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Assessment of Methods for Control of Fugitive Emissions from Paved Roads

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Assessment of Methods for Control of Fugitive Emissions from Paved Roads

by

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ABSTRACT

In a number of metropolitan areas of the country, failure to attain national primary air quality standards for total suspended particulates (TSP) has fostered a detailed reexamination of the nature of the urban TSP problem. Reentrained dust from paved streets and other traffic-related emissions are now recognized as major sources of TSP in urban areas. While numerous reports and studies have examined this subject, some significant aspects of urban road dust have not been studied in enough detail, if at all. Examples of this are the effects of gutters and pavement composition and shape. This report discusses those areas of the urban road dust problem that are felt to require further attention and outlines the priorities with which the data should be obtained. The approaches to be taken to obtain the desired information are also defined.

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INTRODUCTION

Failure to attain the national primary air quality standards for total suspended particulates (TSP) in a number of metropolitan areas of the country has fostered a detailed reexamination of the nature of the urban TSP problem. While TSP control strategy development has routinely included an analysis of the contributions of traditional point and area sources superimposed on a constant background level, adequate consideration has not been given to the contributions of nontraditional dust sources. Reentrained dust from paved streets and other traffic-related emissions have now been recognized as major sources of suspended particulates in urban areas and potential leading causes of TSP concentrations in excess of the ambient air quality standards. To attain these standards, a thorough knowledge of the contribution of urban road dust to ambient TSP levels is required.

While the subject of urban road dust and its numerous offshoots has been discussed and studied in literally hundreds of reports, there are still many questions left unanswered. Has every area that relates to urban road dust been studied thoroughly? What areas require further study? What areas have not been studied at all? Do these areas contribute to the problem significantly enough to warrant study? If so, with what priority and by what means should the desired information be obtained?

To answer the above questions, the Industrial Environmental Research Laboratory (IERL) retained TRC - THE RESEARCH CORPORATION of New England to conduct a search and review of the existing literature relating to all aspects of urban road dust to point out areas or topics requiring further research or study. This report presents the results of this review.

Section 2 presents a general discussion of the subjects that relate to urban road dust. The generic areas of deposition, removal, measurement, etc. are covered and specific topics under these areas are discussed. In-depth consideration of chemical and physical properties of urban road dust is not given in this report since such information is adequately covered in other reports. The aim of this study is to point out research needs.

Section 3 discusses the contents of the reports reviewed for this study with emphasis on the thoroughness of coverage of each subject matter area relating to urban road dust. Section 4 discusses the subject matter areas that have not been given adequate coverage in the literature, including both generic and specific topics.

Section 5 presents the recommendations of this study. The gaps in the available information in relation to the benefits derived from their study are evaluated. Priorities for studying control measures are assigned as functions of the relative impact of the road dust. Finally, the approaches to be taken to obtain the desired information are defined.

Section 6 lists the references reviewed in this project. These were obtained from computerized literature searches, government and TRC files, and an EPA library visit. A brief summary of each report is presented in a separate Appendix which is available through either TRC or IERL. Not every one of the vast number of reports dealing with an aspect of urban road dust could be examined during the course of this project; however, it is felt that the major ones have been reviewed in all of the subject areas that have been investigated.

SECTION 2

SUBJECTS RELATING TO URBAN ROAD DUST

The intent of this section is to provide the reader with a general overview of the major factors that relate to urban road dust. By examining the generic areas (e.g., methods of deposition) and then the specific topics (e.g., vehicles) associated with road dust, the reader will better understand the following sections of this report that discuss the information covered in the literature and the areas requiring further research. It is not the intent of this report to provide a comprehensive review of the physical and chemical nature of urban road dust as this has adequately been done before.[1-3] The aim of this report is to point out what areas need to be further researched, and how to approach such research, in order to better understand and reduce the impact of urban road dust on the environment.

In dealing with the subject of urban road dust, there are five major areas that need to be addressed. They are:

- The means by which the material comprising urban road dust is deposited on the road surface.
- The variables that affect the surface loadings once the material is deposited on the road.
- The physical and chemical nature of the deposited material.
- The impact of the material on its surroundings.
- The methods of removal or control of the material.

These areas are discussed in the following subsections and then summarized in Table 1 which is presented at the end of Section 2.

METHODS OF DEPOSITION

The origins of the material comprising urban road dust are quite varied. Natural processes and the activities of humans both contribute to the surface loadings. The primary methods of deposition have been identified as the following:

- Motor vehicles
- Sanding and salting
- Pavement wear
- Litter
- Biological debris
- Wind and water erosion from adjacent areas
- Atmospheric pollution fallout.

These methods are depicted in Figure 1.

Motor vehicles contribute materials in a number of different ways. Tire wear, settleable exhaust, wear of brake and clutch linings, corrosion and abrasion of panels and undercoatings, mud and dirt carryout from unpaved areas and construction sites, and truck cargo spills all deposit particulate matter. Lubricants, coolants, hydraulic fluids, and oil leaks deposit organic material. Of these deposits, mud and dirt carryout seems to be the most significant in terms of mass deposition rate (kg/curb-km/day).[1]

Sanding and salting deposit particulate material on the street on only a few occasions per year. However, a good deal of this material remains on streets for long periods of time due to street cleaning schedules and inefficiencies.

Pavement wear and decomposition contribute various types of particles to the street surface loading. These include asphalt, cement, aggregate, expansion joint compounds, and fillers.

Litter is comprised of cans, bottles, broken glass, plastic, tobacco, etc. Some of this material is reduced in size until it is no longer recognizable as a specific object and contributes to the overall surface loading.

Biological debris includes leaves, grass clippings, sticks, insect parts, and animal waste. Again, these debris can be reduced to small size by the actions of vehicle traffic and merge with the overall particulate loading.

Soil adjacent to roadways can become part of the street surface loading due to wind and water erosion. This is particularly true in more arid areas and areas lacking curbs, sidewalks, roadside vegetation, or other inhibiting agents.

Finally, atmospheric fallout of dust and particulate pollutants from other areas contributes to road dust. This material can originate from remote industrial and agricultural sources and be transported over long distances to the road surface via air currents.

1 MOTOR VEHICLES
- a TIRE WEAR
- b EXHAUST
- c BRAKE & CLUTCH LININGS
- d MUD & DIRT CARRYOUT
- e TRUCK SPILLS
- f CORROSION & ABRASION OF PANELS & UNDERCOATINGS
- g LUBRICANTS, COOLANTS, HYDRAULIC FLUIDS, OIL

2 SANDING & SALTING

3 PAVEMENT WEAR

4 LITTER

5 BIOLOGICAL DEBRIS

6 WIND & WATER EROSION FROM ADJACENT AREAS

7 ATMOSPHERIC FALLOUT

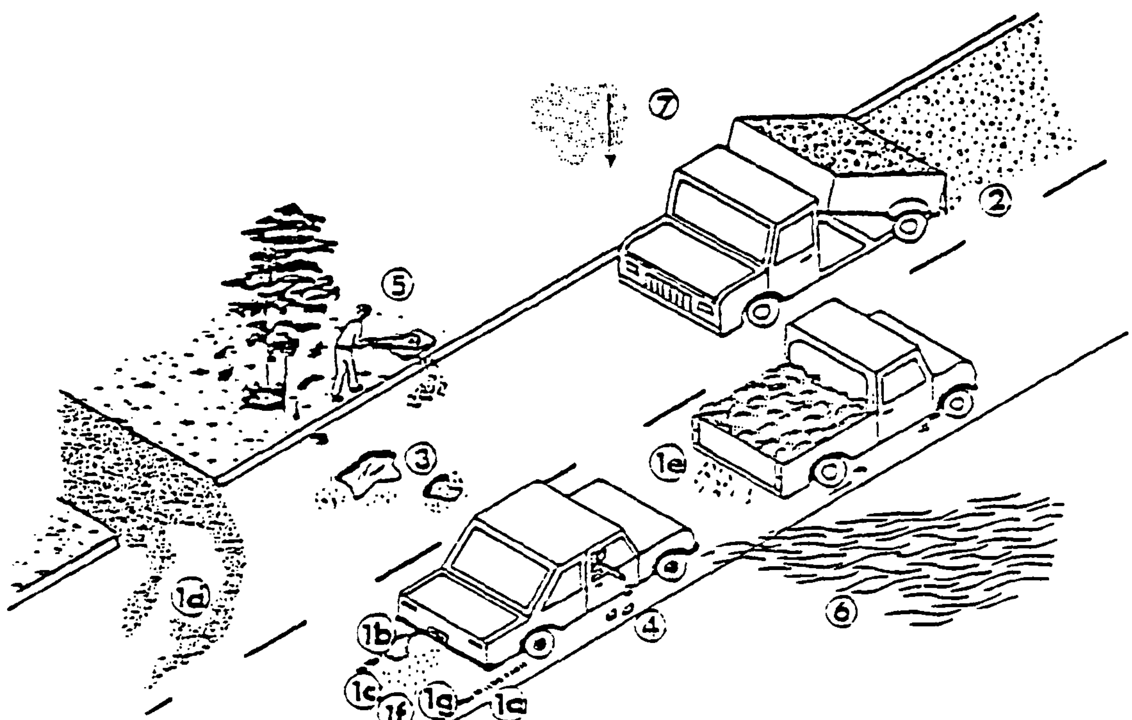

Figure 1. Methods of Deposition

VARIABLES AFFECTING ROAD DUST LOADINGS

Any variation in one of the deposition processes just described affects the amount of material accumulating on the street. In addition, once the material has been deposited on the street surface, other processes can affect the surface loading. These include:

- Meteorological conditions
- Vehicle traffic
- Roadway configuration
- Pavement composition

Meteorological conditions play a very significant role in the variability of surface loadings. Rain will flush the streets and remove a significant portion of the road dust. Snow will cover the dust and prevent it from becoming resuspended. Ice and the freeze/thaw cycles contribute to pavement wear. Fog and dew add moisture and inhibit resuspension, and wind speed, mixing depth, and atmospheric stability can affect the quantity of dust that becomes reentrained.

Vehicles are not only sources of road dust, they also affect the loadings through several mechanisms. The speed, size, volume, and mix of vehicles (e.g., trucks vs. cars) passing over the pavement affect turbulence and resulting dust suppression. Speed variations (idling, stop and start, free flowing) affect emission loadings. Engine conditions are important since a cold engine exhausts more particulate matter than a warm one under the same conditions. Even parked cars can adversely affect road dust to the extent that they hinder street cleaning effectiveness.

Roadway configuration provides another set of variables that affect the amount of road dust that accumulates on the streets. The physical layout of the road (e.g., road slope, gutters and sewers, cobblestones, grooves in the pavement), and conditions alongside the street surface, such as curbing size and shape, vegetation, embankments, buildings and medians, are all important factors. Elevated roads impose still another set of conditions (e.g., wind exposure) that affect surface loadings.

Lastly, the pavement composition itself affects the surface loadings. Different types of surfaces wear at different rates, and some are more easily cleaned than others. The type of resurfacing material used, the frequency of its application, and pothole patching practices all can affect dust formation and deposition and cleanability.

PHYSICAL AND CHEMICAL NATURE OF ROAD DUST

Another realm of study concerning urban road dust deals with the physical and chemical nature of the particulate material. The physical aspect is basically particle size and shape. The chemical aspect relates to material composition.

Suspendability of road dust is of paramount importance since this is the principal aspect that relates to human health. If none of the surface material became suspended, there would be no contribution to the particulate air pollution problem. The quantity of material suspended by any of the mechanisms discussed previously depends primarily on particle size. Particle size also affects the amount that remains suspended to become part of the TSP background and the amount that falls out of the atmosphere within a short distance from the roadway.

The chemical nature of the road dust determines whether or not the material is of a hazardous nature to its surroundings (e.g., toxic to humans, harmful to vegetation and water supplies). It also helps establish the origins of the dust and can point the direction towards effective controls.

A variety of measurement and examination techniques are used to determine the physical and chemical nature of the material deposited on street surfaces. Filter analyses can help to determine particle size distributions, shape, and chemical characteristics as well as relative concentration. Hi-vols and dustfall buckets are used to measure ambient concentration levels and fallout rates. Impactors are used to measure levels and size distributions. Tracer and wind tunnel studies are used to help determine fallout rates, trajectories, and emission factors.

ROAD DUST IMPACT

The primary impact of road dust is on the land, air, and water in the immediate area of the roadway. Vegetation, soils, and animal biota are all affected, with the salt and lead components of the dust causing particular harm. These and other harmful pollutants can enter water resources via flushing, leaching, and runoff; thus causing a water pollution problem. The impact on air quality, the contribution to urban TSP levels, has prompted most of the reports written on the subject of road dust. The major concern seems to be ambient TSP concentrations rather than toxic effects. Not only are local urban areas impacted, but the environment can be adversely affected at great distances due to long range atmospheric transport.

REMOVAL/CONTROL METHODS FOR URBAN ROAD DUST

Removal and/or control of urban road dust can be separated into two relatively distinct categories. The first involves the control or elimination of the sources of urban road dust. The second involves the removal and control of the dust after it has accumulated on the street surface.

The sources of urban road dust were discussed previously in Methods of Deposition. The sources readily adaptable to control measures are construction sites, unpaved areas, and truck cargo spills. The amount of road dust originating from these sources can be reduced by paving, chemical stabilization, tire scrapers, wheel washes, and the wetting or covering of loaded trucks. Most other sources are not really amenable to controls per se. Reductions in the amount of sand and salt applied, the number of vehicles on the roads, and the amount of litter deposited can reduce surface loadings. A reduction in the use of sand and salt can be affected by improved plowing techniques, utilization of a road surface texture or coating that minimizes ice adhesion, or pavement heating. Washing the sand before application removes the fines which can become resuspended and leaves the coarse particles which are necessary to prevent skidding. Improvements in pavement wearability, automobile degradation, and gasoline additives could likewise reduce loadings; but these steps cannot really be classified as specific control methods.

Once the material has accumulated on the streets, it is removed via a number of mechanisms. These include:

- Reentrainment
- Wind erosion
- Displacement
- Rainfall runoff to a catch basin
- Street cleaning methods.

These are illustrated in Figure 2.

Two of these removal methods, rainfall and wind erosion, are natural phenomena and are thus highly sporadic and nonreliable as control methods. Reentrainment and displacement are related to vehicle speed, size, mix, and volume. Street cleaning methods include sweeping, vacuuming, flushing, coating and resurfacing, and various combinations of these methods. These methods vary in cost and effectiveness. Effectiveness is largely a function of frequency and timing (e.g., sand and salt should be removed as soon as possible during thaw periods).

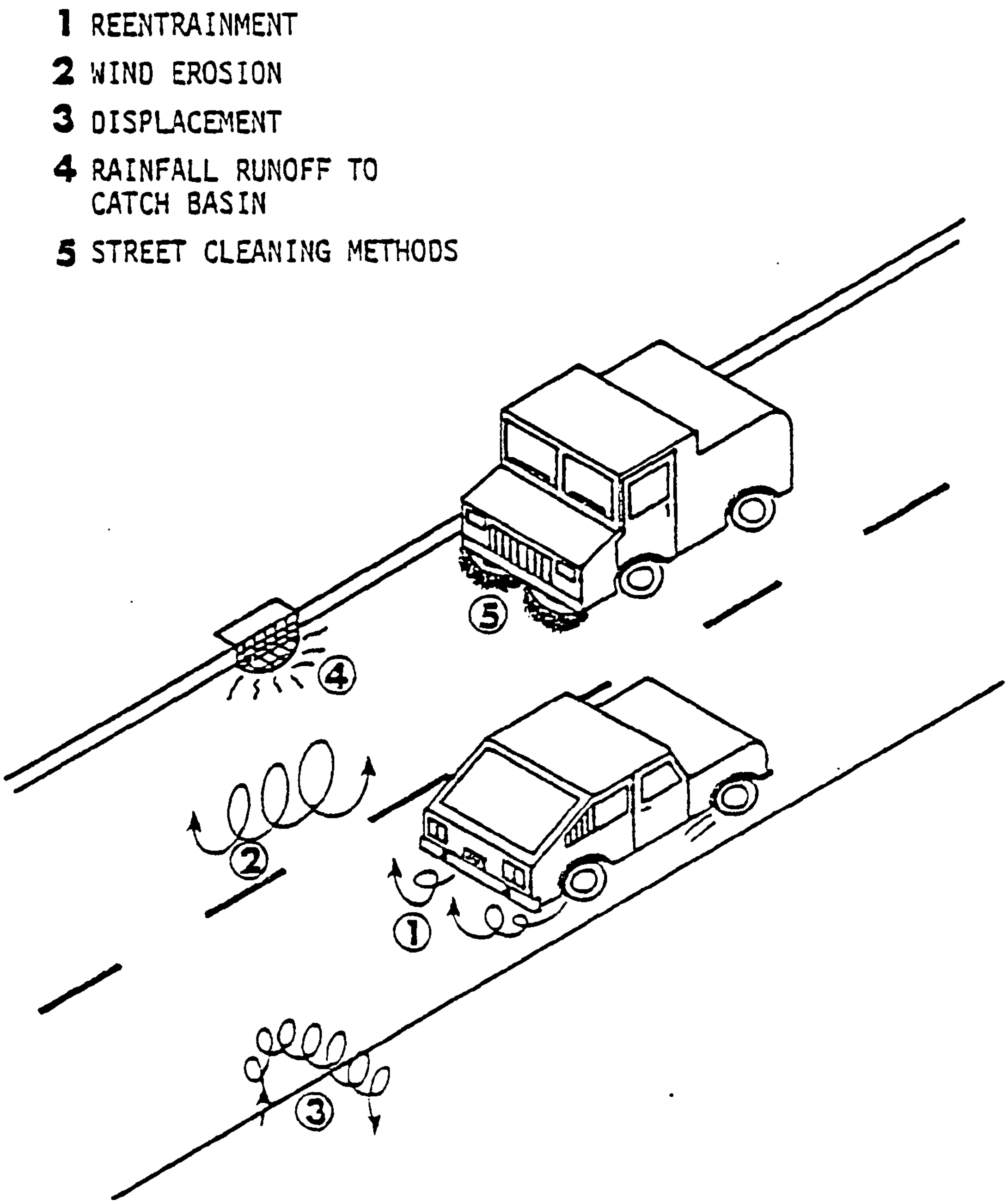

Figure 2. Methods of Removal

TABLE 1. SUBJECTS RELATING TO URBAN ROAD DUST

I. Methods of Deposition

A. Motor Vehicles

1. Tire wear
2. Exhaust
3. Brake and clutch linings
4. Mud and dirt carryout
5. Spills from truck cargoes
6. Corrosion and abrasion of panels and undercoatings
7. Lubricants, coolants, hydraulic fluids, oil

B. Sanding and Salting
C. Pavement Wear
D. Litter
E. Biological Debris
F. Wind and Water Erosion from Adjacent Areas
G. Atmospheric Fallout

II. Variables Affecting Road Dust Loadings

A. Meteorology

1. Icing
2. Precipitation
3. Fog and dew
4. Freeze/thaw cycle
5. Wind speed
6. Mixing depth
7. Atmospheric stability

B. Vehicles

1. Speed
2. Size
3. Mix
4. Volume
5. Speed variations
6. Parking practices
7. Engine temperature

TABLE 1. (CONTINUED)

C. Pavement and Roadway Configuration

1. Grooves in pavement
2. Cobblestone
3. Gutters and sewers
4. Curbing size and shape
5. Crown and bank slopes
6. Medians
7. Embankments
8. Vegetation along road
9. Buildings along road
10. Elevated roads

D. Pavement Composition

1. Cleanability
2. Emission factors
3. Resurfacing material and frequency
4. Patching practices

III. Physical and Chemical Nature of Road Dust

A. Surface Loading

B. Resuspended Dust Background

C. Fallout Rate with Vertical and Horizontal Distance from Roadway

D. Particle Size and Shape

E. Chemical Composition

F. Measurement and Analysis Techniques

1. Hi-vols
2. Impactors
3. Dustfall buckets
4. Filter analysis
5. Tracers
6. Wind tunnel studies
7. Modeling

TABLE 1. (CONTINUED)

IV. Road Dust Impact

A. Water Pollution

1. Run-off
2. Leaching
3. Flushing

B. Impact on Vegetation, Soils, Terrestial and Aquatic Biota

C. Contribution to Urban TSP Levels

V. Removal/Control Methods for Urban Road Dust

A. Control of Sources

1. Carryout sites, unpaved areas, truck cargo spills

a. paving
b. chemical stabilization
c. tire scrapers
d. wheel washes
e. wetting or covering of loaded trucks

2. Snow and ice removal

a. plowing
b. road surface texture or coating to minimize ice adhesion
c. road heating
d. washing sand

3. Traffic reduction

B. Removal Methods

1. Reentrainment
2. Wind erosion
3. Displacement
4. Rainfall runoff to catch basin
5. Street cleaning methods

a. sweeping
b. vacuuming
c. flushing
d. coating/resurfacing
e. combination of the above.

SECTION 3

SUBJECTS COVERED IN THE LITERATURE

The reports that were studied and reviewed during this project are listed in Section 6. A brief summary of each report is presented in a separate Appendix which is available through either TRC or IERL. The reports have been grouped according to subject matter as follows:

- Comprehensive examinations of road dust
- Regional non-attainment analyses
- Area source inventories
- Field and lab tests of road dust components
- Control measures analyses
- Analysis techniques
- Water pollution aspects
- Miscellaneous
- Additional report summaries.

The reports included in these groupings are discussed in the following subsections. The discussions center on the thoroughness of the coverage of each area of subject matter.

COMPREHENSIVE EXAMINATIONS OF ROAD DUST

Three reports were reviewed that provide a good, in-depth analysis of the subject of urban road dust.[1-3] It is recommended that any reader who wishes to obtain a more comprehensive knowledge of this subject examine these reports.

The study by Axetell and Zell[1] is probably the most extensive review of urban road dust published to date. The primary purpose of the study described was to evaluate control measures for reducing emissions of reentrained dust. Information for the review and evaluation was obtained by several different methods including a literature review, collection of unpublished data from traffic-related air pollution studies, compilation of control measure cost data, a survey of public works officials, and design and implementation of five different field studies to evaluate the effectiveness of specific reentrained dust control measures. The field studies examined broom sweeping, vacuum sweeping, flushing, and control measures for a mud carryout construction site. Several recommendations for further research are given.

The objective of the study described by Sartor and Boyd[2] was to investigate and define the water pollution impact of urban storm water discharge and to develop alternate approaches suitable for reducing pollution from this source. One of the focal points of the study was determining the amounts and types of material which commonly collect on street surfaces. Surface loadings were determined by collecting samples in ten land-use categories in twelve cities throughout the country. The samples were analyzed to determine their physical, chemical, and biological properties. Field tests were conducted to determine the effect of rainfall on surface loading. Another section of the report examined the effectiveness of current public works practices for street cleaning methods and effectiveness.

The objectives of the investigation described by Shaheen[3] were the isolation, identification, and estimation of specific contributions of motor vehicle traffic to materials deposited on urban roadways and thus to urban stormwater runoff pollution. These objectives were accomplished via a literature review and a field test program. Samples of road dust were taken in Washington, D.C. with the following data analyses performed: deposition rates, seasonal variations, land use effects, curb height effects, composition, concentrations, and particle size.

REGIONAL NON-ATTAINMENT ANALYSES

Several studies have been performed in which the ambient TSP concentrations in a city or region were analyzed with the intent of pinpointing the various contributing sources.[4-12] In many cases, only existing data were analyzed and no new sampling was conducted; while in other studies, additional data were obtained to better isolate the various factors.

An EPA report[4] presents the results of a fourteen city study of ambient TSP concentrations that were measured using hi-vols. Both chemical and physical analyses were performed on the hi-vol filters. The particulates were categorized into minerals, combustion products, biological materials, and miscellaneous. A large segment of the analysis centered on rubber: concentrations, loadings, and particle size.

Draftz and Blakeslee[5] describe a field study in which hi-vol samples were obtained and analyzed near selected streets in Philadelphia. The results defined twenty-three particle types and their sizes and concentrations, including tailpipe and tire emissions as well as quartz and calcite eroded from the pavement.

The City of Philadelphia was also the subject of a report by Record and Bradway.[6] This study entailed two features. One involved field experiments to measure the influence of specific sources through the deployment of hi-vols and other sampling equipment. The second involved the use of diffusion modeling techniques. A test was also conducted to measure the effectiveness of street washing in reducing ambient particulate levels. Some of the results presented include chemical analysis and particle size analysis at various distances from streets.

A limited hi-vol sampling study was performed in the Duwamish Basin of Washington.[7] Filter analyses were conducted with the following transportation elements identified: road dust, tire rubber, exhaust, soot, and fly ash. The latter two elements become part of the surface loading through atmospheric fallout.

A report by GCA[8] describes a particulate study in Idaho in which sampling was performed with hi-vols and impactors in order to identify emission sources. The effect on ambient air quality of the application of water by street sprinklers and the hosing down of construction areas was also tested. No definite conclusions regarding urban road dust were offered, but some general recommendations for dust suppression were suggested.

Harrison[9] discusses an investigation of hi-vol data in Chicago. Some general observations of ambient TSP levels were made, but no specific analysis of road dust was performed.

Air quality modeling of particulates and SO_2 was the subject of two PEDCo reports.[10,11] Both studies were essentially identical. They were performed by the same company for the State of Florida, with only the area under analysis changed. Previously published emission factors for vehicle exhaust and reentrained dust from paved roads were used in the model for area source contributions. Results were of a very general nature.

The use of a "diffusion wind atmospheric dispersion model" for particulates was the subject of a report by Shannon.[12] This study, conducted in Tulsa, concluded that the results for suspended particulates were not very accurate and this was possibly due to the exclusion of resuspension from the emission inventories.

AREA SOURCE INVENTORIES

Two reports prepared by EPA fall into the category of road dust impact on the surrounding air environment.[13,14] Both studies used previously published values for emission factors to calculate dust emissions from paved roads and vehicle exhaust based on vehicle miles traveled. These road dust emissions were then incorporated into area source inventories encompassing many fugitive sources. Urban road dust was not directly addressed.

FIELD AND LAB TESTS OF ROAD DUST COMPONENTS

A large number of studies have been conducted which have the intent of either determining the contribution to road dust from one or more types of deposition processes or the impact on the environment from removal processes.[15-35] These include both field studies and laboratory tests. Many of these deal with the physical and chemical nature of the road dust.

Two reports describe field studies that examined several road dust elements.[15,16] The MRI report[15] summarizes the development of emission factors for fugitive dust entrainment from paved roads. Test results included particle size distributions, concentrations, vertical distributions, horizontal distributions as a function of wind speed, and surface loading intensities. Emission factors were determined for specified particle size ranges and various land-use categories. The study described by Cahill and Feeney[16] determined the physical and chemical nature of road dust near a concrete roadway with steady, high speed traffic. Different roadway shapes were examined (cut, at-grade and fill sections) with the major emphasis placed on lead levels in the surrounding environment.

Sehmel[17] described a study of particle resuspension by vehicles using a tracer element placed on the road dust. Effects of vehicle and wind speed were noted along with vehicle size.

A report by the Texas State Department of Health[18] presents information on the variation of TSP concentration with height above the ground. While no specific data were presented as to road proximity, the results should be applicable to vertical distributions of suspended roadway dust.

The subject of tire wear contributions to urban road dust has been discussed in many reports.[19-24] The various aspects of tire wear studied include tread depth measurements to determine wear as a function of season, tire type, tire position, and car age; lab and field tests to determine the size and chemical nature of tire wear products; field tests to determine the effect of rubber compounding, tire construction, road surface nature, and vehicle speed on tire wear; and the development of a testing method to identify tire rubber in roadway dust.

Shuler and Hegman[25] and Dahir and Meyer[26] describe field and lab experiments, respectively, aimed at determining the abrasive nature of road dust (pavement "polishing"). The physical properties of collected dust samples were examined through various microscopic methods.

Jacko and DuCharme[27] present a fairly comprehensive analysis of brake and clutch emissions with emphasis on asbestos. Total asbestos emissions and the percent that drops out, is airborne, or is retained, are given for various vehicle sizes.

The contribution of vehicle exhaust to road dust and the environment, with particular emphasis on the lead component, is discussed in several reports.[28-33] The studies include: lab tests of the exhaust of various cars to determine lead, carbon, and suspended particulate sizes and concentrations; field tests of lead levels in the air, water, soils, plants, and animals of an ecosystem; a comprehensive analysis of lead in the environment; EPA's analysis of the health effects of lead; a discussion of an analytical method used to determine the lead concentrations in street dust obtained from field samples; and a comprehensive analysis of lead concentration near streets as a function of vertical distance and total suspended particulates.

A report by Spring, Howell and Shirley[34] presents the results of a dustfall study conducted to determine the concentration of six constituents in atmospheric fallout. Samples were taken at various distances and directions from a highway.

An American Public Works Association report[35] describes a field study which analyzed litter composition in relation to land-use categories. Samples were categorized as paper, glass, metal, plastics, rock and inorganic, organic including food, vegetation, wood, cloth, and dust and dirt.

CONTROL MEASURE ANALYSES

Another large group of studies center around the control and/or reduction of urban road dust.[36-56] Various current control methods are examined as to their costs and effectiveness and new methods are proposed and evaluated. Some reports cover field tests while others merely summarize previously published information.

Three reports discuss some general guidelines for controlling fugitive emissions.[36-38] Among the methods suggested for urban road dust are increased sweeping and flushing of streets, restriction of parking and traffic to dust free surfaces, paving or oiling of unpaved roads and lots to reduce carryout, reduction of vehicle speed and volume on unpaved areas, addition of curbs and sidewalks to unpaved road shoulders, and providing soil cover (vegetation, aggregate materials, chemical stabilization) to adjacent areas.

The costs and effectiveness of street sweepers are discussed in five reports.[39-43] Horton[39] uses information obtained from other literature to compare the efficiencies of mechanical, regenerative, and vacuum sweepers. Sartor, Boyd and Van Horn[40] describe a field study conducted to determine street sweeper effectiveness. Various factors were defined which affect street sweeping performance: land use, cleaning frequency, particle size, loading uniformity, surface type and condition, and sweeper type and operation. In another report by Horton,[41] a comparison of the effectiveness of a mechanical sweeper and a regenerative air-type sweeper is made. This was done via a field test using synthetic debris. Levis[42] discusses the broom sweeper program in Manhattan, New York, with emphasis on parked car effects. The purpose of the project described by Pitt[43] was to determine the range in capabilities of current street cleaning equipment. The study was conducted in San Jose, California, and it examined specific concentrations of various pollutants in different particle size ranges.

Sultan[44] reports preliminary results of the testing of 46 commercially available dust stabilization chemicals. While not directed specifically at urban road dust, the results could easily be made applicable.

The subject of snow and ice control is covered in many reports.[45-56] Murray and Eigerman[45] present the findings of a search for new technology for pavement snow and ice control. Among the alternatives considered were chemical deicers, pavement heating, new snow removal methods, and a hydrophobic substance to reduce water and ice adhesion. The development of such a hydrophobic substance is the subject of a report by Ahlborn and Poehlmann.[46] As a result of the program, two coating formulations were identified as showing promise although there were drawbacks of short wear life and flammable vapors. Brant[47] discusses sanding practices and possible methods of air pollution reduction such as applying less sand, applying coarser sand, applying quartzitic or granitic sand, and immediate street cleanup after winter storms. References 48-55 thoroughly discuss the subject of deicing salts. Specific topics include the benefits and costs of using deicing salts and their effects on water quality, fish, wildlife, vegetation, soils, trees, vehicles, highway structures, and pavements. Reference 56 presents the snow and ice control policy of the State of Connecticut.

ANALYSIS TECHNIQUES

Two of the reports studied present analysis techniques useful in determining road dust impact on ambient TSP levels.[57,58] The analyses utilize area source inventories in conjunction with emission factors to determine relative impact. Empirical linear regression equations are used.

WATER POLLUTION ASPECTS

While many of the references may mention the water pollution aspect of road dust, several reports deal exclusively with this subject.[59-62] Reference 59 discusses several non-point sources of water pollution from urban-suburban areas. Many of these sources relate to road dust. Wanielista[60] describes road dust effects, but the material was obtained from other references. Sylvester and DeWalle[61] describe a field study on runoff and particulate emissions from a highway bridge. Reference 62 contains several papers dealing with water runoff from roadways.

MISCELLANEOUS

There are a number of reports that deal obliquely with some aspect of urban road dust.[63-68] While road dust is not directly discussed, the information contained in these reports could be applicable to the subject.

References 63 and 64 deal with meteorology. Information is given on diffusion and transport and on wind erosion forces as applied to soil loss. These topics are useful in analyzing road dust impact on the air environment and in determining erosion of soil onto street surfaces.

Sklarew, Turner and Zimmerman[65] describe the modeling of carbon monoxide emissions. Similar techniques could possibly be applied to particulate emissions.

The air quality impacts of transit improvement, preferential lane, and carpool/vanpool programs are described by Direnzu and Rubin.[66,67] These deal with vehicle volume which is directly related to road dust emissions. A report by Cabagnaro[68] is similar and describes planning and management studies for the abatement of air pollution from automobiles.

ADDITIONAL REPORT SUMMARIES

The last reference is a bibliography prepared by PEDCo in 1976 for the U.S. EPA containing numerous summaries of reports dealing with road dust.[69] Many of these summaries are for the same reports reviewed by TRC. A few of them cover reports that TRC did not obtain, but cover the same subject material and thus do not add any new information.

SECTION 4

SUBJECTS NOT COVERED IN THE LITERATURE

A comparison of the material presented in Section 3 with the listing of subject areas presented in Table 1 reveals those subjects that have not been given adequate coverage in the literature. These subjects are summarized in this section. The relative importance of these informational gaps is discussed in Section 5.

Of the five generic areas presented in Table 1, three have been reasonably well discussed and studied in the literature. These are the methods of deposition, the physical and chemical nature of the road dust, and the impact of the road dust. There are only a few specific topics that do not appear among the references reviewed. Under methods of deposition, truck cargo spills and the corrosion and abrasion of panels and undercoatings were not analyzed. No information was found on the use of wind tunnels in modeling road dust emissions. All other areas were addressed.

The variables affecting road dust loadings, one of the other two generic categories presented in Section 2, were essentially ignored in the literature. Mention is frequently made as to the quantitative aspects of these variables, but very little actual data is available. In particular, information on the effects of vehicle mix, volume, and speed was not found. Pavement and roadway configuration and its effect on surface loadings and reentrainment is an area almost completely ignored. Not only are hard data unavailable, but discussion on the possibility of its importance is lacking as well. Pavement composition is another topic only briefly mentioned in the literature.

Many of the subjects pertaining to removal/control methods, the fifth generic category, were thoroughly discussed, but several topics were not covered at all. Mention is made of control methods for carryout sites, unpaved areas, and truck spills, but little hard data are available. The effectiveness of washing sand to remove fines was not studied. Although removal methods are fairly well covered, with some actual field data, the studies have been limited to existing methods of control. Information on the development of new types of street cleaners is lacking.

SECTION 5

DISCUSSION AND RECOMMENDATIONS

The aim of this study is to define the informational gaps in urban road dust research, evaluate these gaps as to their relative importance, and outline the approaches to be taken to obtain information in those areas that would potentially have the most beneficial impact on air quality. The informational gaps were pointed out in Section 4. The evaluation of these gaps, their relative priorities, and the approaches to obtain the desired information are the subjects of this Section. The emphasis of this research is on the impact of road dust on air quality (the contribution to urban TSP levels), rather than the toxic nature of road dust, since this seems to be the more prevelant concern of various cities, states, and Federal government agencies at this time.

EVALUATION OF INFORMATIONAL GAPS IN RESEARCH

After reviewing the pertinent literature on the subject of urban road dust, it is apparent that the basic analysis of the problem itself has been thorough. The methods by which material is deposited on the streets and the rates at which this deposition occurs have been reasonably well defined. Table 2 presents deposition rates for various processes. It is recognized that these rates can vary considerably but it is felt that the relative magnitude of the process rates, in relation to the others, is representative. The few informational gaps in research on deposition, notably truck cargo spills and undercoating abrasion, would seem of low priority since they contribute very little to surface loading according to this table. The chemical and physical nature of road dust has been well studied and documented. Results for the various constituents such as lead, salt, and rubber, and for various size ranges are available for a number of land-use categories and highway types. Finally, the impact of the road dust on the surrounding environment is well recognized. The effect of various road dust constituents on nearby land, water, and vegetation and the contribution to ambient TSP levels is basically understood and quantified.

On the other hand, the variables affecting road dust loadings and removal/control methods have not been given adequate coverage in the literature. These areas are discussed in the following subsections.

TABLE 2. DEPOSITION PROCESSES

Source	Constituents	Typical deposition rate, kg/curb-km/day	Range, kg/curb-km/day
1. Mud and dirt carryout	Soil from construction sites, unpaved parking areas, etc.	28.2	Extreme
2. Litter	Cans, bottles, broken glass, cigarette butts, plastic, other debris	11.3	Extreme
3. Biological debris	Leaves, grass clippings, sticks, animal droppings, insect parts, etc.	5.6	Extreme
4. Ice control compounds	Sand, salt, cinders, calcium chloride	5.6	0-16.9
5. Dustfall	Atmospheric fallout	2.8	0.6-7.0
6. Pavement wear and decomposition	Asphalt, cement, aggregate, expansion joint compounds and fillers	2.8	1.4-42.3
7. Vehicle-related			
-Tire wear	Rubber	2.8	1.7-14.1
-Brake and engine component wear	Metals, lubricants, brake and clutch linings	1.4	0.6-7.0
-Settleable exhaust	Combustion products, fuel additives	0.6	0.3-2.8

TABLE 2. (CONTINUED)

8. Spills	Sand, dirt, chemicals	No data: est<0.6	
9. Erosion (runoff and blowing) from adjacent areas	Soil	5.6	Extreme
Total		67.6	

Source: Axetell and Zell[1]

Variables Affecting Surface Loadings

Although the basic concepts of the mechanisms and rates of deposition of materials on street surfaces and the chemical and physical makeup have been well documented, the variables affecting the loadings, which could be of considerable importance for future air quality improvement, have not received much attention. As discussed previously, these variables are meteorology, vehicles, pavement and roadway configuration, and pavement composition. The suggested priorities for studying the parameters under these variables are as follows:

1. Pavement and Roadway Configuration -

   Several studies have touched on the possible effects of pavement and roadway configuration, but studies specifically aimed at defining these effects have not been made. Some of the results briefly mentioned in these studies are: curbing reduces reentrained dust by a factor of four, curbing height is significant, sidewalks and vegetation reduce soil erosion, and roadways with surrounding embankments have less impact on the immediate area than elevated roadways.

   Sartor and Boyd[2] determined the distribution of surface material across a typical street. Their results are presented in Table 3. Since the majority of the surface loading material accumulates within 0.15 meters of the curb, a redesigned curb and gutter could potentially facilitate surface material collection and subsequent removal by flushing and/or vacuuming.

   Other aspects of pavement and roadway shape, such as the effects of medians, guard rails versus barriers, shoulder stabilization, grooves, and crown and bank slopes, should be studied since they show a potential for reduced or redistributed surface loadings. The impact of nearby buildings should also be examined.

   Should any of those variables be found to have a significant effect on surface loadings, their incorporation to existing roadways could be relatively straightforward, as in the case of curbing size and shape. New roadway construction could easily be modified accordingly.

TABLE 3. DISTRIBUTION OF SURFACE MATERIAL ACROSS A TYPICAL STREET.*

Street location, distance from curb	Normal weight of material, % of total
0-0.15 m	78
0.15-0.30 m	10
0.30-1.02 m	9
1.02 m - 2.44 m	1
2.44 m to center line	2

Source: Sartor and Boyd[2]

*The numbers presented in this table represent the average results of tests conducted on urban streets in several different cities.

2. Pavement Composition -

One study found a large difference between surface loadings on asphalt and those on concrete roadways.[2] Whether this relates to pavement erosion or cleaning or both is not known and should be examined. Should one material prove to be more effective in reducing air pollution, this information could easily be applied to resurfacing and new roadway construction.

3. Vehicles -

Many of the effects of vehicles, such as volume, speed, and size, are already well recognized. Other effects, such as mix and speed variations, could be relatively easy to assess. Additional research should be performed in these areas. Another possible research area is the distribution of vehicles on a highway. As pointed out in Table 3, most of the surface loading is near the curb. Reduced reentrainment may occur if the use of lanes with curbs is somehow restricted. Engine temperature, while perhaps important, would be difficult to control and thus its study should be low priority.

4. Meteorology -

Rain, snow, fog and dew, wind speed, mixing depth, and atmospheric stability can affect surface loadings and the amount of reentrainment to varying degrees. Even though the magnitudes of these effects may not be defined, such definition would seem of low priority since humans have essentially no control over such phenomena.

Control of Sources

Perhaps of greater importance than the study of the variability of surface loadings is the study of removal/control methods. Many of the concepts discussed above will merely serve to prevent the already present road dust from becoming reentrained. The material must still be effectively removed from the street surface or, better still, prevented from being deposited in the first place.

To evaluate the priorities for the prevention of material deposition, Table 2 can again be utilized. According to the information presented in the table, mud and dirt carryout accounts for about forty percent of the material deposited on roadways. There are many suggested and tested methods for the control of dust and dirt from construction sites and unpaved areas, such as wheel washes, oiling, paving, immediate cleanup of tracked-out material, chemical stabilization, wetting or covering of loaded trucks, and tire scrapers. These methods should be examined in further detail and other potentially acceptable measures should be evaluated.

The contributions to road dust from litter and biological debris are also significant. However, aside from public awareness programs and littering fines, little can be done in this area to prevent deposition.

Erosion of material from adjacent areas is important, but further study of this does not seem valuable. Control methods, such as sidewalks, vegetation and chemical stabilization, are already known and all that is required is their implementation.

Another deposition source of similar magnitude to erosion and biological debris is the application of ice control compounds, mainly sand and salt. This is an area where further research is needed. The effect of sand washing has not really been evaluated and could be significant. Improved plowing methods, the use of a hydrophobic substance, and other similar methods of reducing sand and salt use have been studied, but further analysis is warranted.

The contributions to surface loadings from motor vehicles seem to be of minor importance compared with some of the other deposition processes. Since the contributions from vehicles have been fairly thoroughly studied, further study would not seem productive at this timé.

The other two processes of minor importance are dustfall and pavement wear. Nothing much can be done to prevent dustfall and so no study is necessary. Pavement wear should be studied to some extent, at least with respect to asphalt versus concrete, but this should have a relatively low priority.

Removal Methods

The third area in which further research is needed is road dust removal methods. Once the material is on the street, it must be removed efficiently. The removal processes, discussed previously, are reentrainment, wind erosion, displacement, rainfall runoff, and street cleaning methods. Table 4 presents some typical removal rates for these processes.

Two of these processes, reentrainment and displacement, are directly related to vehicular movement. These have been fairly well studied already and information obtained from the studies of the variables affecting surface loadings will provide helpful knowledge in these areas. One additional study area should be the reduction of vehicle-induced turbulence.

TABLE 4. URBAN ROAD DUST REMOVAL PROCESSES

Process	Typical rate of removal from street surfaces, kg/curb-km/day	Assumptions incorporated
Reentrainment	28.2	For 10,000 ADT; net removal rate = 4.5 g/VMT*
Displacement	11.3	Estimated from dustfall rate just beyond curb
Wind erosion	5.6	Force of same magnitude as reentrainment, but only operative 20% of time
Rainfall runoff	14.1	Removal efficiencies of 50% for rain of 0.25-1.27 cm and 90% for rain of >1.27 cm
Sweeping	9.9	Average efficiency of removal = 50%; weekly cleaning

*ADT: Average Daily Traffic, VMT: Vehicle Miles Traveled

Source: Axetell and Zell[1]

Wind erosion and rainfall runoff are natural processes. These are well understood and not easily controllable and further study is not warranted.

The final process, street cleaning, is one on which a great deal of work has been performed. Dozens of studies have been conducted which evaluate street cleaning programs and sweeper effectiveness. However, these studies have almost exclusively centered on existing street cleaning methods and practices and the results have primarily shown that such existing practices are relatively ineffective. Research should first be carried out to see whether the current methods can be made effective either through a revised cleaning cycle (e.g., daily and/or immediately after sanding and salting) or through improvements to existing equipment. Research should then center on developing new street cleaning methods with much greater removal efficiencies.

An additional high priority item which would fall into this category would be the development of an effective street dust loading measurement procedure. A method should also be developed that could link street loadings to the resuspension rate.

SUGGESTED PRIORITIES

The research needs described above can be summarized by separating them into high, medium, and low priority categories. The high priority items are those that either have the potential of providing fairly immediate air quality improvement or are necessary prior to the further research studies. The medium priority items are those that are felt to have potential, but require time to develop and implement. Some of these also depend on the results of the high priority research. The low priority items are those that have not been fully researched to date, but whose impact is assumed to be relatively minor. Table 5 presents the priority categorization.

It is recommended that future areas of investigation regarding the problem of urban road dust be conducted according to this prioritization. This will help to produce the desired information in the most effective manner. Suggested approaches for obtaining the information are presented in the next subsection.

RESEARCH APPROACH

The approaches to the high priority research studies are outlined in the following subsections. Development of approaches for the medium and low priority items are not warranted at this time.

TABLE 5. RESEARCH PRIORITIES

High Priority:

- Determination of the effects of more frequent street cleaning and cleanup immediately after application of sand and salt utilizing existing technology
- Analysis of control methods for mud and dirt carryout sites and truck spills
- Improvement of existing street cleaning equipment
- Development of a standard procedure for determining street loadings
- Development of a method to link street loading to resuspension rate
- Study of ways to reduce the amount of sand and salt applied to street surfaces including sand washing, plowing improvement, and development of hydrophobic substances
- Study of curbing effects: size, shape and relationship with gutter design, need to pave or stabilize shoulders

Medium Priority:

- Development of new methods of street cleaning
- Further study of the effects of vehicle speed, size, mix, speed variations and volume
- Study of asphalt versus concrete surface loadings
- Study of crown and bank slope effects
- Study of redesigned road surfaces such as grooves or grids
- Study of the effects of sidewalks and vegetation
- Study of reducing vehicle-induced turbulence
- Study of meteorological effects

TABLE 5 (CONTINUED)

Low Priority:

- Determination of the effects of vehicle distribution on roadways
- Study of median effects, guard rails versus barriers
- Study of cut, at-grade, and fill section roadways
- Study of building effects along roadways
- Study of vehicle engine temperature effects

Procedure for Determining Street Loadings

Various measurement techniques exist to determine ambient TSP concentrations, particle sizes, and chemical makeup. However, an effective street dust loading measurement procedure is lacking. Therefore, the first step of any research effort should be the development of such a measurement technique that is accurate, representative of a significant length of street, repeatable, and that can be performed by a technician-level personnel. With such a technique available, the effectiveness of the various research studies can be better determined and results can be compared. Perhaps the best initial approach to this would be to examine the methods used by previous studies and compare their benefits and shortcomings.

Daily Street Cleaning and After Winter Storm Cleanup

This type of study was also recommended by Axetell and Zell[1] and their approach is viable. They propose several design considerations which should be incorporated in any such study:

- At least one control site with a similar exposure should be located near but outside the cleaning area.
- Particulate samples should be taken daily and possibly for even shorter intervals.
- Traffic counts should be taken for periods concurrent with the particulate samples.
- Wind speed and direction measurements should be made in the study area.
- Rainfall records should be kept, including the duration and quantity of rainfall.
- Detailed records of the street cleaning operations should be kept--time, weight of material removed, any problems with cleaning equipment.
- Seasonal changes in the amount and type of material on streets should be accounted for in scheduling alternative cleaning methods.

Various street cleaning methods should be tried; in particular, flushing and vacuuming. The after storm cleanup should occur as soon as the snow and ice melt for each storm during the seasonal period. Results can then be compared to a control area nearby where cleanup is performed only in the spring.

Control for Mud and Dirt Carryout Sites

Again, this type of study was proposed by Axetell and Zell.[1] Their approach is a good one:

> "Liaison and cooperative field work with construction industry trade associations on reasonable methods to minimize mud carryout from construction sites. There would be no need for ambient air sampling in such a study; a good method for measuring the amount of material tracked from the sites would provide a better measurement of effectiveness."

In addition, a research study should be conducted to determine if any new methods of control for these types of sources are possible. One possibility is the use of charged fog.

Improvement of Street Cleaning Equipment

Manufacturers of street cleaning equipment should be contacted to engage their help in developing and testing mechanical or operational modifications that would improve cleaning effectiveness. An engineering study could be performed to advise on such modifications.

Sand and Salt Reduction

Some work has been done already in the area of plowing improvement and the development of a hydrophobic substance.[45,46] Further development work can carry on from the results of this research. The effect of washing sand to remove fines can probably be determined through a cooperative field test program with a local municipality. Two comparable test areas could then be used - one using washed sand all winter and one using the usual material.

Curbing Effects

Curbing effects can be studied in several ways. One method would be to locate a section of roadway that incorporates sections with curbs and sections without curbs passing through a single type of land-use category. Surface loading measurements could then be compared. Another method would be to locate a long stretch of curbed roadway and change the curbing height and shape along different sections of it. A third research approach could utilize a wind tunnel to analyze the effect on reentrainment of various curb/gutter configurations.

Method to Link Street Loading to Resuspension Rate

Perhaps the best approach for the development of such a method would be to continue the work of Axetell and Zell.[1] They postulated that the street loading reaches an equilibrium level, at which the deposition and continuous removal processes are about the same, within a basicly short period of time - three to five days after a rain or street cleaning. They developed an emperical equation and tried to determine the values of the constants, but soon dropped the effort due to the large number of secondary variables which affect the deposition and removal rates. Further efforts can concentrate on quantifying some of these secondary variables.

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16. ABSTRACT The report gives results of an assessment of methods to control fugitive emissions from paved roads. In many U.S. metropolitan areas, failure to attain national primary air quality standards for total suspended particulates (TSP) has fostered a detailed reexamination of the nature of the urban TSP problem. Reentrained dust from paved streets and other traffic-related emissions are now recognized as major sources of TSP in urban areas. Although many studies have examined this subject, some significant aspects of urban road dust have not been studied in enough detail, if at all. Examples of this are the effects of gutters and pavement composition and shape. This report discusses urban road dust problems that are felt to require further attention and outlines the priorities with which the data should be obtained. The approaches to be taken to obtain the desired information are also defined.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Pollution	Aerosols	Pollution Control	13B	07D
Pavements	Drains	Stationary Sources		13M
Roads		Paved Roads		
Processing		Fugitive Emissions	13H	
Leakage		Particulate	14B	
Dust			11G	

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