

The Federal Highway Administration's Particulate Matter Research Program

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Abstract

Federal Highway Administration (FHWA) has developed its research needs for understanding particulate matter (PM) emissions resulting from vehicle traffic on transportation facilities. Particulate Matter is a pollutant that impacts transportation project development and highway usage due to air quality regulations that have been implemented to protect human health. Laws and regulations such as the Clean Air Act and the transportation conformity rule as well as other initiatives covered by the National Environmental Policy Act are highlighting the need for a better understanding of PM and its association with the transportation sector.

In an effort to broaden the understanding of mobile PM emissions, the FHWA established an integrated research program to fill “gaps” in the current understanding of mobile source induced PM pollution, including both PM₁₀ and PM_{2.5}, the two size fractions currently being regulated. An expert panel was established and charged with developing the direction of FHWA's research. The panel included representatives from Federal agencies, State DOTs and air quality agencies, universities, research centers and consulting organizations. The result of their efforts was a work plan outlining the general areas and specific topics likely to impact the highway community.

The research work plan included five topic areas believed to affect transportation agencies and Metropolitan Planning Organizations (MPOs) in their transportation and air quality planning process. These topics included monitoring, characterization, sources, analysis methods, and control strategies with a suggested list of 14 separate projects for accomplishing the work in these five areas. The first priority was to collect both traffic and PM emission data concurrently and coincidentally, which would enable the correlation between vehicle activity and emission concentrations. This information would form the basis for research in the other topic areas.

A study was initiated in the summer of 2001 using traffic data collected by transportation departments and PM emission data collected at EPA Supersites and other EPA monitors. This research effort will continue for a two-year period and collect data from 7 cities across the United States representing different geographical regions. Source apportionment will be performed to estimate highway vehicles' contribution to ambient PM_{2.5} in each urban area. The study will also investigate the contribution from regionally transported vehicle emissions and the fugitive dust component generated locally by vehicle traffic.

Introduction

Air quality has been a problem associated with highway vehicles for the last three decades. Attempts to control the emission from vehicles have taken many forms but are often implemented through air quality laws and regulations, which address vehicles, fuels or the transportation facilities on which the vehicles travel. Most notably, the Clean Air Act and its subsequent amendments have increasingly restricted the emissions from vehicles. The law has addressed the emission standards by which the engines must attain to be “certified” and saleable inside the United States. The law has addressed the fuels that are used in the vehicles such as the sulfur content of gasoline and diesel. It has also addressed the process of expanding highway networks, frequently resulting in programs that limit motor vehicle use.

The law has had an effect. Emissions from vehicles are down substantially since the 1970s. Carbon monoxide (CO), predominantly a pollutant from the combustion process and from vehicle engines, is almost no longer a problem. Lead (Pb), an additive to gasoline to enhance performance, is no longer a problem. Ozone (O₃), the gas most commonly associated with smog remains a problem however its presence has decreased. Particulate matter (PM₁₀ and PM_{2.5}) is still a problem as are oxides of nitrogen (identified as NO_x compounds). These last two pollutants, PM and NO_x, have also been reduced but the complexities of atmospheric chemistry causes them to remain a problem since PM and NO_x are precursors for ozone.

Further complicating emission reductions is the science itself of emissions and atmospheric chemistry. Strategies developed to reduce either the PM precursors or NO_x can lead to an increase in the other pollutant not being reduced and ultimately to ozone increases. Particulate matter is very similar to ozone since it can be formed from “precursor” compounds in the atmosphere such as sulfur and nitrogen compounds which make controlling the sources a challenge. PM also can be a “regional” problem, not just restricted to the locality in which it was emitted.

Recently, another group of pollutants present in the atmosphere have impacted mobile sources and have other atmospheric processes. The new pollutants are referred to as air toxics and consist of 188 compounds identified by EPA as likely hazards to human health. Although most of them are not associated with mobile sources, twenty-one are associated with motor vehicles and controlling them will require new strategies by vehicle manufacturers. Atmospheric processes such as global climate change can be exasperated by vehicle emissions. As engines become more efficient and generate less CO, engines generate more carbon dioxide (CO₂) which is considered a greenhouse gas (GHG) because it accumulates in the atmosphere and is believed by many to cause atmospheric temperatures to rise.

Because of the emergence of particulate matter as a new and potentially very serious problem to the highway community, the Federal Highway Administration (FHWA) has undertaken a research program to try to identify the extent of PM pollution resulting from motor vehicles and to identify methods of reducing emissions and their harmful effects. This paper outlines FHWA’s approach to assessing the highway sector’s contribution to particulate matter emissions including

the current status of the PM Research Study which is collecting and analyzing emission and traffic monitoring data to define the contribution from motor vehicles.

Phase 1 - Identifying the Transportation Component

In June of 1997, EPA promulgated a new particulate matter standard that it considered necessary to address human health problems that the existing standard missed. The existing annual standard, $50 \mu\text{g}/\text{m}^3$ for the PM_{10} standard, remained essentially unchanged since it addressed “coarser” material that the EPA still considered a health problem. The new standard addressed smaller size particles, $\text{PM}_{2.5}$, which could get lodged in the air passages of the lungs. It was believed that this size was equally hazardous to human health as was the PM_{10} size material but its origin was different. The new $\text{PM}_{2.5}$ standard did not “replace” the existing standard but extended the standard to be consistent with the finding of the most recent health studies that EPA and other organizations had been conducting. This new standard was clearly focused on combustion sources, and therefore on motor vehicles. Realizing the implications of this to the transportation community, FHWA began research into understanding the contribution of vehicles to PM emissions. This program began during the 1999 calendar year in an initial (Phase 1) effort to identify the limits of knowledge and to determine the “gaps” that existed; additional research needed to expand the knowledge and fill in the gaps could then be outlined.

This effort was initiated by performing a literature review to determine all relevant research that had been conducted on highway related particulate matter emissions. It included several categories of direct and indirect tailpipe emissions, brake-wear, tire wear, fugitive dust entrained into the atmosphere by vehicle motion, and emissions transported from one region to another. The goal of this effort was to define the knowledge that existed and determine the gaps existing in the knowledge base. This formed the outline for discussions by researchers and practitioners of additional research needs to fill in the gaps.

After completing the literature review, a workshop was conducted to evaluate the information found in the literature review. The workshop convened a panel of researchers, scientists, air quality planners, and policy analysts and organized them into groups to discuss the results of the literature review and studies that were ongoing or planned. Many of the participants had themselves performed research and knew the limits of the current state of knowledge. The goal of the workshop was to focus on the areas needing further research, identify critical “gaps” in knowledge, and categorize specific research projects into several areas that could be used to structure individual research projects. The results of the workshop were further evaluated and compared with the literature review to develop a set of recommendations for further research.

A final “workplan” was completed in November 2000 which outlined recommended research that needed to be performed by the highway community. The “strategic workplan”, as it is known, identifies fourteen projects in five categories that define the highway component of PM pollution. These individual projects and categories were framed within four “policy” questions that drive the needed research. Figure 1 illustrates the projects, categories and questions guiding the research. The “workplan” is intended to serve as the guide for all projects conducted to further the understanding of transportation related PM emissions.

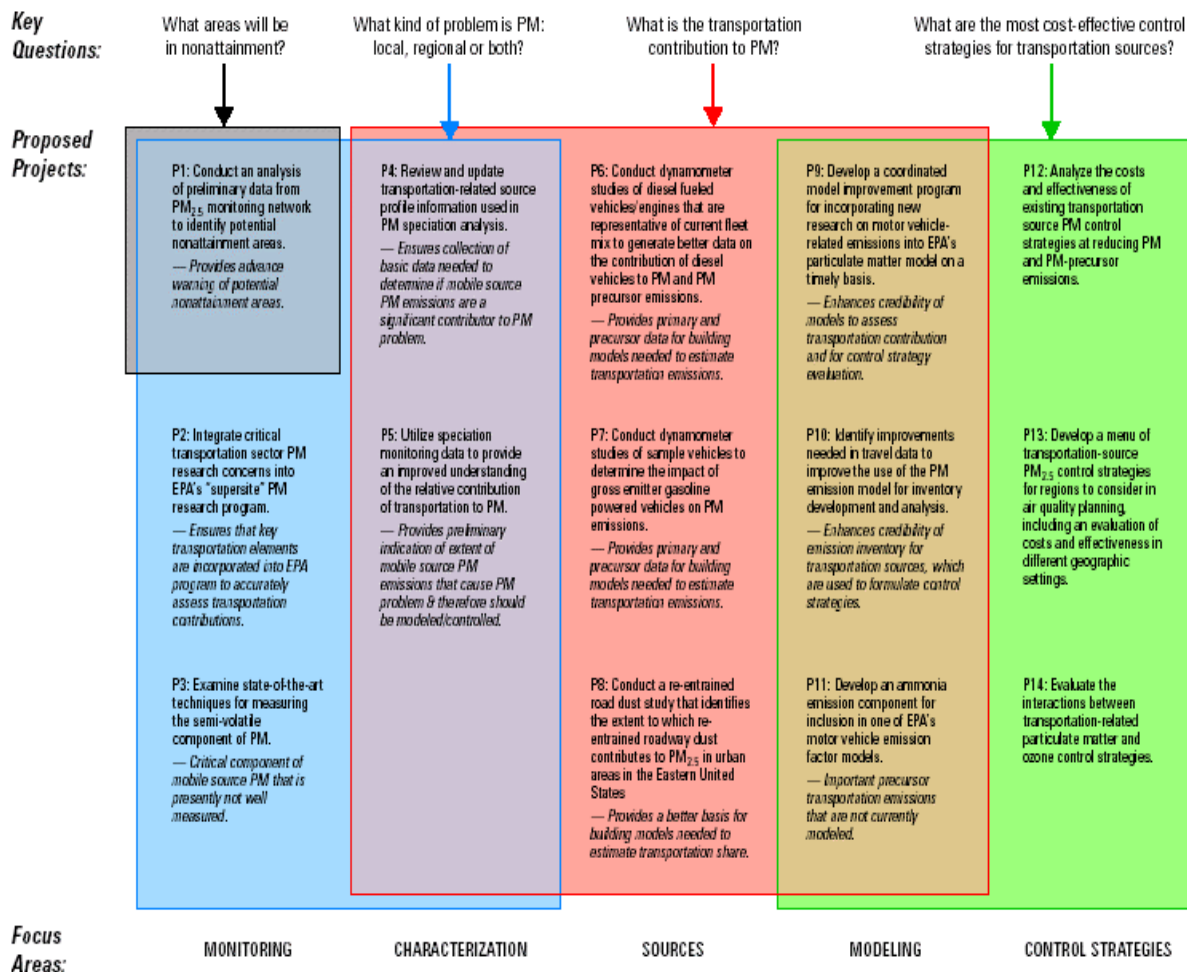


Figure 3. Connection Between Transportation Issues and Research Agenda

Figure 1. FHWA's PM Projects listed in Figure 3 of the "Strategic Workplan".

Also developed as part of this strategic workplan was a schedule for initiating the different projects that is partly driven by the regulatory requirements established by the new PM standard. The establishment of the new standard began a process having many parts. First, a monitoring network to measure PM_{2.5} needed to be established. This would involve deploying over one thousand new monitors over a 2-year period. This first step would also involve developing a sampling protocol for collecting and analyzing the PM_{2.5} samples. The second step would then be to collect and analyze the data for three years so that areas could be designated as being in attainment or nonattainment. While this process is progressing, EPA will be reviewing the standards as required by the Clean Air Act and will reaffirm the standards if that is the finding of their review. This will start the clock for the designations and for transportation officials to decide what strategies they must use to reduce the transportation contribution. This schedule is shown in Figure 2 and serves as the impetus for FHWA's research effort.

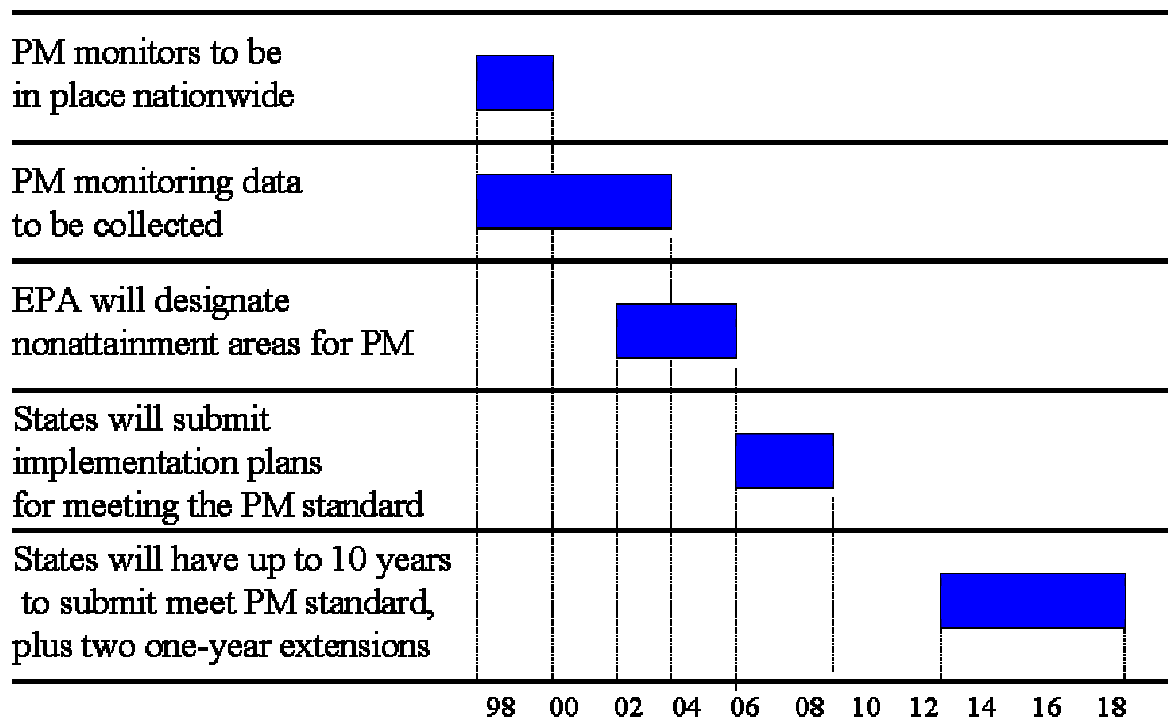


Figure 2. A proposed schedule for implementing PM_{2.5} standard based on required time frames.

The next section discusses the current status of FHWA's research program by describing two data collection projects illustrated in Figure 1. Two of these projects, P1 and P2, are intend to collect the traffic and emission data from EPA Supersites. The Supersites were selected since they were believed to be the most cost-effective, expedient method to obtain the data necessary to determine the contribution from mobile sources. As will be discussed, the data from this effort requires the cooperation of several organizations collecting the traffic and emissions data.

Phase 2 – Establishing the Sampling Sites and the Data Requirements

With the Strategic Workplan completed and serving as a guide, FHWA proceeded to undertake the research outlined. It should be noted that in developing the workplan, consideration was given to the priority and sequence with which the projects should be planned. Some projects had high priorities and needed to be started early while others could be performed at a later date. The schedule provided for some projects to be performed in "parallel" while others clearly had to be performed before others so that their results could be useful to later projects. Not all projects will be undertaken by FHWA. The Workplan is intended to serve as a guide for the highway

community so it is anticipated that other transportation organizations, the EPA, Department of Energy, or other organizations will support some of the listed projects.

One of the major priority projects involved collecting data that could be used to identify the motor vehicle contribution. Projects P1 and P2 in Figure 1 involve collecting traffic data at sites in close proximity to PM instruments. PM instrumentation is extensive in its areal coverage following the establishment of the PM₁₀ standard in 1987. In the years following the 1997 PM_{2.5} standard promulgation, more than 1000 PM_{2.5} instruments have also been deployed. Although there are many PM monitors available to provide PM emission data, traffic data in close proximity to the PM sites is a concern. Other issues of concern included the presence of other pollutant instruments such as CO monitors, meteorological instruments, selecting sampling sites, and establishing collection schedules.

Fortunately, some concerns were allayed due to a specialized EPA monitoring network known as the “Supersites”. The FHWA project required using existing instruments and instrument networks. This could be accomplished since the EPA had plans to establish a “Supersite” monitoring program containing all instruments necessary to evaluate the highway component except traffic monitors. It was decided early that these Supersites would be the logical network for the highway study. An extensive evaluation was then made to determine the location of the sites and their associated “satellite” sites and the traffic monitoring equipment in close proximity. This was accomplished in the fall of 2001 and the sites selected can be seen in Figure 3.

The FHWA effort will not establish additional traffic or emission concentration monitoring instruments for collecting “new” data. It will rely on existing monitoring networks for both traffic and emissions. The emissions data will be collected from the EPA Supersite network as noted earlier. The traffic data will come from several different sources including the State Departments of transportation monitoring networks and local government traffic departments.

One issue being considered is reconciling the traffic count sampling frequency with that of the emission concentration instruments. Sampling frequency is also a problem within traffic counting programs since some counts may be made in 15-minute intervals and others averaged over longer times. Similar problems also exist for the emission samplers. Differences may be reconciled by “averaging” the data over the same period (say 1 hour) while preserving the more detailed data for other interpretations. “Normalizing” this data will be essential in making correlations between emission concentrations and traffic volumes and in making comparisons of these correlations from city to city.

Along with the emissions and the traffic data is the meteorological data. This is an essential component of the data set since air quality is a function of weather. Inversions, wind, temperature, relative humidity, amount of solar radiation reaching the surface and other parameters are all important influences on the formation of particulate matter. Collecting the meteorological data at the same time and averaging the data over consistent time intervals as the traffic and emissions data is important when trying to make correlations between traffic and emissions.

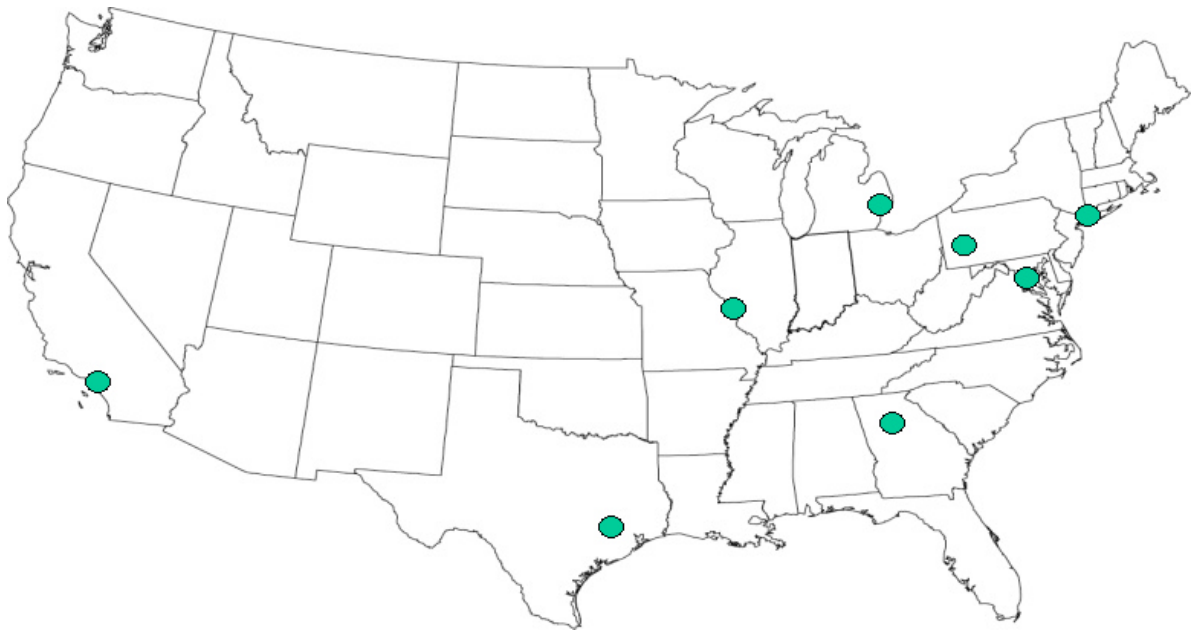


Figure 3. Locations of the FHWA and EPA Monitoring Sites.

Phase 3 – Analyzing the Data and Evaluating the Relationships

Currently, the FHWA PM research project is beginning the data collection and analysis phase. This phase will collect the traffic data and the emissions data necessary in making the correlation between traffic and PM emissions. The EPA Supersites are providing PM₁₀ and PM_{2.5} data as well as meteorological data and other emissions data such as chemical speciation data to help in the identification of the pollutant source. State and local agencies are providing the traffic data. The relationships that will be investigated in the PM Research Study are discussed below using some preliminary data from two sites evaluated during the site selection phase of the project. Results that are to be evaluated include variability from one geographic locality to another, from time of day, from season, from atmospheric transport as well as the contribution from fugitive dust.

There are several sets of data that have been compiled from two sites that will be used to illustrate the type of data we are seeking to use to understand the relationship between highway traffic and the particulate matter emissions. The Figures 4 through 6 illustrates the particulate matter concentrations as they vary throughout the day. The peak concentration times roughly correspond to the times when highway traffic peaks associated with “rush hour” occurs. There was no traffic data collected with this PM emission data and therefore making a correlation with the traffic is speculative. Figures 4 (Winter 1999), 5 (Winter 2000) and 6 (Summer 2000) show somewhat different pattern over a one-year period. The FHWA Program is attempting to

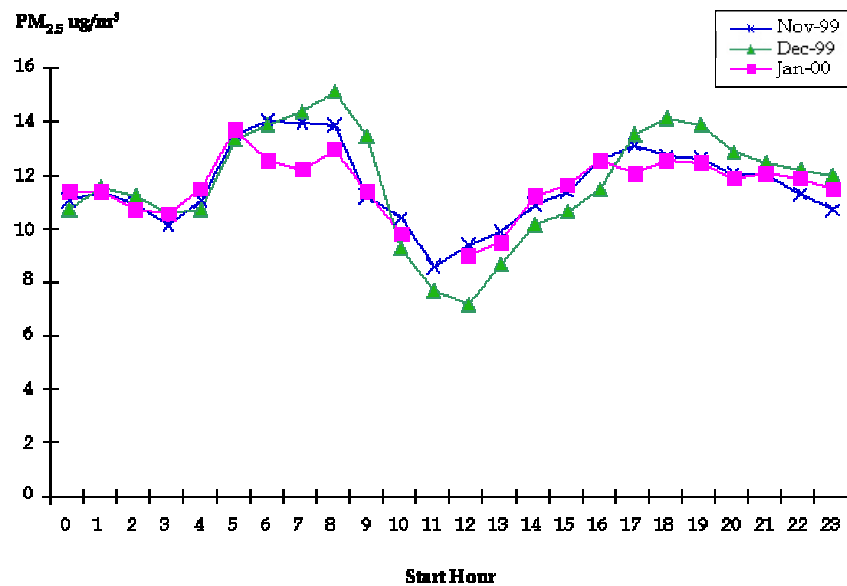


Figure 4. Illustration of emission concentrations versus hour of the day and time of year (Winter 1999).

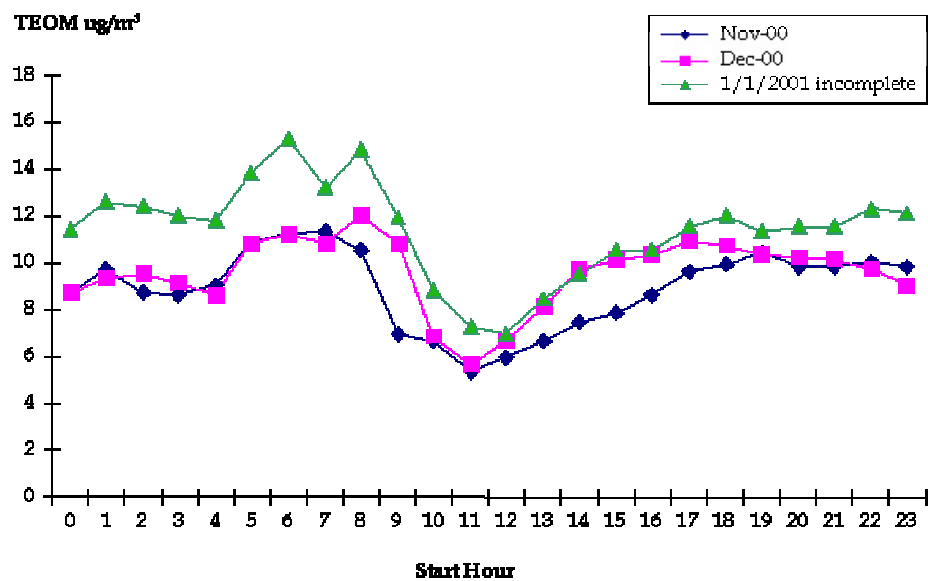


Figure 5. Illustration of emission concentrations versus hour of the day and time of year (Winter 2000).

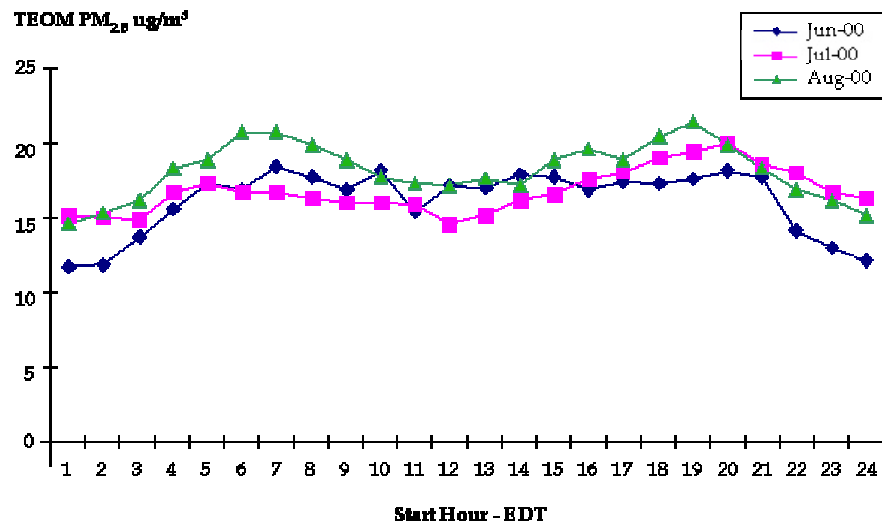


Figure 6. Illustration of emission concentrations versus hour of the day and time of year (Summer 2000).

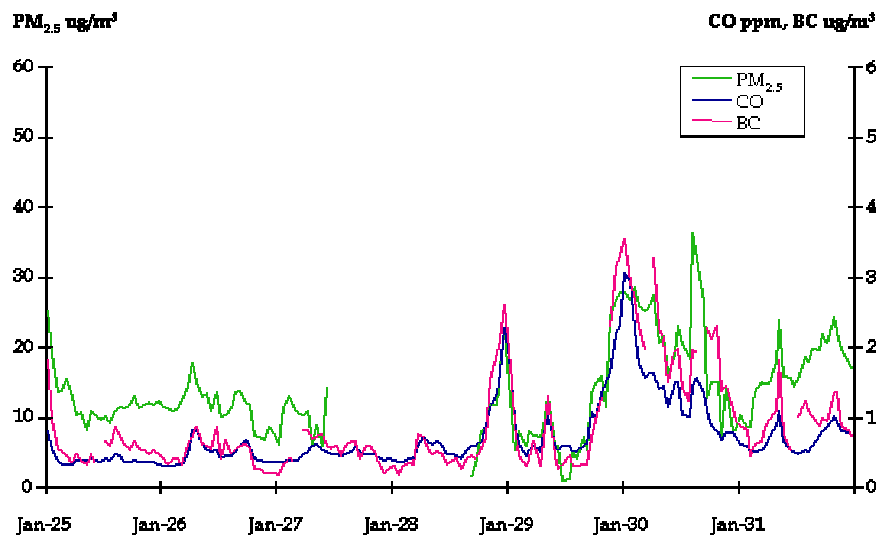


Figure 7. Illustration of using surrogate data to correlate PM emissions concentrations and vehicle emissions.

understand whether these concentration variations relate to traffic changes throughout the year. These figures may also illustrate a “seasonality” nature associated with PM emissions.

Figure 7 illustrates the use of “surrogate” measurements that are being used to provide additional information to assist in the correlation between vehicles and PM emissions. In this figure, CO emissions “track” the PM emissions and may suggest a mobile source component. CO is a gas typically associated with combustion, and specifically, with motor vehicles. Collecting information such as this at the same times as the PM and traffic data are collected can increase the confidence with which the correlations are made. Also illustrated in this figure are “black carbon” emission concentrations that provide information on the various constituents of the PM. Black Carbon is often associated with the emissions from diesel trucks. Its presence can then assist efforts to isolate a diesel truck component to the emissions of particulate matter.

Another data set contains information illustrating both the traffic and emission concentration relationships that FHWA is trying to identify. Figure 8 shows the traffic measurement for both passenger cars and trucks over time. This information is important to assist in determining whether it is possible to discern if trucks or cars are contributing more to particulate matter concentrations. Figures 9 and 10 illustrate the traffic and emission data. These figures suggest that peak truck traffic does not occur at the same times as car traffic and therefore when making interpretations as to whether PM emissions come from trucks or cars, the emissions patterns must also be correlated with the traffic times.

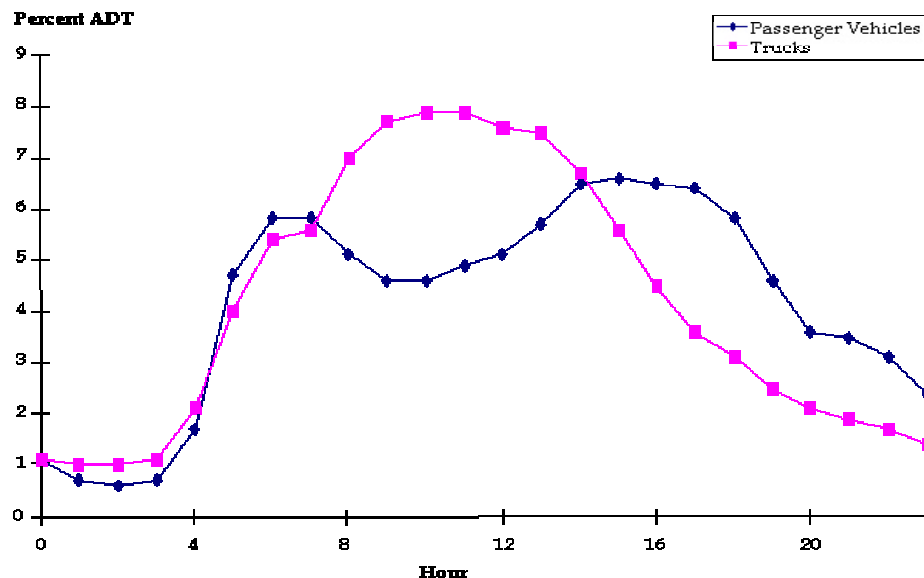


Figure 8. Evaluation of the differences between truck and passenger vehicle traffic.

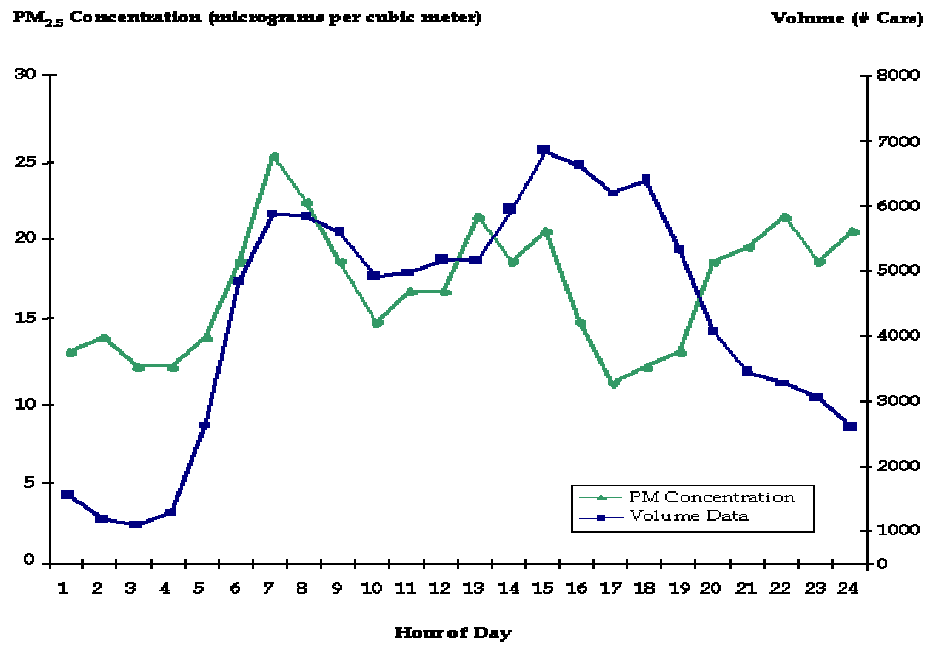


Figure 9. Evaluating vehicle traffic volume and emission concentrations.

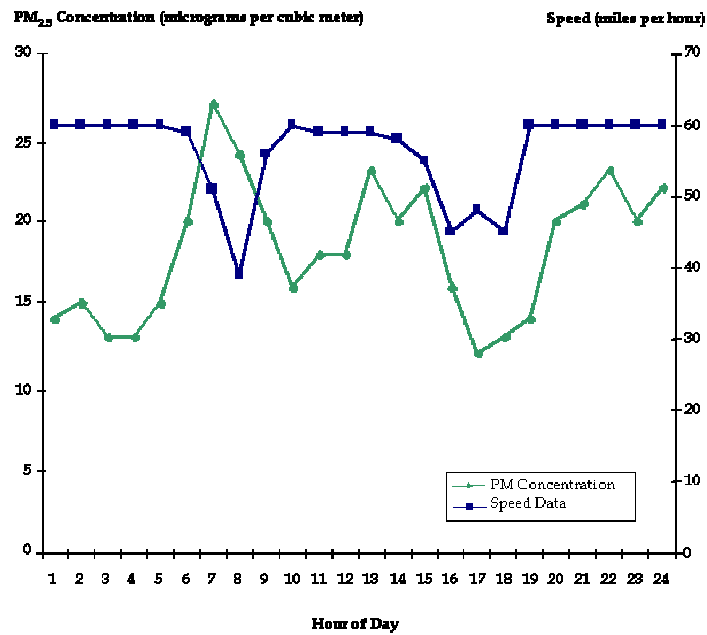


Figure 10. Evaluating vehicle speed and vehicle emission concentrations.

Data will also be investigated to relate the weather, time of year (season), and other phenomena affecting PM concentrations. By examining each of the seven different locations for 2 years, it is believed that the interrelationships between traffic, meteorology, emissions and geographic locations can be explained especially as it relates to PM exceedances.

Conclusions

Particulate matter is a complex pollutant resulting from many sources. Vehicles undoubtedly contribute to the emissions but the degree to which this occurs is not well known. It is important to establish this relationship since strategies to reduce emissions of PM must be properly targeted if the emissions are to be decreased and the air quality improved. The Federal Highway program is trying to establish what the relationship is between mobile sources and PM. The two-year data collection effort should provide us with some of this information.

It must be remembered that particulate matter is comprised on many different compounds and that no clear evidence has been found linking the actual causal agent to health problems. It could be the mass of the particles, the number that impact the lung, the size which may determine if a particle becomes “lodged” or “exhaled”, a particular chemical component causes health problems, whether it is some combination of these or something totally different. The FHWA research is not focused on the health effects since this is better handled by other organizations with this expertise. FHWA’s efforts are focused on determining the highway component. As has been discussed throughout this paper, the FHWA program is concentrating on determining the PM emissions from motor vehicles and what their contribution is to the total PM emission concentrations being recorded at the PM monitoring sites. Some preliminary results have been presented that describe the relationships FHWA is seeking to understand. This project is a multi-year effort established to explain PM variations spatially and temporally and the role motor vehicles play in ambient PM concentrations. It is believed that by extracting information from both traffic and emission concentration monitors collected simultaneously and in close proximity to one another, that the mobile source linkage can be established and quantified.

References

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Divita, Frank; Margiotta, Richard; et al; “Estimating the Transportation Contribution to Particulate Matter Pollution: Phase 1 – Establishing the Data Collection and Analysis Program”, Prepared for Federal Highway Administration by Louis Berger Group, Washington, DC, 2001.