TECHNICAL MEMORANDUM

CALIFORNIA ROAD DUST SCOPING REPORT

UC Davis-Caltrans Air Quality Project
http:/AQP.engr.ucdavis.edu

Task Order No. 2
UC Davis Contract No. 43A0014

DRAFT: February 28, 2000

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Prepared in response to

Request to identify potential research needs associated with improving on-road reentrained road dust emission inventory estimates.

California Road Dust Scoping Report

Introduction

It is estimated that about 30 percent of PM-10 emissions in California are associated with traffic activity on paved roads[1]. This estimate is based on the methodology that is recommended in the AP-42. The resulting estimate of PM-10 emission levels are based upon four variables, one of which is VMT. In this methodology, road dust emissions levels are directly proportional to VMT because the road dust emission equation in the AP-42 produces a road dust emission factor, which is multiplied by VMT to obtain the resulting emission levels. As VMT increases in the future, the use of this methodology will produce estimates of increasing PM-10 emission levels due to the assumed linear relationship between road dust emissions and VMT.

Recent studies have shown that the fundamental equation used to estimate road dust emissions may be flawed. This new information questions the underlying premise of the fundamental equation for road dust emissions.

This report discusses the following topics:

- A background on paved road dust emissions.
- The emission estimation methodology for paved road dust emissions, as recommended by the AP-42.
- Primary PM-10 emissions from exhaust, brake wear, and tire wear, as estimated by the PART5 model and the AP-42 methodology.
- Recent studies on paved road dust emissions.
- Planned research on paved road dust emissions.
- A recommended research plan to better understand the PM-10 emissions from paved roads.

Background

In general terms, primary[*] particulate emissions from paved roads originate from the loose material present on the road surface. As it is moved or removed, this loose material or silt is continuously replenished by other sources, such as application of snow and ice controls, carryout from construction activities in the area, and wind and/or water erosion from surrounding areas. In the absence of excessive additions of silt, the traditional methodology assumes that paved road silt loading reaches an equilibrium value in which the amount of material suspended matches the amount deposited. The equilibrium silt loading (sL) is dependent upon numerous factors. It is believed that the most important factors are: mean speed of the vehicles travelling the road, the average daily traffic (ADT), the number of lanes and the ADT per lane, the fraction of heavy vehicles travelling, rain or snow fall, and the presence/absence of curbs, storm sewers and parking lanes.

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[*] Primary pollutants are those emitted directly from sources, while secondary pollutants are those formed in the atmosphere by chemical reactions between primary pollutants and chemical species normally found in the atmosphere. Thus, paved road dust emissions are primary pollutants.

Paved road dust emissions from vehicles traveling on paved roads in California is computed using the emission factor equation provided in the fifth edition of the U.S. EPA AP-42 document. This computation is done separately from the EMFAC model. The resulting emission factor is then multiplied by the appropriate VMT to produce road dust emissions.

Emission Estimation Methodology for Paved Road Dust Emissions

As found in the AP-42, the quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression:

$$E = k\,(sL/2)^{0.65}\,(W/3)^{1.5}$$

where

E = particulate emission factors (having units matching the units of k)
k = base emission factor for particle size range
sL = road surface silt loading (having units of grams per square meter)
W = average weight of the vehicles traveling the road (in tons)

As can be seen from the equation, paved road dust emissions are dependent upon the silt loading factor and the average weight of the vehicles traveling the road. Thus, using the most current and accurate silt loading factors and average weight of vehicles will provide the best estimate of paved road dust emissions.

It is important to note that the above equation calls for the average weight of all vehicles traveling the road. As an example, if 99 percent of the traffic on the road are 2 ton cars while the remaining 1 percent consists of 20 ton trucks, the average weight "W" is 2.2 tons. The above equation is not intended to be used to calculate a separate emission factor for each vehicle weight class. Using the existing methodology, only one emission factor is calculated to represent the fleet average weight of all vehicles traveling the road. A brief history of the development of the emission estimation methodology for paved road dust emissions is given in Appendix A.

k – Base Emission Factors

The base emission factor varies with aerodynamic size range as shown in **Table 1**. The base emission values given are based on a regression analysis of numerous emission tests, many of which took place in states other than California, including 65 tests for PM-10[2]. It is assumed that the EPA base emission factors reasonably represent the size distribution of California road dust. More recently, the PM-2.5 base emission factors were updated in the October 1997 version of the AP-42. The ratio of PM-2.5 to PM-10, which was used to determine the updated PM-2.5 base emission, was taken from a recent study on fugitive particulate matter[3].

Table 1: Base Emission Factors

Size Range	K		
	[g/VKT]	[g/VMT]	[lb/VMT]
PM-2.5	1.1	1.8	0.0040
PM-10	4.6	7.3	0.016

The assumption that the EPA base emission factors reasonably represents the size distribution of California dust presents a research need in this area to confirm or disprove this assumption. If the data exist and are obtainable, a comparison of the size distributions of California road dust could be made to the size distribution of road dust in other states. If the data does not exist or is not obtainable, the corresponding measurements could be made to allow such a comparison.

sL - Silt Loading Factors

Virtually the same silt loading factors are used throughout the state of California. These silt loading factors are based on a total of eight silt loading measurements each in the South Coast Area, Coachella Valley, and Bakersfield[4]. These measurements may not fully represent the variability in California silt loading. Midwest Research Institute (MRI) made the measurements in 1995[5]. An approximate average of the silt loading factors throughout all California counties is given in **Table 2**. Attached in Appendix B is a copy of the complete list. The current AP-42 recommended default silt loading factors are included for comparison in **Table 3** and **Table 4**. It should be noted that the recent studies used to obtain the AP-42 silt loading factors found no correlation between the silt loading factors and road type, thus the current AP-42 recommended default silt loading factors are not road type dependent. This is a significant difference from the California approach and further research into the relationship between road type and silt loading is needed to resolve the discrepancy.

Table 2: Silt Loading Factors from the California ARB

Road Class	Silt Loading Factor [grams/m^2]
Factors used by ARB, approximate average over all counties	
Freeway	0.020
Major	0.035
Collector (high ADT/low ADT)	0.035/0.320
Local (high ADT/low ADT)	0.035/0.320

The default silt loading factors for non-limited access roads (i.e., roads with multiple intersections and access ways where speeds are typically less than 55 mph) recommended in the AP-42 are given in Table 3. Although hundreds of paved road sL measurements were used to create the default values, the lack of uniformity of roadway classification, measurement, and analysis techniques made it impossible to find a coherent relationship between road type and sL values. The sL values in the dataset that was used to create the default values ranged from 0.01 to 1.0 for high ADT roads (roads with at least 5,000 vehicles per day). Consequently, these default values are expected to yield only an order of magnitude estimate of the paved road dust emission factor. As mentioned previously, paved road dust silt loading is dependent upon many factors including traffic characteristics (speed, ADT, and fraction of heavy vehicles), road characteristics (curbs, number of lanes, parking lanes), local land use (agriculture, new residential construction), and regional/seasonal factors (snow/ice controls, wind blown dust). As a result, the collection and use of site-specific silt loading data is highly recommended in the AP-42 documentation.

Table 3: AP-42 Default Silt Loading Factors for Non-Limited Access Roads

Conditions	Silt Loading Factors [grams/m^2]	
	High ADT roads [1]	Low ADT roads
Normal	0.1	0.4
Worst Case [2]	0.5	3

[1]High ADT refers to roads with at least 5,000 vehicles per day.
[2]For conditions such as post winter storm or areas with substantial mud/dirt carryout.

The default silt loading factors for limited access roads recommended in the AP-42 are given in Table 4. Fewer sL values exist for limited access roads in comparison to non-limited access roads. Nevertheless, the available data does not suggest great variation in sL values for limited access roadways from one part of the country to another. The values in Table 4 would best correspond with the freeway silt loading factor in Table 2 based on roadway classification. For normal conditions, the silt loading factors are in good agreement considering the variation in sL measurement values.

Table 4: Ap-42 Default Silt Loading Factors for Limited Access Roads

Conditions	Silt Loading Factors [grams/m^2]
Normal	0.015
Worst Case [1]	0.2

[1]For conditions such as post winter storm or areas with substantial mud/dirt carryout.

W - Average Vehicle Weight

The California statewide average vehicle weight is assumed to be 2.4 tons. This estimate is based on an informal traffic count estimated by MRI while they were performing silt loading measurements[6]. Since the EPA default average vehicle weight is 3 tons and the paved road dust emission factors vary with the average vehicle weight raised to a power of 1.5, the California statewide average vehicle weight should be reinvestigated to ensure an accurate average vehicle weight. An estimate of the current California statewide average vehicle weight could be done with existing data in the EMFAC model, DMV databases, and other sources. In addition, the investigation should consider county specific average weights due to variability of vehicle distribution among counties.

Primary PM-10 Emissions from Exhaust, Brake Wear, and Tire Wear

The importance of paved road dust as a source of PM-10 is shown in a comparison of emission factors for brake and tire wear emissions. To calculate the emissions from brake and tire wear in California, the methodology used in the EPA PART5 model is used. In PART5, the brake wear emission factor is assumed to be the same for all vehicle classes and has a value of 0.0125 grams per mile. The tire wear emission factor is dependent upon the number of wheels the vehicle has and has a value of 0.008 grams per mile for four wheeled vehicles. When running the PART5 model for the 1999 calendar year, the following results are obtained for light-duty gasoline vehicles:

Table 5: PART5 Results for Light-duty Gasoline Vehicles

Exhaust PM [grams/mile]	Brake Wear PM [grams/mile]	Tire Wear PM [grams/mile]	Paved Road Dust[1] [grams/mile]	Total Direct PM [grams/mile]
0.013	0.013	0.008	0.262	0.296

[1]Values of 0.020 grams/m^2 for silt loading and 2.4 tons for average vehicle weight were used in this calculation.

As can be seen for **Table 5**, the paved road dust emissions make up more than 88 percent of the total direct PM emissions from light-duty gasoline vehicles.

Recent Studies on Paved Road Dust Emissions

Considering the importance of paved road dust emissions in PM inventories in California, there have been several studies that have investigated the current methodology of estimating paved road dust emissions. These investigations have primarily compared measured road dust emissions to road dust emissions predicted with the AP-42 methodology. The following is a brief review of some current research and is not a full literature review on the topic of paved road dust emissions.

A recent study[7] provides a critique of empirical emission factor models for paved road dust emissions. In particular, this study investigates the use of the AP-42 model for estimating PM-10 emissions from paved roads. The author makes the following conclusion:

- The examination of the AP-42 model shows that it is not likely to provide adequate estimates of PM-10 emissions from paved roads.

This conclusion is supported by three independent studies discussed in the paper:

- In Denver, the relationship between silt loading and measured emission factors was very different from the relationship between silt loading and the AP-42 predicted emission factors (AP-42: $E = 4.6*(sL)^{0.65}$ versus Denver: $E = 0.95*(sL)^{0.16}$).
- In Spokane, the AP-42 predicts a constant value of about 10.5 g/VKT while the measured emission factors ranged from 0.47 to 1.71 g/VKT over a study period of two months. The authors conclude, “no correlation was found between experimentally determined emission factors and silt loading observations.”

- In Sacramento, the measured emission factor was relatively steady and averaged 0.1 g/VKT over four days while the measured silt loading factor varied substantially. The varying silt loading produced predicted emission factors ranging from 0.03 to 0.3 g/VKT.

In addition, studies are ongoing by the University of California, Riverside, and the University of California, Davis, to better understand and quantify paved road dust emissions. These studies are not showing clear correlations between roadway silt loading and dust production, or VMT and dust production in urban areas[8].

Research at University of California, Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT) includes a two-year study to develop and evaluate a reliable method to estimate PM-10 and PM-2.5 emissions from paved roads[9]. From January 1996 to June 1997, a series of measurements of PM-10 and PM-2.5 emissions from paved roads were carried out in Riverside County, California. The project involved measurement of upwind and downwind vertical profiles of particulate mass concentrations in addition to meteorological variables such as wind speed and vertical turbulent intensity. The difference in PM-10 between upwind and downwind locations is used to determine the emission factor. The resulting measured emission factors are given in **Table 6** along with the measured silt loading and the resulting AP-42 predicted emission factors. Overall, the measured emission factors for paved roads range from 0.1 to 10 [g/VKT]. There is also some indication that well maintained freeways have values at the lower end of the range, while older roads have values between 1 to 10 [g/VKT]. In addition, it was found that silt loading factors are a poor indicator of the emission factor. The poor correlation between silt loading factors and measured emission factors can be observed in Table 6.

Table 6: Measured and Predicted Emission Factors for Paved Road Dust[10]

Site	Date	Silt Loading [g/m^2]	CE-CERT Measured Emission Factor [g/VKT]	AP-42 Predicted Emission Factor [g/VKT]
Canyon Crest Dr.	3/18/97	0.065	0.4	0.3
Canyon Crest Dr.	11/20/96		0.89	
Canyon Crest Dr.	6/5/97	0.085	0.74	0.36
Main Street	6/17/96		3.58	
Main Street	6/19/96	5.93E-03	2.61	0.063
Main Street	9/3/96	5.93E-03	2.72	0.063
Main Street	9/5/96		3.51	
Main Street	9/24/96		2.6	
Main Street	11/19/96		3.01	
Riverside Dr.	3/17/97	0.2	0.8	0.62
Riverside Dr.	5/29/97	0.17	0.67	0.56
Riverside Dr.	3/19/97	0.19	1.76	0.6
Riverside Dr.	6/4/97	0.085	1.1	0.36
Fogg Street	5/27/97	0.38	8.57	0.94
Fogg Street	3/26/97	0.13	31.3	0.47
Fogg Street	6/3/97	0.14	5.27	0.5

CE-CERT is also planning on expanding its investigation into paved road dust emissions. CE-CERT has found that in many instances the difference in PM-10 between upwind and downwind locations was near the measurement precision of the filter sampling. Thus, their objective in the expanded investigation would be to more accurately characterize PM emission rates from vehicles on paved roads in California. Their measurement approach would be based on real-time optical sensors rather than filter collection. This would allow greater measurement sensitivity, the collection of much more data in a given period of time, and the ability to characterize emissions as a function of vehicle operating parameters and road surface conditions.

Research at University of California at Davis UCD) includes two studies involving the measurement PM-10 emissions from paved roads at intersections[11,12]. The first study evaluated PM-10 associated with a Sacramento area intersection (Florin Road and Stockton Boulevard). This field study involved measuring silt loading and the emission factors for the intersection area and was conducted during August 1995. A comparison of the measured emission factor to the AP-42 predicted emission factor is given in **Table 7**. In this table, lowest, highest and average silt loading measurements are given. This study also estimated the average vehicle weight "W" by periodically counting the percentage of passenger cars, light and medium trucks, and heavy trucks and buses. The study found the average vehicle weight to be around 2.15 tons, lower than the ARB recommended weight of 2.4 tons.

Table 7: Measured and Predicted Emission Factors for Paved Road Dust[13]

Site	Date	Silt Loading [g/m^2]	UCD Measured Emission Factor [g/VKT]	AP-42 Predicted Emission Factor[1] [g/VKT]
Stockton Blvd. (Northbound)	8/23/95	0.002	0.188 ± 0.080	0.027
Florin Road (Westbound)	8/23/95	0.054	0.188 ± 0.080	0.267
Average of Four Sites	8/23/95	0.015 ± 0.026	0.188 ± 0.080	0.116 ± 166

[1]In this analysis, the average vehicle weight was 2.15 tons.

This study also did a comparison to the ARB methodology. The ARB procedure recommends allocating VMT to freeways, major streets, and local and collector streets, then applying an emission factor to each allocated component. The most recent recommended California silt loading factors are given in Table 2. Using these silt loading factors and an average weight of 2.4 tons, the ARB emission factor for freeways would be 0.163 g/VKT, major streets would be 0.234 g/VKT, and local and collector streets would be 0.986 g/VKT (assuming local and collectors have both low ADT). In this study, the measured silt loading factor ranged from 0.002 to 0.054 g/m^2 and averaged 0.015 g/m^2. This average is a factor of 1.3 to 21 lower than the silt loading factors recommended by the ARB. In this study, the measured emission factor was 0.188 ± 0.080 g/VKT, and includes all roadway sources, not just suspended paved road dust. This measured emission factors is a factor of 1.2 to 5.2 lower than the calculated emission factors used by ARB for major streets or local and collector streets.

The second study by UCD was conducted in the vicinity of the heavily traveled Sunrise Boulevard/ Greenback Lane intersection in Sacramento, CA in winter 1997. Although silt loading measurements were taken in this study, measured emission factors were not. Thus, a comparison between measured emission factors and predicted emission factors cannot be made. However, it is important to note that the measured silt loadings in this study were an order of magnitude greater than the silt loadings found in the previous study.

Planned Research

Due to the importance of paved road dust emissions in California PM inventories, several organizations are planning research in this area. The list of organizations who were contacted follows:

California ARB (Pat Gaffney (916) 322-7303)
UCD (Lowell Ashbaugh (530) 752-2848)

The California ARB along with University of California, Riverside, CE-CERT have planned research to continue their investigation of paved road dust emissions. The project is titled *Measurements of PM-10 and PM-2.5 emission factors from paved roads in California* and is scheduled for completion in March 2001. This project will use instrumented vehicles to attempt better measurements of the particulate produced by vehicle travel on paved roads. The project objectives are:

- determine PM2.5 and PM10 emission factors from Southern California roadways using real-time upwind-downwind measurements
- characterize the emissions from individual vehicles over a wide range of parameters such as vehicle speed, weight, and shape for various types of roadways
- evaluate the PM emission rates from trackout of crustal material from unpaved to paved areas

This study will incorporate roadside real-time PM measurements, as well as real-time measurements from samplers mounted to the front and directly behind a moving vehicle.

UCD has no current plans for additional research in paved road dust emissions.

Additional research may be planned by the following organizations:

NCHRP (Ron McCready (202) 334-3034)
EPA (Connie Hart (734) 214-4336)

* additional research plans to be included

Research Needs

Since there are several recent studies that question the relationship between paved road dust emissions levels and silt loading factors, the greatest research need is to determine the correct relationship between the paved road dust emissions and the variables that it may be dependent upon. These variables include mean speed of the vehicles traveling the road, the average daily traffic (ADT), the silt loading and vehicles weight, the number of lanes and the ADT per lane, the fraction of heavy vehicles traveling, and the presence or absence of curbs, storm sewers and parking lanes. An investigation could possibly be carried out on the existing data or new data could be collected.

If such an investigation cannot be carried out and the AP-42 methodology is to be used in its present form, research needs would include:

- A comparison of the California road dust distribution to the EPA road dust distribution is needed to confirm or disprove that the EPA base emission factors reasonably represent the size distribution of California dust.

- County specific silt loading measurements are needed to more accurately represent the variability of the silt loading in all the California counties.

- Since some recent research results show no correlation between silt loading and road type, research is needed to find the relationship between road type and California silt loading values, which are currently assumed to be road type specific.

- Since the average vehicle weight in California is based on an informal traffic count, the California statewide average vehicle weight should be reinvestigated to ensure an accurate average vehicle weight. In addition, the investigation should consider county specific average weights due to variability of vehicle distribution among counties. An estimate of the current average vehicle weight could be done with existing data in the EMFAC model, DMV databases, and other sources.

- Developing paved road dust emission equations for different weight classes (e.g. light-duty vehicles and heavy-duty vehicles) may provide a more accurate estimate of emission factors in comparison to using an equation that uses the average weight of all vehicles traveling the road. A recent study[14] on emission rates for unpaved shoulders along a paved road, found that dust entraining vehicles (defined as vehicles with large size or poor aerodynamics traveling at high speeds) caused significant dust entrainment in comparison to non dust entraining vehicles. These results support the need to investigate paved road dust emissions from different weight classes.

Recommended Research Plan

Recommended research can take two paths. First, if it is assumed that the equation in the AP-42 methodology does not correctly predict paved road dust emissions then research would be needed to develop a new methodology. Second, if it is assumed (or proven) that the equation in the AP-42 methodology is fundamentally correct but requires more accurate inputs, then research would be needed to determine the more accurate inputs.

If a new methodology is to be developed, the following steps would need to be taken:

1) Expand this report into a more comprehensive literature review covering research that has been carried out to develop a new methodology to estimate paved road dust emissions.
2) Review the existing databases of paved road dust emissions to determine if sufficient data exists to develop a new methodology (is only silt loading data available or is data available on vehicle speed, number of lanes, fraction of heavy vehicles traveling, etc?)
3) Conduct experiments to collect data on paved road dust emissions and the variables believed to effect the road dust emissions (i.e., on vehicle speed, number of lanes, fraction of heavy vehicles traveling, etc.)
4) Perform nonlinear multivariant regression analysis to determine how the variables effect paved road dust emission and develop a new equation to predict emissions based on this analysis.

If the existing methodology is to be used, the following steps would need to be taken to provide more accurate inputs:

1) Expand this report to into a more comprehensive literature review covering research that has been carried out to provide more accurate inputs into the AP-42 methodology, such as determining average vehicle weights or county specific silt loading factors.
2) Review the existing databases and data sources (i.e. EMFAC, DMV, etc.) to determine if sufficient data exists to develop more accurate inputs.
3) Conduct experiments to collect data on the following:
   - County specific silt loading measurements which would more accurately represent the variability of the silt loading in all the California counties.
   - The relationship between road type and California silt loading values.
   - An accurate California statewide average vehicle weight and possibly a county specific average vehicle weight.
   - Emission factor equations for different weight classes (e.g. light-duty vehicles and heavy-duty vehicles) which may provide a more accurate estimate of emission factors in comparison to using an equation that uses the average weight of all vehicles traveling the road.

This recommended research plan exists only as a possible starting point and does not encompass all necessary research needed in this area. This plan also assumes that one of two approaches needs to be taken.

Appendix A

The first version of the paved road dust emission factor equation in the AP-42[15] came out in 1984 and used silt loading as the primary independent variable. It was based on emission measurements for inhalable particles (IP defined as particles < 15 µm) and the PM-10 emission factor was obtained by scaling the IP factor by the measured particle mass distribution. The IP emission factor was directly correlated with silt loading and inversely correlated with vehicle speed. Because the silt loading and vehicle speed were inversely correlated, the silt loading was chosen to be the only independent variable[16]. The measured data was collected at commercial/industrial roads, an expressway, and a rural road. As expected, the silt loading was highest on the rural road and lowest on the expressway.

Regression analysis was carried out on 10 data points to develop the following equation:

$$E = a*(sL)^b$$

where the unknown constants "a" and "b" are obtained by fitting the 10 data points with the following linear equation obtained by taking the logarithms of both sides of the above equation:

$$\ln(E) = \ln(a) + b*\ln(sL)$$

The latest version of the paved road dust emission factor equation was developed using a data set consisting of about 65 data points for a variety of roads ranging from public paved roads to uncontrolled industrial roads. The data indicated that the average weight of the vehicle explained some of the variance of the observed emission factor and was thus incorporated into the equation. A more complete discussion of the formulation of the paved road dust emission factor equation can be found in recent literature[17].

Appendix B*

Insert copy of ARB county specific loading factors.

* Source : California ARB, *Emission Inventory Procedural Manual, Volume III, Methods for Assessing Area Source Emissions*, October 1997.

Reference:

[1] Gaffney, P., Bode, R., and Murchison, L., *PM-10 emission inventory improvement program for California*. Report available from Patrick Gaffney, Air Resources Board, 2020 L Street, Sacramento, California, 95814.
[2] *Emission Factor Documentation For AP-42, Sections 11.2.5 and 11.2.6 – Paved Roads*, EPA Contract No. 68-D0-0123, Midwest Research Institute, Kansas City, MO, March 1993.
[3] *Fugitive Particulate Matter Emissions*, EPA Contract No. 68-D2-0159, Work Assignment No. 4-06, Midwest Research Institute, Kansas City, MO, April 1997.
[4] California ARB, *Emission Inventory Procedural Manual, Volume III, Methods for Assessing Area Source Emissions*, October 1997.
[5] Muleski, Greg, *Improvement of Specific Emission Factors (BACM Project No. 1), Final Report*, Midwest Research Institute, March 29, 1996
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[13] University of California, Davis, *Traffic Generated PM-10 Hot Spots*, Final Report to Caltrans, Contract No. 53V606 A2, August 1996.
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[16] C. Cowherd, Jr., and P.J. Englehart, *Paved Road Particulate Emissions*, EPA-600/7-84-077, U.S. Environmental Protection Agency, Washington, DC, 1984.
[17] Venkatram, Akula, *A critique of empirical emission factor models: a case study of the AP-42 model for estimating PM-10 emissions from paved roads*, Atmospheric Environment 34 (2000) 1-11.