et al. (2003)[6] report that for paved roads the value of b is approximately equal to 3. The value of a is specific to the road measured and can be calculated from the speed of the TRAKER at the time of the measurement and knowledge of T_T and T_B.

Using the TRAKER van as a test vehicle on an unpaved road and simultaneously measuring the horizontal flux of PM_{10} with upwind/downwind towers, Etyemezian et al. (2003)[6] found that the PM_{10} horizontal flux was proportional to the speed of travel. This result was reinforced by a similar relationship for other vehicles examined during the same field campaign. In summary, the equations that relate the TRAKER signal to emissions are[6]:

$$T = a\, s_T^3 \tag{3}$$

$$EF_T = kT^{1/3} \tag{4}$$

$$\theta_T = EF_T / s_T \tag{5}$$

where *EF* is the emission factor (g/vkt), θ is the emission potential ([g/vkt]/[m/s]), and k is the constant that relates emissions to the TRAKER signal and is approximately 0.33 (σ_g=1.5). The subscript *T* indicates that the parameter is specific to the TRAKER vehicle (i.e., a 1979 Chevy van). Using Equation (5) to define the emission potential, θ_T, and rearranging Equations (3) and (4) gives:

$$\theta_T = k \cdot a^{1/3} \tag{6}$$

Thus, the emission potential is dependent only on the parameter *a*, which is related directly to the "dirtiness" of the road – in terms of its potential to emit PM_{10} dust when a vehicle passes.

A number of authors[1,7,8,9] have pointed out that horizontal fluxes measured with the upwind/downwind technique may overestimate the mass of PM_{10} that is actually available for transport over long distances. That is, some of the PM, especially the fraction associated with coarse particles, may deposit within one kilometer of the source by particle impaction or settling. It follows, that methods calibrated using the upwind/downwind technique, such as silt measurement and TRAKER, are subject to the same concerns.

METHODS

The field study was designed to assess the abilities of the TRAKER and the UCR measurement systems to measure road dust emissions over a wide range of paved road types in Clark County Nevada. A prescribed route, developed by the Clark County Department of Air Quality and Environmental Management (DAQEM), was followed by both the DRI and UCR teams on two consecutive days (6/30/04 and 7/1/04).

The TRAKER system was first used in Las Vegas to survey road dust on over 100 miles of paved roads[5]. The concentration of airborne particles is monitored through inlets that are mounted near the front tires of a vehicle. These particle sensors are influenced by the road dust generated from the contact of the tire with the road. A background measurement of particle concentrations is obtained simultaneously at a location on the vehicle farther away from the tires. The difference in the signals between the influence monitors and the background monitor is related to the amount of road dust generated. Details of TRAKER operation are provided elsewhere[6].

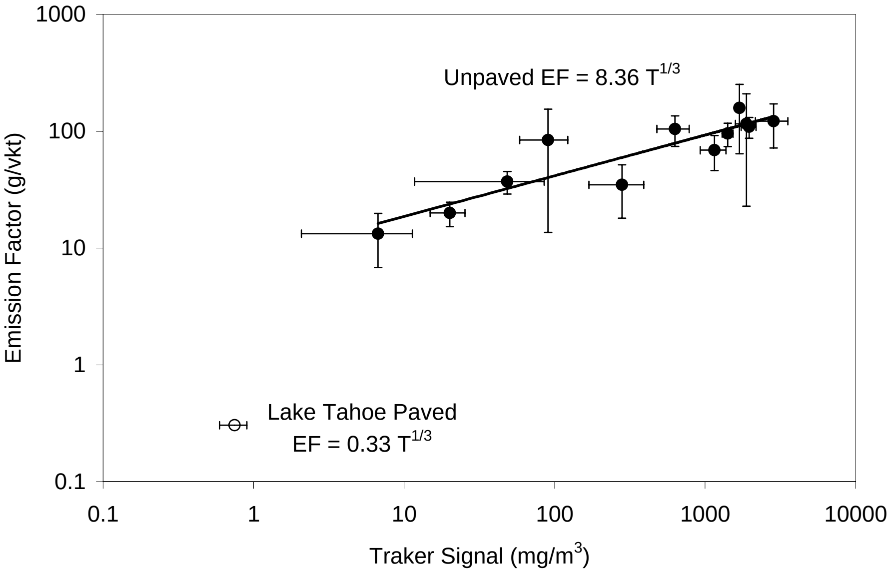
On 03/31/03, the TRAKER was operated in conjunction with a horizontal flux tower near Lake Tahoe, located at the Nevada-California border. The TRAKER signal was compared with the flux of particles measured downwind of a road. The flux of particles past the tower was calculated only when the winds were blowing within 45 degrees of the line perpendicular to the road. Between 12:10 and 16:40, this criterion eliminated 10,300 of the 16,141 1 s measurements on the tower. The resultant winds for the period were from the southwest (222 degrees) at 1.6 m/s.

Over the same interval, the TRAKER vehicle made 45 (23 southbound and 22 northbound) passes in front of the instrumented tower. The average and standard deviation of the TRAKER vehicle speed over the 150 m before and after the tower was 20.1 m/s ± 0.1 m/s (or about 39 miles per hour). For comparison, the average speed of all vehicles as measured by the road tube counter collocated with the flux tower was 21.1 m/s ± 0.3 m/s (equivalent to 41 mph). The average and standard deviation of the TRAKER signal over the 45 passes was 0.748 mg/m^3 ± 0.415 mg/m^3.

The flux of PM_{10} normal to the road was calculated when winds were within the 45 degree criterion. The flux was then multiplied by the total number of seconds between 12:10 and 16:40 and multiplied by the fraction of the measurements that were valid (i.e. 5,841/16,141). This scaling factor was used to estimate the total flux over the time interval from the subset of valid flux measurements when the winds were within 45 degrees of perpendicular to the road. The total flux in units of mg/m over the period was divided by the total number of vehicles (1683) passing the tower to calculate an average fleet average PM_{10} emission factor of 0.305 g/vkt.

Prior to these measurements, the TRAKER vehicle had not been compared with directly measured paved road particulate matter (PM) emissions. **Figure** 1 below shows the average measured TRAKER signal versus the fleet average emission factors from 03/31/03. The points on the upper right of the figure were calculated from unpaved road experiments at Ft Bliss[6]. The paved road emission factor obtained at Lake Tahoe is lower than the unpaved road trend line by approximately a factor of 25.

Figure 1. Regression of measured PM emission factors with TRAKER measurements. The line was drawn through the unpaved road tests by holding the exponent of the regression equation at 1/3.



The reason for the difference between the unpaved and paved road TRAKER relationship with emission factor is unknown. Hypotheses include:

- The traffic counter identified the fleet passing the flux tower as 98% light duty and 2% heavy duty vehicles. Recent field studies indicated that unpaved road dust emission factors increase linearly with both vehicle weight and vehicle speed[10]. Typical light duty vehicles have a mass of ~1.5 Mg (1 Mg = 1 metric ton) and heavy duty trucks have a mass of ~9 Mg. Based on these assumptions, the average mass of a vehicle passing the flux tower was ~1.6 Mg per vehicle, whereas TRAKER has a mass of ~3.1 Mg. If the relationship between emission factors (in g PM/vkt) and vehicle mass exists for paved roads as well as unpaved roads, then the fleet average emission factors should be lower than the TRAKER emission factor by a factor of 2 (i.e. 1.6 Mg/3.1 Mg). This would bring the Lake Tahoe emission factors more in line with the unpaved road measurements by a factor of 2.
- On unpaved roads, loose dust may be entrained by the wake of the vehicle. If this is not occurring on paved roads, the flux of particles downwind of the roadway may be less. It is not

know at this time if the vehicle wake causes greater suspension of dust from unpaved roads compared to paved roads.

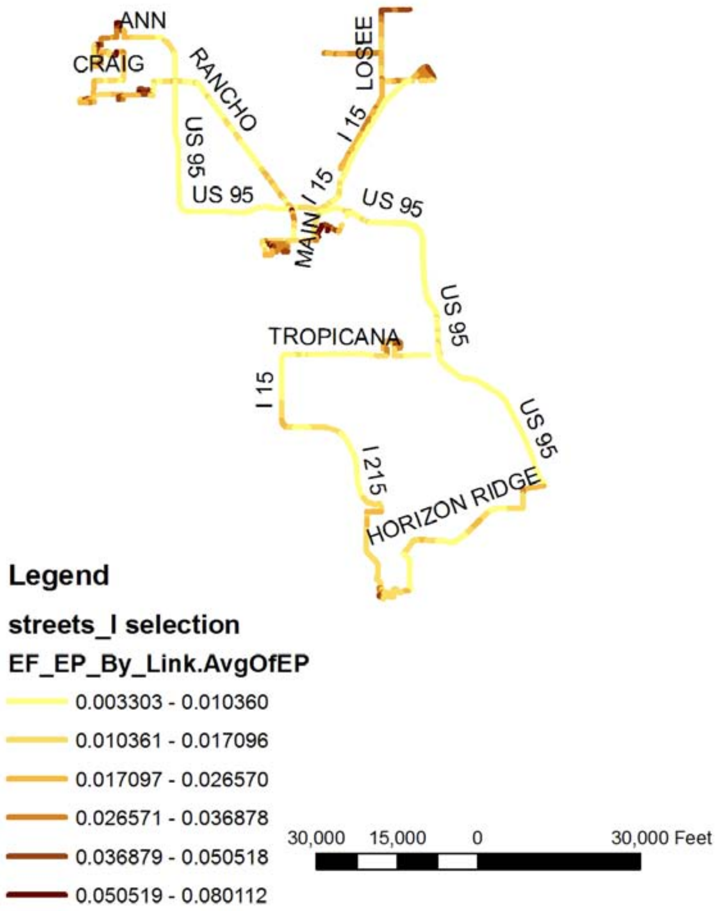
The Lake Tahoe emission factor is the only comparison of the TRAKER signal with a paved road emission factor. In the Las Vegas, Nevada study, TRAKER exclusively surveyed paved roads. Based only on the one calibration point collected in Lake Tahoe, the revised equation relating the fleet average emission factors with the TRAKER signal is:

$$EF = 0.33(T)^{0.33}. \qquad (7)$$

RESULTS

It is useful to average measurements over longer periods, or equivalently, over comparatively long sections of road such as the roadway sections included in the 2003 traffic demand model (TDM) developed by the Clark County Regional Transportation Commission. By averaging measurements obtained by the TRAKER over the corresponding links in the traffic demand model, it is possible to filter out much of the high frequency noise that is associated with individual point measurements. **Figure** 2 shows valid TRAKER measurements of emission potentials obtained during the Clark County study on 6/30/04. Recall that the emission potential, θ, is a measure of the dirtiness of the road with units of g PM_{10} /vkt/(m/s). To obtain the emission factor (g PM_{10} /vkt), the emission potential must be multiplied by the vehicle speed. The emission potential appears to be greatest on smaller, less frequently traveled roads as well as on roads that are near the fringes of areas where new home construction is prevalent.

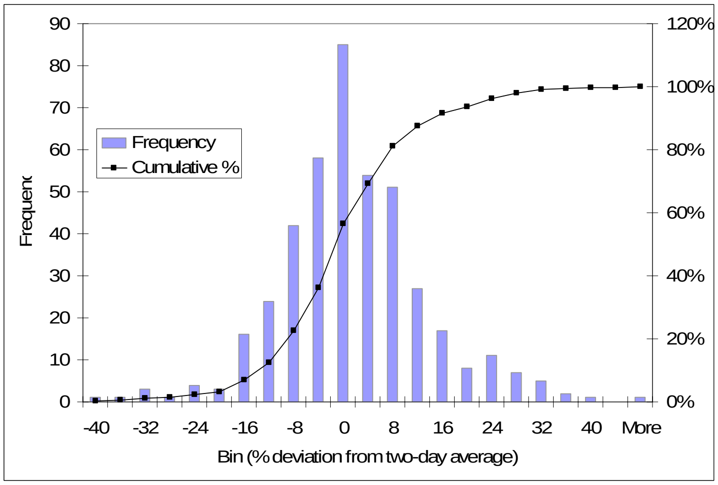
Figure 2. TRAKER emission potentials in units of g/vkt/(m/s) averaged by link. Data from 6/30/04 and 7/1/04 measurement periods.



Individual, one-second emission potentials measured with the TRAKER exhibit an inherent variability for several reasons. First, the road surface is not homogeneous in the cross lane direction. Therefore, depending on where the vehicle tires are within a specific lane, emission potentials (and emission factors) may vary significantly. This is especially true for smaller, less frequently traveled roads where debris may accumulate near the curbs and gutters. A tire close to the curb would then result in greater dust emissions than a tire traveling close to the street centerline, an area that is generally cleaner. Second, especially on long routes, it is usually difficult to remain in the same lane of traffic during multiple sampling periods and there may exist some variability in road dust emission potential because of differences of travel lane. The ability to capture such variability is an important advantage that vehicle-based road dust emission measurements have over silt loading techniques where the area vacuumed may not be representative of the area over which tires travel. By employing “natural driving” practice, vehicle-based technologies more accurately capture the actual PM_{10} road dust emissions that result from “real-world” driving.

Figure 3 shows the distribution of the percent deviation in link-averaged emission potentials between the two consecutive sampling days. The overall patterns indicate that, at least on a link average basis, the precision of the measurement is always less than 50% and that there is not a systematic bias between the first and second sampling days. This is supported by the histogram which shows that the percent difference between the first and second sampling day is approximately normally distributed with a mean of zero and a standard deviation of 10%. This rather good precision is attributed in part to the relatively low ambient winds during the two sampling days. Prior work with TRAKER[11] has shown that high winds can affect the air flow field around the TRAKER vehicle and inlets and result in higher measurement uncertainties.

Figure 3. Distribution of percent difference in link-averaged emission potentials between first and second sampling day. The near-zero mean indicates that there does not appear to be a day-to-day bias in TRAKER measurements.



CONCLUSIONS

The TRAKER system was used to assess the spatial distribution of road dust emission potential in Clark County as part of a collaborative study that included simultaneous measurements performed with a similar system developed at UCR, the SCAMPER. Results from the TRAKER confirmed earlier findings[11] from a study completed in Boise, Idaho. Specifically, lower speed roads were found to have higher emission potentials – a measure of the amount of PM_{10} available for suspension from the road - than high speed roads.

A comparison of link-averaged emission potentials between two consecutive days of sampling on the same set of roads indicated that the precision of the TRAKER measurement was generally in the

±10% range. In addition, the differences between measurements on the two days were symmetric about 0% suggesting that there was no inherent bias between the two sample days. It was noted however that the ambient wind speed on both days was quite low and that under higher wind speed conditions, the precision of the TRAKER measurements may not be as good. Results from another study slated to begin in Winter, 2005 will be combined with data from the summer of 2004 measurements and a comparison between emission factors measured by the TRAKER and the SCAMPER will follow.

KEYWORDS

Emission factors, Clark County, TRAKER, SCAMPER

ACKNOWLEDGEMENTS

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