ALTERNATIVE METHODS FOR DETERMINING EMISSIONS FOR RE-ENTRAINED ROAD DUST ON TRANSPORTATION PROJECTS:

USER GUIDE

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ABSTRACT

The Federal Transportation Conformity Rule specifies that re-entrained road dust is to be considered in the emissions analysis of transportation projects when this fugitive dust source is a significant contributor to PM_{10} or $PM_{2.5}$ nonattainment problems. The evaluation of the air quality impacts of new transportation projects and the improvement of existing paved road networks requires the estimation of traffic-generated emissions including re-entrained road dust. Estimation of the PM_{10} or $PM_{2.5}$ emission factors for calculating re-entrained road dust emissions utilizes the calculation methods published in the U.S. Environmental Protection Agency's emission factor handbook (AP-42).

In recent years, there has been increasing dissatisfaction with EPA's traditional AP-42 methodology for estimating re-entrained dust emission factors for paved road networks. The AP-42 methodology uses a predictive emission factor equation with specific input parameters. One essential parameter is surface dust loading, which requires on-site road surface sampling at multiple locations--a time-consuming, costly, and potentially hazardous undertaking. As a result, there are serious source representation issues related to the affordable number of samples that are typically used to represent spatial and temporal variations across paved roadway networks.

For preparation of paved road dust emission inventories when localized surface dust loading data are not available, EPA has published a limited set of national default values as a function of primary road category. While these default values are useful for tracking national emission trends, they are less acceptable for application to localized areas such as urban complexes in specific geographic regions. As a result, there is concern about the potential inaccuracy of road dust emission estimates when default values of surface dust loading are applied to specific transportation projects.

This report presents guidelines for implementing alternative approaches to the traditional AP-42 method, resulting in greater accuracy of emission estimates for re-entrained dust from paved roads. The alternative approaches center around the new mobile monitoring method that does not require road surface sampling. Mobile monitoring can either be used as a replacement method, or it can be used in hybrid fashion in combination with the traditional AP-42 method. These new approaches make it much more affordable to develop a reliable set of road dust emission factors by road category that can be applied on a localized basis to assess the impacts of transportation projects. While paved roads are the major focus of this study, unpaved road characterization has similar challenges and potential amenabilities to mobile monitoring technologies.

The mobile monitoring method is based on a vehicle continuously sampling its own dust plume on a second-by-second basis as it travels along representative roadway segments. The method relies on dust plume concentration as a relative measure of road dust emissions. With

the exception of one of the two hybrid applications, each mobile monitoring method configuration requires only one emission calibration test series against the roadside reference method approved by U.S. EPA. This new method is currently in the peer review process as an important step toward EPA standardization based the recent benchmark Nevada comparison study of two different mobile monitoring systems.

The application of mobile monitoring has significantly less physical constraints than the AP-42 method, is less labor intensive, is safer, and provides critically important information on emission variations across roadway systems. As a result, mobile monitoring cost-effectively increases the accuracy of emission estimates in comparison to the AP-42 method. In addition, mobile monitoring can even be used without independent emission calibration to locate road surface sampling sites as a tool to locate representative road surface sampling sites to expedite the reliable application of the AP-42 method.

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1. BACKGROUND

Most of the areas of the United States that have been unable to attain the national ambient-air quality standards (NAAQS) for PM_{10} (particles smaller than 10 µm in aerodynamic diameter) have significant emission contributions from open dust sources. Also referred to as fugitive dust sources, these sources include unpaved roads and parking lots, and paved streets and highways. Fugitive dust sources also generate emissions of $PM_{2.5}$ (particles smaller than 2.5 µm in aerodynamic diameter), which is referred to as the fine fraction of PM_{10}.

On a nationwide basis, fugitive dust consists mostly of soil and other crustal materials. However, fugitive dust may also be emitted from powdered or aggregate materials that have been deposited on roadway surfaces by spillage or vehicle track-out. Dust emissions from paved roadways contain tire and brake wear particles in addition to re-suspended road surface dust composed mostly of crustal geological material.

Emissions from open dust sources exhibit a high degree of variability from one site to another, and emissions at any one site may fluctuate widely. The site characteristics that cause these variations may be grouped into (a) properties of the exposed surface material from which the dust originates, and (b) measures of energy expended by vehicles or other machinery interacting with the surface.

The dry-particle size distribution of the exposed soil or surface material determines its susceptibility to mechanical entrainment. The upper size limit for particles that can become suspended has been estimated at approximately 75 µm in aerodynamic diameter. Conveniently, 75 µm in physical diameter is also the smallest particle size for which size analysis by dry sieving is practical. Particles passing a 200-mesh screen on dry sieving are termed “silt”.

A calculation of the estimated emission rate for a given source requires data on source extent, uncontrolled emission factor, and control efficiency. The mathematical expression for this calculation is given as follows:

$$R = SE\, e\, (1 - c) \tag{1}$$

where: R = estimated mass emission rate in the specified particle size range

SE = source extent

e = uncontrolled emission factor in the specified particle size range (i.e., mass of uncontrolled emissions per unit of source extent)

c = fractional efficiency of control

The source extent (activity level) is the appropriate measure of source size or the level of activity that is used to scale the uncontrolled emission factor to the particular source in question. For vehicle travel, the activity level is the travel length times the average daily traffic count

(ADT), with each vehicle having a disturbance width equal to the width of a travel lane. Roadway source extent is often expressed in units of vehicle-miles traveled (VMT). Additional information about emission factor equations is given in the Fugitive Dust Control Handbook developed by the Western Regional Air Partnership.[1]

Early in the EPA field testing program to develop emission factors for fugitive dust sources, it became evident that uncontrolled emissions within a single generic source category may vary over two or more orders of magnitude as a result of variations in source conditions (equipment characteristics, material properties, and climatic parameters). Therefore, it would not be feasible to represent an entire generic source category in terms of a single-valued emission factor. In other words, it would take a large matrix of single-valued factors to adequately represent an entire generic fugitive dust source category.

In order to account for emissions variability, therefore, the approach was taken that fugitive dust emission factors be constructed as mathematical equations for sources grouped by the dust generation mechanisms. The emission factor equation for each source category would contain multiplicative correction parameter terms that explain much of the variance in observed emission factor values on the basis of variances in specific source parameters. Such factors would be applicable to a wide range of source conditions, limited only by the extent of experimental verification.

A compendium of predictive emission factor equations for fugitive dust sources is published in Volume I of the U.S. EPA's Compilation of Air Pollutant Emission Factors commonly referred to as AP-42[2]. A set of particle size multipliers for adjusting the calculated emission factors to specific particle size fractions (including $PM_{2.5}$) is provided with each equation.

The National Environmental Policy Act (NEPA) requires that government agencies document and consider the environmental impacts of major transportation projects. The assessment of the effects of traffic emissions on nearby population employs both AP-42 emission factor models and equations, and EPA-recommended air quality dispersion models and guidelines.

For areas not meeting National Ambient Air Quality Standards (NAAQS), transportation conformity requires transportation plans, programs, and projects to "conform to" the goals established in State Implementation Plans (SIP). Conformity means that transportation activities will not cause new air quality violations, worsen existing violations, or delay timely attainment of the NAAQS. In this case, the regulated components of re-entrained road dust include PM_{10} and $PM_{2.5.}$

Conformity analyses are conducted at both the regional and project-level. Under regional conformity, a state demonstrates that emissions from motor vehicles under a transportation plan or travel improvement program are within acceptable thresholds. Under project-level conformity analyses, also known as "hot spot analyses," new projects sponsored by the Federal Highway

Administration (FHWA) or Federal Transit Administration (FTA) must be shown not to produce concentrations that lead to an exceedance of the NAAQS as a requirement to obtain project funding or approval.

2. STATE OF PRACTICE

2.1 TRADITIONAL AP-42 METHOD – ROADWAYS

The traditional AP-42 method for determining dust emissions from paved and unpaved roadways uses emission factor equations developed by roadside plume profiling at representative locations across the country. Paved roadway test sites were distributed across the various standard categories: local, collector, arterial and freeway. Road surface samples were collected during the same time periods along with traffic counts and vehicle categorization.

As with the other equations for fugitive dust sources, the equation for paved roadways was developed through stepwise regression analysis of the test data. In this process, correction parameters were identified in order of importance, so that emission factors could be adjusted to specific road and traffic conditions. Factors that were considered as affecting roadway emissions included:

- Average daily traffic (ADT)
- Speed of traffic
- Weight of vehicles
- Precipitation/evaporation balance
- Seasonal climate
- Control methods
- Geographical location (urban/rural)
- Nearby land usage
- Type of soil in area
- Presence or absence of curbs, storm sewers, and parking lanes

The regression analyses of test data showed that paved road dust emissions primarily depend on the following road and traffic conditions:

- Road surface silt loading (as determined by manual vacuuming of traffic lanes, edge to edge)
  - Strong inter-correlation with vehicle speed
  - Available default values for roadway categories: local, collector, arterial, freeway
  - Normal equilibrium between silt addition and removal processes
  - Disruption of equilibrium by mud/dirt track-out and anti-skid material application

- Vehicle weight (fleet average for mixed traffic)
  - Inter-correlation with vehicle speed

The other correction parameters considered in the regression analyses of the test data for paved roadways were found not to add significantly to the predictive capability of the emission factor equation.

According to the final predictive emission factor equation for paved roads found in AP-42, the quantity of particulate emissions from resuspension of loose material on the road surface due to vehicle travel on a dry paved road may be estimated using the following empirical expression:

$$E = k\left(\frac{sL}{2}\right)^{0.65} \times \left(\frac{W}{3}\right)^{1.5} - C \qquad (2)$$

where: E = particulate emission factor (having units matching the units of k),

k = particle size multiplier for particle size range and units of interest (see below),

sL = road surface silt loading (grams per square meter) (g/m^2),

W =average weight (tons) of the vehicles traveling the road, and

C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

In Equation 2, the values of the particle size multiplier (k) for PM_{10} and for $PM_{2.5}$ are 7.3 g/VMT and 1.1 g/VMT, respectively, which yields a $PM_{2.5}$ /PM_{10} ratio of 15 percent. The decision to calculate $PM_{2.5}$ emissions as a fixed proportion to PM_{10} emissions was based on difficulty in determining an independent emission factor equation for $PM_{2.5}$ of sufficient reliability. The difficulty results from the much smaller proportion of paved roadway $PM_{2.5}$ concentrations at roadside test locations, in relation to background $PM_{2.5}$ levels.

Note that the “C” factor was included in Equation 2 to eliminate the possibility of double-counting of vehicle exhaust, brake wear and tire wear, because all of these components are captured in the roadside plume profiling used to develop the emission factor equation for paved road dust. Admittedly, the contribution of these components is usually small compared to the fugitive dust component, even when looking at the $PM_{2.5}$ size fraction of the emissions. The exception might be when using the equation to estimate $PM_{2.5}$ emissions from limited-access roadways with high-speed traffic. It should also be noted that particles that settle back on the road surface are not collected by the roadside plume profiling tower used to develop the equation and are therefore not subject to double counting. Finally, although the release of Mobile 6.2 in 2003 provided updated estimates of vehicle exhaust emissions for inclusion in the “C” factor, the factors for brake and tire wear were not viewed as requiring changes from the 1980’s values.[3]

Nationwide default values of the silt loading (sL) correction parameter for paved road emissions have been developed for road categories delineated by distinct ranges of ADT values. The loadings decrease with increasing ADT. For example, local roads have the lowest traffic but the highest loadings. Most inventories are dominated by arterial and collector categories because high emission levels are produced by combinations of high traffic volumes and moderate silt loadings.

In order to gain more reliable values for silt loading for emission determinations in a given geographic area, it is recommended that representative silt loadings be measured across the local roadway system. However, measurement surveys of silt loadings are time consuming, labor intensive, and potentially hazardous. These measurements require road lane blockage and manual vacuuming of full-width lane sections at multiple locations across a road network to assure representativeness. There are obvious safety issues in doing this work, especially on busy roads.

Because of the hazardous, costly, and time consuming nature of collecting roadway silt samples, there are serious issues related to obtaining an adequate number of samples to be considered representative of the spatial and temporal variations across the roadway system. Also, there is insufficient guidance in AP-42 as to the number and size of samples to collect within each roadway category.

A study done by Teng et al. (2008) looked at the problem of determining the number of silt loading samples required to accurately represent a roadway system[4]. This study found that the number and size of roadway silt sampling plots should be directly proportional to the ratio of miles within each roadway category to the total number of miles in the roadway network as well as the amount of silt loading variance within the roadway category. Thus it was concluded that local roads should dominate the number of samples. However, this study did not take into account the Average Daily Traffic (ADT) for each roadway classification. In determining emission inventories across a roadway system, the traffic parameter is vehicle miles traveled (VMT), which is the product of road miles and average ADT within each roadway category.

2.2 NATIONAL DEFAULTS FOR SILT LOADING

This section summarizes available national, regional and local sets of silt loading default values, as well as the most recent set of national default values presented in AP-42.
It should be noted that silt loading surveys of a particular geographical area are always preferable to using default silt loading values, as long as it can be shown that the collected silt loading data are representative of the study area. However, for reasons stated elsewhere in this report, issues of safety, site accessibility, labor requirements and lack of prior general knowledge of silt loading variability in an area present significant challenges in designing cost-effective silt loading survey programs.

Historically, the most common national default values of paved road silt loadings include the National Emissions Inventory (NEI), EPA's AP-42 (Chapter 13), and the California Air Resources Board (CARB). Table 1 presents default silt loading values consolidated from the NEI, AP-42, and CARB and organized by applicable range of ADT. These values are intended to be the most widely applicable to the country as a whole, with California values more representative of the southwest. The "worst case" values reflect the contributions of hot spot sources. There is a relatively good consistency between the "normal" default values categories in terms of ADT ranges.

Table 1. Default Silt Loading Values (g/m^2) Based on ADT (vehicles/day)

ADT/ Source	Local < 500	Collector 500 – 10,000	< 5,000	> 5,000	Major > 10,000	Freeway > 10,000
NEI	1.0	→	0.2	0.04	→	→
AP-42	→	→	0.4 (normal) 3.00 (worst)	0.1 (normal) 0.5 (worst)	→	→
CARB	0.320 1.6 (rural)	0.035	→	→	0.035	0.02

In the methodology used for the NEI, paved road silt loadings are assigned to each of twelve functional roadway classifications (six urban and six rural) based on the average annual traffic volume of each functional system by State. The average daily traffic volume is calculated by dividing annual VMT by State and functional class (from Highway Statistics, Table VM-2) by State specific functional class roadway mileage (from Highway Statistics, Table HM-20).

In the 1993 version of the AP-42 section on paved road dust emissions, the range of silt loading values for normal conditions was 0.01 to 1.0 g/m^2 for high ADT roads and 0.054 to 6.8 g/m^2 for low ADT roads. For limited access roads, a default value of 0.015 g/m^2 was recommended. A default value of 0.2 g/m^2 was recommended for short periods of time following application of snow/ice controls to limited access roads.

Other inventories include the Utah Department of Environmental Quality's "post-storm" default silt loading values, and Clark County's (NV) extensive silt loading database. Parameters used to characterize available silt loading data include the following:

- Special Studies
    - Year-long monthly data for ID, NV, MT
    - Application of anti-skid materials in CO, AK, MN
    - Construction track-out in MO, KS
- General Information
    - Road classification
    - Average daily traffic
    - Posted speed limit
    - Location of measurement

The latest revision of to Section 13.2.2 of AP-42, which incorporates information added in 2001 by Midwest Research Institute[12], presents recommended default silt loadings for normal baseline conditions and for wintertime baseline conditions in areas that experience frozen precipitation with periodic application of antiskid material. These default silt loadings, which are meant to be applied nationally, are given in Table 2. The winter baseline is represented as a multiple of the non-winter baseline, depending on the ADT value for the road in question. As shown, a multiplier of 4 is applied for low volume roads (< 500 ADT) to obtain a wintertime baseline silt loading of 4 X 0.6 = 2.4 g/m^2.

Table 2. Ubiquitous Silt Loading Default Values with Hot Spot Contributions from Anti-Skid Abrasives (g/m^2)

ADT Category	**< 500**	**500-5,000**	**5,000-10,000**	**> 10,000**
Ubiquitous Baseline g/m^2	0.6	0.2	0.06	0.03 0.015 limited access
Ubiquitous Winter Baseline Multiplier during months with frozen precipitation	X4	X3	X2	X1
Initial peak additive contribution from application of antiskid abrasive (g/m^2)	2	2	2	2
Days to return to baseline conditions (assume linear decay)	7	3	1	0.5

Because of better roadway design in California, the CARB ubiquitous baseline values for average daily traffic counts below 10,000 (see Table 1) are about half the values specified in Table 2. Air pollution control agencies in California, such the San Joaquin Valley and the Bay Area, use the CARB values rather than the AP-42 values for silt loading. Several other California air districts have similar methods. A description of the inventory methods used by California agencies can be found at the CARB website[8]. All are using local interpretations of AP-42 with only minor adjustments if any.

It is suggested in AP-42 that an additional (but temporary) silt loading contribution of 2 g/m^2 occurs with each application of antiskid abrasive for snow/ice control. This was determined based on a typical application rate of 500 lb per lane mile and an initial silt content of 1 % silt content. Ordinary rock salt and other chemical deicers add little to the silt loading, because most of the chemical dissolves during the snow/ice melting process.

To adjust the baseline silt loadings for mud/dirt trackout, the number of trackout points is required. It is recommended that in calculating PM_{10} emissions, six additional miles of road be added for each active trackout point from an active construction site, to the paved road mileage of the specified category within the county. In calculating $PM_{2.5}$ emissions, it is recommended that three additional miles of road be added for each trackout point from an active construction site.

It is suggested the number of trackout points for activities other than road and building construction areas be related to land use. For example, in rural farming areas, each mile of paved road would have a specified number of trackout points at intersections with unpaved roads.

It should be noted that negative $PM_{2.5}$ emission factors will result when Equation 2 is used with (a) default silt loading values for ADT categories greater than 5,000 and (b) an average fleet weight less than or equal to 3 tons. This outcome occurs if the "C" correction parameter for vehicle exhaust, brake wear, and tire wear is based on the original data acquired in the 1980's. Mobile 6.2 released in 2003 provides updated exhaust emission profiles that are more representative of the U.S. vehicle fleet, but retains the older emission factor data for brake and tire wear, because it was believed that the older factors were still representative.[3]

In order to further expand and improve the national default values in Table 2, additional silt loading data would need to be collected and analyzed based on the parameters which influence silt loading. This additional research would focus on the influence of "hot spots" created by unpaved road and construction activity track-out, as well as presence or absence of curbs, gutters, stabilized shoulders, and pavement condition. These parameters were deemed statistically significant based on a study which analyzed twenty Clark County, NV silt sampling sites from 2001-2003.[9] The results of the study are presented in Table 4 below. The observed large values of variance indicate the spread of measured silt loading values within each roadway category.

Table 3. Clark County Silt Loading Study

Roadway Classification		**Average silt loading, g/m^2**	**Sample count**
Function classification	Collector (1)	3.88	20
	Local (2)	6.59	41
	Minor Arterial (3)	0.94	26
	Major Arterial (4)	0.42	6
Number of lanes	2	5.37	65
	4	0.98	24
	6	0.48	2
	8	0.46	2
Curb and gutter	Absent (0)	10.96	27
	Present (1)	1.19	66
Type of shoulder	Gravel (0)	4.13	79
	Stabilized (1)	3.47	14
Pavement condition	Poor (0)	7.72	27
	Good (1)	2.52	66
Construction	Absent (0)	3.17	86
	Present (1)	14.63	7

Results of the random-effects model developed in this study indicate that the presence of curbs and gutters, stabilized shoulders, and good pavement conditions each reduce silt loadings. Conversely, the presence of nearby construction activities results in increased silt loadings. The four preceding factors were all concluded to impact silt loadings on the same level of magnitude.

Number of lanes was not found to be significant in the calibration of the model, but roadway functional classification was highly correlated with number of lanes. Neither parameter was included in the final model.

Other possible parameters (not included in the previous study) include posted speed limit (or vehicle speed), proximity of roadway to unpaved areas, and whether a route is normally traveled by rock, sand, and/or gravel quarry trucks.

The national default silt loading values are based on a relatively small number of representative studies, considering the many contributors to paved road surface dust and the associated amounts of PM_{10} or $PM_{2.5}$ that are emitted by vehicle traffic. Further research is needed to characterize all of the factors which contribute to paved road silt loadings. As stated above, improvements to the national default silt loading tabulation would include adjustments for specific factors such as the absence or presence of curbs and gutters, stabilized shoulders, construction activities, posted speed limit, pavement condition, and any other factors that may be deemed statistically significant.

2.3 THE EMISSION INVENTORY PROCESS

Transportation conformity is required under section 176(c) of the Clean Air Act (42 U.S.C. 7506(c)) to ensure that federally supported highway and transit project activities are consistent with ("conform to") the purpose of a state air quality implementation plan (SIP). Conformity to the purpose of the SIP means that transportation activities will not cause new air quality violations, worsen existing violations, or delay timely attainment of the national ambient air quality standards. EPA's transportation conformity rule establishes the criteria and procedures for determining whether transportation activities conform to the state air quality plan.

The emission calculations for transportation projects mimic those used in emission inventorying of existing paved road systems and of projected roadway improvements and expansions, for purposes of addressing attainment of the air quality standards. Roadway emission characteristics must be projected for transportation projects involving future highway construction, based on similar existing roadways in the same geographical area or in other areas with the similar climate, land use, traffic loads and roadway designs.

Inventories of dust emissions from paved roadway systems are developed by multiplying AP-42 emission factors (mass of emissions per vehicle mile) for each roadway class by the length (miles) of each class and by the traffic counts (ADT values) that are representative of each class of roadway over the averaging period. The inventories are normally compiled on an annual basis by roadway class and vehicle mix, which gives the opportunity to incorporate seasonal variations of emission factors. The full emission inventory for a defined study locality is complete when all active road segments have been included in the calculations.

It is always recommended that local road and traffic data be used for emission inventory calculations. Typically local data are available on VMT totals by roadway category. In addition, data are usually available on the mix of vehicle types averaged across the roadway system, but not within each roadway category.

Table 4 illustrates the emission calculation method using annual VMT and road mileage data for 2006 from Clark County, NV.[7] Shaded values are for illustration purposes only and do not represent actual data. Because traffic-entrained dust emissions are negligible when traffic speeds are below 10 mph, the VMT portion of stop-and-go traffic should be excluded from the emission inventory.

These example data and calculations to obtain area-wide estimates of PM_{10} and $PM_{2.5}$ emissions utilize hypothetical emission factors to illustrate the procedure. More detailed calculation options can be implemented, dependent on the resolution of available VMT and vehicle fleet data as a function of time and spatial position within the study area.

Table 4. Hypothetical Calculation of Paved Road Dust Emissions for a County (all vehicle types)

Road class	Interstate/ Other	Urban/ Rural	Road miles	AP-42 Emission Factor (g/VMT)	Total Annual VMT (10^6 miles)	Annual PM-10 emissions (tons)	Annual PM-2.5 emissions (tons)
Principal Arterial	Interstate	Rural	85	0.180	871	173	26
Principal Arterial	Other	Rural	168	0.670	450	332	50
Minor Arterial		Rural	19	0.890	53	52	8
Major Collector		Rural	227	0.870	162	155	23
Minor Collector		Rural	95	1.030	25	29	4
Local		Rural	1,863	2.110	127	296	44
Principal Arterial	Interstate	Urban	70	0.090	2,568	255	38
Principal Arterial	OFE	Urban	40	0.180	1,393	276	41
Principal Arterial	Other	Urban	125	0.240	1,668	441	66
Minor Arterial		Urban	402	0.822	3,688	3,337	502
Collector		Urban	280	0.970	1,055	1,128	169
Local		Urban	3,050	0.890	2,329	2,283	343
			6,424		14,391	8,756	1315

For regional and national inventories of transportation emissions, EPA uses the National Mobile Inventory Model (NMIM)[5] to develop and consolidate county-level emission inventories of vehicle exhaust emissions from on-road and non-road sources. As developed by EPA/OTAQ, NMIM is a very large program that executes the MOBILE6 model once per month for each county.

NMIM does not contain all of the information necessary to prepare a county-level emission inventory for fugitive dust from paved roadways, because emission factors are not provided. However, the national county database (NCD) of highway and vehicle fleet characteristics that is incorporated within NMIM can be used in the absence of local data to develop roadway activity levels. This information, when coupled with mobile monitoring at the local level, can be used to develop road dust emission inventories at the county level when emission factors are available for the 18 combinations of vehicle and roadway categories used by NMIM.

2.4 DEVELOPMENT OF MORE ACCURATE METHODS

The opportunities for developing more accurate estimates of re-entrained road dust emissions from paved roads lie primarily in the development of improved emission factors, in relation to what is available in the traditional AP-42 methodology. Within the constraints of the traditional methodology, improved emission factors are achieved through improved silt loading characterization.

While local silt loading surveys are always preferable to the use of default values of road surface dust loadings for input to the AP-42 emission factor equation, the use of default values is the least costly option for the user. However, the accuracy of the resulting emission estimates depends directly on the applicability of available default values to the study area of interest. Use of default values is more appropriate for emission inventories across an air quality control region than for characterizing existing roadways or transportation projects of limited size.

A new emission factor development approach of greater accuracy than the AP-42 method, centers on a new mobile monitoring method that has emerged in the past few years. The mobile monitoring approach can either be used as a replacement for the AP-42 method, or it can be used in hybrid fashion in combination with the AP-42 method, as discussed below.

The alternative mobile monitoring method is based on a vehicle continuously sampling its own dust plume on a second-by-second basis as it travels along representative roadway segments. The mobile monitoring method relies on plume concentration as a relative measure of plume emissions, and each method configuration requires only one calibration test series against the roadside reference method. The application of mobile monitoring has significantly less physical constraints than the AP-42 method, is less labor intensive, and provides critically important information on emission variations across roadway systems.

The mobile monitoring method is especially useful in preparing a detailed and accurate road dust emission inventory for a specified study area. The test vehicle is driven over statistically sampled roadway classes in normal traffic to determine an average dust plume concentration for each roadway class or specific road segment. The VMT values for roadways in the study area can be used as the initial basis for proportional sampling of each roadway class. For example, if urban freeways and expressways account for 30 percent of the VMT, then approximately 30 percent of the mobile monitoring effort should be directed to sampling roads within that functional class.

The sampling should be performed during normal daytime traffic conditions and periods of dry weather. Traffic congestion should be avoided, because road dust emissions are considered negligible when traffic speeds are less than 10 mph.

Once an average dust plume concentration is determined from mobile monitoring of each roadway class, the value is converted to an equivalent emission factor using a linear multiplier. The linear multiplier is based on calibration of the mobile monitor plume concentrations for representative locations within each roadway category, against the corresponding emission factors determined by an accepted roadside EPA reference method. The calibration factor is the average value obtained from tests within each roadway category over a typical traffic speed range. The emission factor is normally presented in units of grams of PM_{10} or $PM_{2.5}$ emissions (particles less than or equal to 10 or 2.5 micrometers in aerodynamic diameter) per vehicle-miles traveled (g/VMT).

Note that no correction to the linear calibration factor is needed to account for test vehicle speed variations, because the mobile monitor travels at typical traffic speeds during the calibration testing. The calibration factor is developed for the normal range of vehicle speeds on paved roads (centering around 25 mph to 45 mph). In addition, if a light-duty mobile monitoring test vehicle is selected with a weight that is close to the fleet average vehicle weight for the study area, no weight correction to the calibration factor is needed.

The mobile monitoring method is currently in the peer review process as an important step toward EPA standardization. The basis for standardization is the recent benchmark Nevada comparison study that used two mobile monitoring configurations (test vehicle and sampling system combinations) for paved roadways.[6] The objective is to obtain regulatory approval for using mobile monitoring in conformity analysis applications. The principal investigator for the subject research study (Task 42) has been in continuous contact with the Clark County, Nevada investigation team for the past two years.

In preparing transportation plans and programs, mobile monitoring would be used to characterize the emission factors for existing roadways in the geographical area of interest. Test roads would be selected with land use, traffic loads and roadway designs that are similar to the roads specified in the transportation project. Ideally, the tests would be performed in the same locality (e.g., metropolitan area) where the transportation project is being considered. The mobile monitoring test results would be used in performing emission calculations to determine the emission impacts of the transportation program, following the standard emission inventory calculation procedures.

The following sections of this document describe specific mobile monitoring configurations that have been field tested and demonstrated to be effective:

1. Fully calibrated mobile monitoring method as a replacement method
2. Hybrid mobile monitoring method in combination with AP-42 silt loading sampling
    a. Use of uncalibrated mobile monitoring to find representative AP-42 sampling locations
    b. Use of mobile monitoring method that is indirectly calibrated against AP-42 silt loading emission factors

No other demonstrated emission factor development approaches have been found during the investigation under NCHRP Task 42.

User guidance for implementing these approaches is presented in the following sections of this report. In addition, a method evaluation scheme is provided to aid the user in determining the trade-offs and in making a final selection of the approach used for a particular application.

3. GUIDELINES FOR MOBILE MONITORING

Mobile monitoring (MM) is a new alternative emission characterization method for determining road dust emission factors on either paved or unpaved roads. The basic design of a mobile monitoring system includes an on-board continuous particle monitor, a sampling tube and inlet probe, a GPS unit, and a data logger. Typically, the particle monitor is a light-weight, battery-operated laser photometer that uses light scattering to measure particulate concentrations at 1-sec intervals.

The emission intensity of any given portion of roadway is proportional to the intensity of the re-entrained dust concentration that is monitored. By traveling over the entire road network, a map of emission intensity is generated. A calibration factor is used to convert the emission intensity to an equivalent emission factor, based on coincident application of the mobile monitoring technology and the roadside plume profiling method (which was used to develop the traditional AP-42 emission factor equation) at representative paved road test sites.

The calibration factor changes with the location of the sampling probe on the outside of the test vehicle and the type of soil being sampled. Two separate sets of calibration factors have been reported, as developed by Desert Research Institute (DRI) and the Center for Environmental Research and Technology at the University of California—Riverside (CE-CERT). The DRI sampling probe is in the front wheel well of the test vehicle and the CE-CERT probe is on a trailer towed behind the test vehicle. The mobile monitors designed and tested by DRI and CE-CERT are currently undergoing peer review for approval as a replacement for the AP-42 silt loading sampling method[6]. Midwest Research Institute (MRI)[10] has used a third probe location in its mobile monitoring system developed for unpaved industrial haul roads, with the probe located midway along the passenger side of the vehicle at a point about 8 inches above the road surface.

The calibration factors developed for mobile monitors depend on the test vehicle speed. However, the DRI and CE-CERT investigators opted to derive an ensemble calibration factor representing a normal speed range for paved roads (25 to 45 mph), excluding periods of traffic congestion. The factors for the two mobile monitoring technologies also apply to the average weight of the test vehicles (2.8 tons), which is closely representative of the nationwide fleet average weight for traffic on paved roads (2.3 tons) [6]. Ensemble calibration factors for converting mobile monitoring data to average emission factors across roadway categories add significantly to the convenience of emission inventory calculations. However, averaging of a calibration factor across the range of test vehicle speeds may add uncertainty to the calibration factor and to the calculated emission factors

Note that in the application of the MRI mobile monitoring technology to unpaved roads, the test vehicle speed was held constant so that speed changes were not interpreted as road dustiness changes. The net result was less variability in the calibration factors, from which the average calibration factor was derived.

3.1 DRI TRAKER

There are currently two versions of DRI's mobile monitoring system, called TRAKER I and TRAKER II (Testing Re-entrained Aerosol Kinetic Emissions from Roads). TRAKER I is comprised of a van that is equipped with three exterior steel pipes acting as inlets for the onboard continuous particle monitoring instruments. Two of the pipes are located behind the left and right front tires and are used to measure emissions from the tires. The third pipe is the inlet for background air and runs along the centerline of the van underneath the body and extends through the front bumper. The background measurement is used to correct the measurements behind the tires for fluctuating dust and exhaust emission contributions from other vehicles on the road. Separate TSI, Inc. DustTraks (Model 8520) are connected to each of the left and right inlet lines as well as on the middle inlet line. A central computer collects all the data generated by the onboard monitors as well as GPS coordinates, and vehicle speed and acceleration with a 1-second frequency.

Figure 1. TRAKER I

The TRAKER II inlet lines are configured so that on unpaved roads, where PM_{10} concentrations behind the front tires could exceed the particle monitor upper limit (150 mg/m^3), clean air can be mixed with air from the wheel well inlets in a controlled manner to achieve a desired amount of dilution. Instead of an onboard sampling plenum as in TRAKER I, a 10-cm diameter external pipe is used to channel/dilute inlet flow into a manifold with connections to DustTrak particle monitors. The circular inlets used currently on TRAKER I are replaced by flattened manifolds on TRAKER II.

Figure 2. TRAKER II

3.2 CE-CERT SCAMPER

The CE-CERT SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways) determines PM emission rates from roads by measuring the PM_{10} concentrations in front of and in the wake of the test vehicle using DustTrak monitors. As a first approximation, after subtracting the background contribution the concentration difference (mg/m^3) is multiplied by the vehicle's frontal area ($3.66\ m^2$) to obtain an emission factor in units of mg/m. The particle monitor for the vehicle wake is mounted on a small trailer with a flat bed, so that the vehicle wake is disturbed as little as possible. The inlet for the wake monitor, which is 10 ft behind the rear of the vehicle, allows sampling as isokinetically as possible over the full range of vehicle speeds. A GPS determines vehicle location and speed, and a PC collects 1-sec data from GPS and PM_{10} measuring devices.

Figure 3. SCAMPER

3.3 MRI MOBILE MONITORING SYSTEM

MRI developed a mobile monitoring system for use on unpaved haul roads.[10] The system uses a DustTrak continuous particle monitor which samples the effluent of a high-volume PM_{10} cyclone. This design collects all particles larger than approximately 15 µm with the cyclone, so that the DustTrak inlet does not get overloaded by the high dust concentrations from the unpaved road. A continuous GPS unit on the test vehicle references each 1-sec PM_{10} concentration reading to its location. Both the DustTrak and GPS data are logged onto a laptop computer. The location of the MRI probe is illustrated in Figure 4.

Figure 4. Mid-vehicle probe location in MRI mobile monitoring system

3.4 EXAMPLE MOBILE MONITORING DATA REDUCTION

A good example of the application of mobile monitoring to a paved road system is provided in the Phase II study funded by the Clark County Department of Air Quality and Environmental Management (DAQEM).[11] The test route traveled by the mobile monitor is shown in Figure 5, which maps the emission factor range for each of the road segments. The test loop covered the range of road classes (arterial, collector, freeway, local), and the other documented road conditions the road class presence/absence of adjacent construction activity, presence/absence of vacant lands, curbing/shouldering, and the number of travel lanes per direction. Using these descriptive fields, it was possible to segregate road characteristics and calculate emission factors for a specific set of conditions.

Table 5 provides a summary of the effects of various road attributes on the emission factor. Note that the construction and vacant land categories are not treated in terms of quantifiable parameters. For example, the data provided by Clark County DAQEM does not specify the extent of construction or the prevalence of vacant land along a specific segment. Thus, these data are presented here for completeness, but the investigators did not recommend their use for any planning or calculation purpose

Figure 5. TRAKER emission factor map

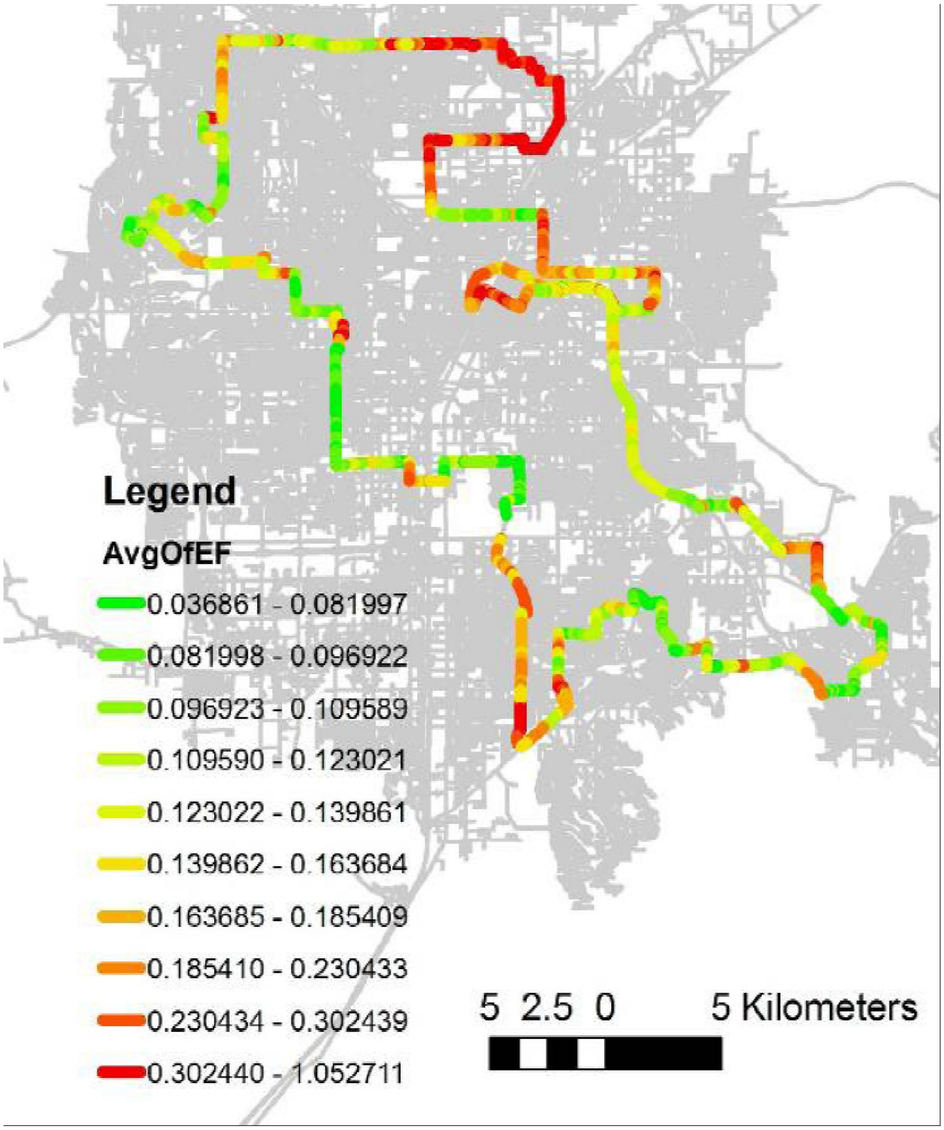

Table 5. Effect of Road Segment Attributes on Emission Factors (grams/vehicle-kilometer traveled)

Class	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
Arterial	0.153	0.093	469	0.004
Collector	0.199	0.121	203	0.008
Freeway	0.166	0.054	107	0.005
Local	0.327	0.241	41	0.038
Lanes/direc	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
1	0.287	0.179	141	0.015
2	0.153	0.079	374	0.004
3	0.143	0.076	257	0.005
4	0.154	0.028	6	0.012
5	0.241	0.047	8	0.016
Constr	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No	0.169	0.113	648	0.004
Yes	0.197	0.122	172	0.009
Vac lands	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No	0.154	0.103	563	0.004
Yes	0.220	0.129	257	0.008
Curbs/shoulders	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No/No	0.572		1	
No/Yes	0.208	0.139	115	0.013
Yes/No	0.158	0.109	533	0.005
Yes/Yes	0.204	0.105	171	0.008

4. GUIDELINES FOR 'MM/AP-42' HYBRID METHODS

There are two newly proposed options for combining mobile monitoring with the traditional AP-42 method involving road sweeping to determine representative silt loading values. These are referred to as hybrid applications of the mobile monitoring method. In both cases a simpler version of mobile monitoring can be used. This entails use of a continuous PM10 sampler with an inlet line attached to the side of a test vehicle at a fixed location where the operating range of the monitor is not exceeded. The sampling intake position would be similar to that used in the MRI mobile monitor, as described above. A GPS unit should also be operated concurrently, with the data from both monitors merged electronically.

For application to PM2.5, the only difference is the use of a continuous PM2.5 monitor in place of the PM10 monitor. Most continuous PM10 monitors provide a size-selective PM2.5 inlet for this conversion. For example, PM2.5 sampling may be performed using a TSI DustTrak with a size-selective impactor on the inlet. Because the greased impaction surface is relatively small, it may become overloaded in high concentration dust plumes. Consequently sampling periods should be selected carefully to mitigate against overloading of particles on the impaction surface, prior to cleanup between monitoring test runs.

4.1 HYBRID OPTION 1

The first option would use mobile monitoring in the normal fashion, but with indirect calibration against the AP-42 method. This would be accomplished by selecting roadway locations where surface silt samples are collected so that the AP-42 equation could be used to provide emission factor estimates. The mobile monitor could be used to travel over parts of the paved road system to identify representative locations for performing the surface sampling. This approach would be far less expensive than applying the more costly reference roadside plume profiling method.

The accuracy of this option would be better than achieved by applying the traditional collection of silt loading samples at a limited number of roadway locations and using of the AP-42 emission factor equation, as long as the same set of silt loading samples were collected in both cases. The increase in accuracy would result from the much more complete characterization of emission factor variation within each roadway category by mobile monitoring at 1-sec intervals along representative roadway segment within each category. As with the directly calibrated mobile monitoring method described in the previous section, this option would also provide maps of emission factors.

4.2 HYBRID OPTION 2

The second hybrid option would use uncalibrated mobile PM10 monitoring to map the relative emissions of a roadway system. The resulting maps of relative emission factor would be used to optimize the location of silt loading sampling sites for each roadway category. This second option reduces the uncertainty of relying on a specific number of silt loading samples to represent a roadway classification when little is known about the actual silt loading distributions on the roadway system.

Table 6 illustrates how the second hybrid option would be applied. In this example 1-sec PM10 concentrations measured along the traveled routes sampled by the mobile monitor would be mapped. Potential locations for silt sampling would be identified by determining short road segments that resulted in typical concentrations for specific road classifications. In this example, it is assumed that 1,000 road segments (numbered in sequence) have been defined, spanning the specified roadway categories.

Table 6. Selection of Silt Sampling Locations Based on Hypothetical Results of Mobile Monitoring of PM10 Concentrations

Road class	Interstate/ Other	Urban/ Rural	Mean Mobile Monitor PM10 (mg/m^3)	Mean Relative PM10 Emission Rate (mg/m^3 *ADT)	Road Segments within 10% of Mean PM10	Potential Silt Collection Sites **
Principal Arterial	Interstate	Rural	0.180	173	NA	None
Principal Arterial	Other	Rural	0.670	**332**	7, 22, 39, 42	22, 42
Minor Arterial		Rural	0.890	52	NA	None
Major Collector		Rural	0.870	155	NA	None
Minor Collector		Rural	1.030	29	NA	None
Local		Rural	2.110	296	NA	None
Principal Arterial	Interstate	Urban	0.090	255	NA	None
Principal Arterial	OFE	Urban	0.180	276	NA	None
Principal Arterial	Other	Urban	0.240	**441**	211, 272, 629, 877, 931	877, 931
Minor Arterial		Urban	0.822	**3,337**	88, 91 102, 127	88, 91, 127
Collector		Urban	0.970	**1,128**	142, 146, 162, 169	142,169
Local		Urban	0.890	**2,283**	171, 181, 183, 188, 191, 197	181, 183, 188

**After excluding non-feasible sampling locations because of safety and other problems

As shown, the road classes representing only a small proportion of total emissions are excluded from silt sampling. Only roadway classes with significant relative emissions, expressed as average daily traffic on the road class multiplied by mean PM10 concentration, would offer representative sites for road surface silt sampling. Once potential sampling locations within ten percent of the mean PM10 concentration for each road class are identified, air quality personnel would select actual sampling locations based on safety and other acceptance criteria.

5. METHOD COMPARISON AND COSTS

This investigation has identified alternatives to the traditional AP-42 method for calculating re-entrained road dust emissions from transportation projects. The available alternative methods consist of mobile monitoring used independently or in combination with the traditional AP-42 method. No other methods are available at this time, but EPA has a strong interest in mobile monitoring as a replacement for the traditional AP-42 method.

Table 7 compares replacement and enhancement alternatives to the traditional AP-42 method for determining road dust emission factors. The recommended replacement method is mobile monitoring calibrated to plume profiling. A less desirable replacement method is mobile monitoring calibrated indirectly against AP-42 silt loading measurements in conjunction with the associated emission factor equation. In either case, calibrations are one-time events and remain intact as long as the mobile monitoring test vehicle and sampling configuration are not modified. As a significant enhancement to the traditional AP-42 method, mobile monitoring can be used to locate representative silt loading sites, thereby reducing the uncertainty of the traditional AP-42 method.

In Table 7, roadside plume profiling is the approved standard for measuring road dust emission factors, and the AP-42 method is the traditional approach that utilizes silt loading surveys in combination with emission factor equations. Note that mobile monitoring is the least restrictive method, in relation to required test conditions, followed by road surface sampling (for silt loading) and plume profiling, which is the most restrictive method. Application of the roadside profiling method to calibrate a mobile monitor requires (a) moderate winds that have a strong component at right angles to the test road orientation, (b) an open area on the upwind side of the road at a test site, and (c) no more than two lanes of traffic upwind of the sampling tower.

The cost of developing a mobile monitoring system involves three elements: dedication of a test vehicle, equipping of the vehicle with the sampling system, and calibration of the mobile monitor. The cost of operating the calibrated test vehicle would be minimal, involving a few hours of time to traverse representative segments of the roadway system of interest. This would be followed by a relatively small amount of time to process the data collected. It is assumed that in most cases, a light-duty vehicle would be available for use as a mobile monitor over a period of several years as needed.

For a simple sampling system consisting of a sampling line, coarse particle trap, continuous particle monitor, GPS unit and data logger, the cost may be as low as $10,000 to $15,000, including installation. For simple sampling configurations, it would be possible to remove the sampling system from the test vehicle when not in use as a mobile monitor.

Calibration of the mobile monitor against the plume profiling method would cost in the range of $50,000, but this calibration would assure the highest accuracy achievable over the lifetime of the test vehicle and the sampling equipment. Calibration of the mobile monitor against the traditional AP-42 method involving silt loading surveys would reduce the calibration cost to about $25,000, but would provide significantly less accurate results. In comparison, the cost of an adequate silt loading survey involving at least partial road blockage and labor-intensive manual road surface vacuuming would also cost in the range of $25,000. Moreover, the silt loading surveys would have to be repeated periodically.

Table 7. Test Method Implementation Requirements

Implementation Requirements	**Emission Factor Test Method**				
	Roadside Profiling (Approved Calibration Method)	**AP-42 Method [Silt Loading Samples + Equation]**	**Mobile Monitoring [Calibrated against Reference Method}**	**Hybrid Option 1 Mobile Monitoring indirectly calibrated by AP-42 Method**	**Hybrid Option 2 Use of Mobile Monitoring to Select Representative Sites for AP-42 Silt Loading Measurements**
Daylight	Yes	Yes	No	No	No
Wind speed	3 to 15 mph	0 to 10 mph	0 to 15 mph	0 to 15 mph	0 to 15 mph
Wind direction	Within 45 deg of normal to road	Unrestricted	Unrestricted	Unrestricted	Unrestricted
Road width	No more than 2 lanes	Unrestricted	Unrestricted	Unrestricted	Unrestricted
Roadside condition	No wind blockage upwind	Unrestricted	Unrestricted	Unrestricted	Unrestricted
Test sites	Multiple	Multiple	NA	Limited	Multiple
Traffic count	Required	Not required	Not required	Not required	Not required
Traffic mix	Required	Not required	Not required	Not required	Not required
Calibration requirement	No	No	Yes	Yes	No
Safety	Roadside protection	Lane blockage and arrow board	Low risk if traveling at traffic speed	Low risk if traveling at traffic speed	Lane blockage and arrow board

6. FINDINGS AND CONCLUSIONS

The emission calculations for transportation projects mimic those used in emission inventorying of existing paved road systems and of expanded roadway systems that are anticipated in future years, for purposes of addressing attainment of the air quality standards. Roadway emission characteristics for transportation projects involving future highway construction must be projected based on emission characteristics of similar existing roadways in the same geographical area or in other areas with the same climate, land use, traffic loads and roadway designs.

The opportunities for developing more accurate estimates of re-entrained road dust emissions from paved roads lie primarily in the development of improved emission factors, in relation to what is available in the traditional AP-42 methodology. Ideally, a new method can be identified that uses a parameter other than road surface dust loading as a measure of the emission potential of a road segment. In recent research, the dust concentration emitted at near the point of generation from the pavement surface has emerged as a more useful surrogate for the "dustiness" of the road surface. The same applies to unpaved roads as well.

Historically, AP-42 emission factors for dust emissions from paved roadways have been developed using a fixed point (road-side) and time-integrated sampling scheme. The resulting emission factor equation encompasses different particle size fractions of interest including $PM_{2.5}$ and $PM_{10,}$ which are represented in a constant ratio of 0.15. The decision to calculate $PM_{2.5}$ emissions as a fixed proportion to PM_{10} emissions was based on the difficulty in determining an independent emission factor equation for $PM_{2.5}$ of sufficient reliability. This results from the much smaller proportion of paved roadway $PM_{2.5}$ concentrations at roadside test locations, in relation to background $PM_{2.5}$ levels. Silt loading is the key input parameter used in the AP-42 emission factor equation to represent the "dustiness" of the road surface.

The AP-42 emission factor equation, as applied to a network of roads, requires on-site road surface sampling to characterize dust loadings – a time-consuming, costly, and potentially hazardous undertaking. A similar AP-42 emission factor equation developed by EPA for unpaved roads uses the silt content of the loose road surface material as the measure of dustiness. Serious source representation issues are related to the affordable number of silt loading samples that are typically needed to represent spatial and temporal variations across paved roadway networks. Just as important is the elimination of representative road surface sampling sites because of safety concerns and other issues.

National default values of silt loading have been developed for use in areas where local sampling of silt loadings is not possible. Default values are primarily associated with the average daily traffic (ADT) count as a basis for roadway categorization. While local silt loading sampling is preferred to using the national default values, the cost of representative sampling for existing roadway systems is often prohibitive. In addition, collecting local samples is not an option for projecting the impacts of new roadway construction. For these cases an improved national default silt loading look-up table could be developed that would include more specific adjustments to baseline default values. Adjustment factors could include items such as the presence or absence of curbs and gutters, stabilized shoulders, and construction activities, posted speed limit, and the condition of the road pavement.

A tabulation of expanded default values of road surface dust loadings for input to the AP-42 emission factor equation provides the least costly option for the user, but serious inaccuracies may result from the use of nationwide or region-wide default values to assess localized transportation projects. A series of approaches of greater accuracy centers on a mobile monitoring method that has emerged in the past few years. This new approach can either be used as a replacement method, or it can be used in hybrid fashion in combination with the AP-42 method.

The alternative mobile monitoring method is based on a vehicle continuously sampling its own dust plume on a second-by-second basis as it travels along representative roadway segments. This cost-effective method is referenced to the standard AP-42 emission factor test method, but relies on *relative* measures rather than *absolute* emission levels. Mobile monitoring of paved road dust emissions has significantly less physical constraints than the AP-42 method, is less labor intensive, and provides critically important information on emission variations across roadway systems.

Note that the mobile monitoring method provides for efficient roadway system representation without dealing with difficult issues of selecting fixed point sampling sites. However, the mobile monitoring method does require calibration against the roadside profiling reference method, although once determined, the calibration factor applies to future use of the identical mobile monitor. Critical items that must be maintained in extending the applicability of a calibration factor include the test vehicle specifications and those of the on-board monitoring system and probe location.

Two new proposed options for hybrid mobile monitoring are founded on the basic principles underlying mobile monitoring and AP-42 methods. One option would use mobile monitoring in the normal fashion with indirect calibration to a limited number of emission factors derived from silt loading samples and the AP-42 equation. The other hybrid option would use uncalibrated mobile monitoring to map the relative emissions of a roadway system and employ the information obtained to optimize the locations of silt loading sampling sites for each roadway category. This second option reduces the uncertainty of using a specific number of silt loading samples to represent an entire roadway system when little is known about the silt loading distributions.

The primary source of uncertainty associated with mobile monitoring is the conversion of the continuously monitored test vehicle dust plume concentrations to equivalent paved road emission factors. This source of uncertainty is of the same order as the uncertainty associated with the AP-42 emission factor equation, which relies on the silt loading as a primary predictor of the magnitude of the re-entrained dust emissions. Because the use of mobile monitoring eliminates the requirement to search for representative individual test sites, the significant uncertainty associated with that part of the AP-42 method is also eliminated.

As one of two hybrid applications, the use of mobile monitoring with indirect calibration to emission factors estimated using silt loading and the AP-42 equation will be less accurate than fully calibrated mobile monitoring, but will lower the cost of calibration. Conversely, use of an uncalibrated mobile monitor to optimize the location of silt loading sampling sites is expected to increase the accuracy associated with traditional silt loading sampling in association with the AP-42 method. In other words, both of these alternatives have greater uncertainty than the fully calibrated mobile monitoring method, but represent improvements over the traditional AP-42 method.

Table 8 compares the direct and hybrid versions of the mobile monitoring method.

Table 8. Mobile Monitoring Method Comparisons

Method	Advantages	Disadvantages	Current Status
Fully Calibrated Mobile Monitor	Can be used as an independent replacement method for finding emission factors Reduces uncertainty associated with spatial and temporal representation One calibration factor can be used when a system design is constant	Calibration is costly and difficult to implement	DRI and CE-CERT have undertaken a series of tests for the calibration of the TRAKER and SCAMPER mobile monitoring systems
Mobile Monitor indirectly calibrated to the AP-42 method	Reduces cost of implementation and is less labor intensive Gives better spatial and temporal representation than AP-42 silt loading sampling	Increased uncertainty in calibration to a non-reference method	Unpublished method in process of development
Unicalibrated Mobile Monitor used to find representative spots for AP-42 silt loading sampling	Decreased uncertainty in choosing representative AP-42 silt loading sample locations	Does not produce a calibration factor for future use with the mobile monitor	Unpublished method in process of development

Although more costly to implement, a fully calibrated mobile monitor as an independent emission characterization method is preferred because it eliminates the spatial and temporal representation problems of silt loading determination as well as the safety concerns of the traditional method. If the mobile monitor remains available for use over a period of years, it represents the least costly option while producing the most accurate results.

In preparing transportation plans and programs, mobile monitoring would be used to characterize the emission factors for existing roadways in the geographical area of interest. Test roads segments would be selected with land use, traffic loads and roadway designs that are similar to the roads specified in the transportation project. Ideally, the tests would be performed in the same locality (e.g., metropolitan area) where the transportation project is being considered. The mobile monitoring test results would be used in performing emission calculations to determine the emission impacts of the transportation program, following the standard emission inventory calculation procedures.

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