NCHRP
National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

July 1997 Number 217

Subject Area: IB Energy and Environment Responsible Senior Program Officer: B. Ray Derr

Relationships Between Implemented Transportation Control Measures and Measured Pollutant Levels

This is an NCHRP digest of partial findings from Phase I of NCHRP Project 8-33, "Quantifying Air Quality and Other Benefits and Costs of Transportation Control Measures." The objective of the project is to develop an improved analytical framework for evaluating transportation control measures. The objective of the task summarized in this digest was to examine the relationships between implemented transportation control measures and measured air pollutant concentrations. This digest is based on an interim report prepared by Steven D. Reynolds of Envair. John H. Suhrbier of Cambridge Systematics, Inc., is the project's Principal Investigator.

INTRODUCTION

Many transportation agencies are implementing transportation control measures (TCMs) as part of their effort to meet the National Ambient Air Quality Standards (NAAQS). A critical issue, which this digest addresses, is the effectiveness of TCMs in improving the measured air quality. This digest will interest those responsible for air quality conformity analysis, air quality monitoring, and programming projects to improve air quality.

TCMs and other forms of mobile source air quality control strategies are typically evaluated in terms of the magnitude of their emissions reductions, with the location and timing of those emissions changes also occasionally examined. The ultimate objective of implementing TCMs is to improve ambient air quality levels. There is considerable interest, therefore, on the part of state and local transportation officials in knowing the degree to which implemented TCMs and other mobile source control strategies are actually accomplishing this objective.

The purpose of this portion of NCHRP Project 8-33 was to examine the relationships among implemented TCMs on measured air pollutant concentrations, to identify major gaps in knowledge, and to describe topics meriting additional research. An underlying finding of the research is that existing air quality monitoring programs are not designed to evaluate the effectiveness of individual air quality control strategies. The national ambient air quality monitoring network consists of three component parts: State and Local Air Monitoring Stations (SLAMS), National Air Monitoring Stations (NAMS), and Photochemical Air Monitoring Stations (PAMS). The objectives of these monitoring stations include determining peak concentrations, background concentration levels, and population exposure. These networks provide measurements of pollutant levels at the local (e.g., carbon monoxide [CO] hot spot), neighborhood, and regional scales for the purpose of determining whether the ambient air is in compliance with the NAAQS. Such networks are not designed to provide an "optimum" data set for use in assessing the effect of particular emission control measures. Additional specialized monitoring normally is required to evaluate the contribution of a specific air pollution control strategy, together with a carefully executed program of

experimental control designed to isolate the effects of other changes that may be occurring simultaneously.

Experience has shown that even special research studies must confront numerous factors that complicate the collection of a suitable data set that can be analyzed to show a particular finding with the desired degree of statistical confidence. These factors include meteorological effects, unusual traffic conditions, and the impact of other control programs. To date, results from such studies are decidedly mixed. While there are some examples where implementation of mobile source air quality control measures have been shown to result in improved ambient air quality levels, there are many more examples where the results have been statistically inconclusive. Further, the vast majority of these existing air quality evaluation studies are for either fuels or vehicle inspection and maintenance programs. The air quality assessment of implemented TCMs has been largely limited to evaluating their impact on localized carbon monoxide (CO) concentrations.

APPROACH

The transportation impacts associated with TCMs can be measured more easily than changes in either emissions or ambient air quality, including changes in vehicle miles of travel, the number of trips, and the time of day at which travel occurs. However, it is of interest to discern the impact that TCMs and other types of mobile source control measures have on actual monitored air quality levels.

The overall objective of NCHRP Project 8-33 is to develop, test, and document an improved methodological framework for the analysis of air quality transportation control measures. Attention is being given to determining the impacts of TCMs on ambient air quality levels. The full range of potential transportation controls is being considered, including market-based measures and evolving nonregulatory approaches. All potentially important transportation-related pollutants are being considered, including carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_x), ozone, and particulate matter.

As part of NCHRP Project 8-33, various studies were reviewed where attempts had been made to establish relationships among *implemented* transportation control measures, emissions, and *measured* pollutant levels (Reynolds 1996). These studies were carried out with the specific objective of determining the effects of individual mobile source control measures on ambient pollutant concentrations. Two types of analyses were examined in this investigation:

- Analyses of ambient measurements of primary and secondary pollutants collected both before and after implementation of specific measures, and
- Controlled experiments, such as tunnel studies, that measured changes in pollutant levels associated with implementing a particular emissions control measure.

Of particular note was the success, or lack thereof, of such studies in discerning the effects of these emission control programs.

While the analysis of actual monitoring data is the most desirable form of air quality assessment, it is also the most difficult because of the inability to control for all important outside influences. Alternatively, mathematical modeling determines the effects of changing a single variable while simultaneously controlling all other factors. Mathematical modeling may not fully represent real world conditions. Controlled experiments represent a compromise between the limits of the two other approaches, but even these can be conducted under only very limited situations and may not be representative of the full range of actual conditions.

TCMs are the primary focus of the research being conducted under NCHRP Project 8-33. Unfortunately, there is not a large body of literature that directly relates TCM implementation to changes in monitored ambient air quality levels or even to measured emissions.

Attention, however, has been devoted to measuring the air quality impacts associated with the implementation of other forms of mobile source air quality controls, principally changes in fuel composition and vehicle inspection/maintenance (I/M) programs. Because the reduction in areawide emissions of these other types of mobile source controls is generally larger than the reductions associated with TCMs, these controls are a useful indicator of the ability to discern the impacts of specific TCMs on monitored ambient air quality levels for different pollutants. Furthermore, the data collection and analysis methodologies that have been used to evaluate the air quality impacts of these forms of mobile source controls provide valuable insights into how successful similar efforts might be if they are applied to the assessment of TCM impacts on ambient air quality.

Consequently, the results of these studies serve as the basis for the recommendations of this investigation.

IMPORTANT MEASUREMENT ISSUES

Numerous challenges and difficulties arise in attempting to detect the effects of modest changes in emissions through an analysis of ambient monitoring data. Important considerations are the magnitude of the changes being made, the relationship to important meteorological variables affecting pollutant levels, and the uncertainties existing in both measured data and the analytical techniques being used.

Ambient pollutant data are affected by changes in meteorology as well as by changes in emission rates. Meteorological variability can have a significant influence on ambient pollutant concentrations on a daily and hourly basis. Unusual source activity, such as large changes in traffic, and measurement errors are additional factors contributing to the variability of measured pollutant concentration levels. The main task of determining the effect of one or more individual transportation emission control strategies, then, is to separate the effects of these particular emission reduction strategies from those associated with meteorological and other factors, as well as from the effects of other stationary and area source emission reduction strategies.

The measurement problems are easier to solve for CO than for other primary pollutants, such as VOCs and NO_x, and secondary pollutants, such as ozone. Because the overwhelming proportion of CO emissions are from motor vehicles, the normal trend in CO emissions can be related to variables that influence vehicle emissions. These include (1) changes in the vehicle emission standard and the associated replacement of the vehicle fleet by newer, cleaner vehicles; (2) changes in vehicle travel; and (3) other possible changes in vehicle emissions as a result of I/M programs or fuel specifications that reduce CO emissions. The determination of TCM influences on ambient CO data requires separating all other effects that influence the ambient data.

For VOCs and NO_x, the problem becomes more complicated because (1) these species are emitted by multiple types of sources, (2) they undergo chemical transformations in the atmosphere, and (3) they are more difficult to measure. TCM influences on secondary pollutants, such as ozone and secondary fine particles, are even more difficult to address because of the nonlinear character of atmospheric chemical reaction phenomena involving the various precursor species, such as VOCs and NO_x. Moreover, secondary pollutant formation associated with a particular source of precursors occurs several kilometers downwind from the source. Emissions from the source of interest are injected into an air mass that invariably contains aged precursors and secondary pollutants resulting from upwind emissions sources. During the downwind transport of precursors emitted from the source of interest, fresh precursor emissions from other sources also are injected into the air mass. The challenge of the ambient data analysis is to untangle the influences of these various source contributions to secondary pollutant formation at the downwind measurement site.

STATISTICAL CONSIDERATIONS

Attainment of the national ambient air quality standards for CO and ozone is determined by measuring peak values for these pollutants. However, to enhance statistical robustness, it is desirable to use all available data in the statistical analysis of ambient data. Analyses that address the overall impact of any emissions strategy on average CO or ozone levels may not accurately model the impact on peak concentration levels.

There is significant variability or "noise" in a data record of short-term (e.g., 1 hr) average ambient concentration data. Rao et al. (1996) found that a multiyear time series of ozone observations can be effectively modeled as a combination of stochastic (short-term) and deterministic (seasonal and long-term) processes. They found that there is a baseline (or reservoir) of ozone upon which random variations that contribute to exceedances are superimposed on occasion. At best, one might hope to discern the effect of TCMs on the deterministic component of the data record. To characterize the effects of a TCM on peak values, one must address the more challenging problem of discerning its influence on the stochastic component of the data record.

In an analysis of ozone data collected in the Northeast from 1980 to 1992, Zurbenko, Rao, and Henry (1995) demonstrated that there was an improvement in ambient ozone air quality in the post-1988 period. The authors noted the possibility that controls on fuel volatility implemented in the Northeast in 1989 and vehicle turnover were responsible for some portion of this improvement. They indicated, though, that they could not establish a direct cause and effect relationship for the observed improvement in ozone with a high degree of statistical confidence. When

assessing the effect of a particular emission control measure, analyses or design data collection programs that isolate the effects of interest to the extent possible are essential.

Two key issues arise in analyzing ambient data to assess the effects of a TCM:

- How many samples are required to discern a specified change in ambient air quality level?
- What is the minimum ambient air quality change that can be "observed" given a specified number of samples?

The number of samples required to achieve a high probability of detecting differences of a specified magnitude can be readily determined for some statistical tests. Suppose, for example, air quality samples are collected 1 day per week at a monitoring station. The mean air quality measurements before and after implementing an emissions control measure are determined. A t-test is used to compare the mean concentrations. Results will be considered statistically significant if the significance probability is 0.05 or less (meaning that the probability is 5% or less of concluding that an air quality change occurred when it did not). The monitoring data collected before implementing the control measure indicate the standard deviation of the measurements is about two-thirds the value of the mean concentration. It is estimated that the control measure might reduce emissions by about 10%, which suggests the mean concentration would be about 10% lower after implementing the measure. The objective is to have at least a 90% chance of detecting the change in mean concentration with a significance probability of 0.05. Using statistical tables (e.g., Dixon and Massey 1983), the required sample size for this case is 2,000, half of the samples taken before and half after the change. Such a measurement program, though, is not practical considering the elapsed time required to collect 2,000 weekly samples is about 40 years.

In the preceding example, it was assumed that the measurements were independent of each other. This assumption was reasonable because the samples were being collected only 1 day per week. As sampling frequency increases, say to once per day, measurements are typically found to be correlated with each other. That is, the concentration on 1 day tends to be similar to those occurring on the preceding and following days (ignoring any complications caused by daily variability in traffic, particularly differences between weekday and weekend travel). When measurements are correlated, the standard statistical tables are no longer applicable. Approximate formulas, however, can be derived for specific cases (e.g., Gilbert 1987). The type of correlation typical of pollutant concentration is called positive autocorrelation (i.e., values close in time tend to be similar). The effect of positive autocorrelation is to increase the sample size required for detecting changes. Thus, if measurements consisted of daily peak concentrations, the number of samples needed would exceed 2,000. In this case, a monitoring program of at least 6 years duration would be required (i.e., 3 years before and 3 years after the emissions change).

Collecting peak daily CO concentrations during two winter periods before and after implementing an emissions control measure, and assuming 120 days per winter season, results in a data set of 480 samples. Such a data set might be useful in discerning a change in ambient concentrations of at least 18%. A data set with 4 full years of data (i.e., 1,461 samples) might be useful in discerning an air quality change of at least 10%.

These examples illustrate the challenge of using analyses of ambient air quality monitoring data to discern the effects of a TCM strategy that has an emissions impact on the order of a few percent. In cases where the influence on emissions is much larger, the effects on ambient air quality are more readily apparent. For example, there have been clear improvements in ambient CO concentrations over the past several years resulting, in large part, from the federal motor vehicle emissions control program (e.g., Federal Highway Administration 1996). These improvements are associated with estimated emissions changes in excess of 20%.

EFFECTS OF MOBILE SOURCE AIR QUALITY CONTROLS

Various researchers have employed statistical techniques to analyze ambient measurement data to determine the effects of oxygenated fuel, reformulated gasoline, and vehicle I/M programs on ambient air pollution levels. Table 1 summarizes the technical approaches and results for eight such investigations. A review of this table indicates mixed results, despite carefully thought out experimental and analytical approaches. From a purely statistical perspective, a majority of these efforts were inconclusive. While the impacts of larger emissions generally could be detected, the effects of smaller reductions in emissions proved much more difficult to discern. Similarly, changes in CO concentrations were easier to detect than changes in other pollutants.

Table 1. Summary of Ambient Air Measurement Evaluation Studies

Investigators	Approach	Findings	Comments
Effects of Oxygenated Fuels and Reformulated Gasoline			
Anderson et al. (1992)	Performed a statistical analysis to determine the impact of oxygenated fuel use on CO concentrations in Denver; adjusted CO data to eliminate the seasonal component; fitted adjusted data set using a quadratic regression curve to determine the long term trend for the ambient CO data; analyzed 1981-1990 ambient CO observations collected at the downtown Denver air monitoring station; compared the CO concentrations that would be forecast by the trend equations to the CO concentrations actually observed for three periods in 1988-1989 when oxyfuels were used.	Found that the observed ambient CO levels (computed as daily, weekly and monthly averages) were actually higher than the values predicted for these periods using the trend equations.	The authors could not "say with statistical certainty that a reduction in the ambient CO concentrations of 9-12% did not occur" during the months that oxyfuels were used. Although no effect of oxyfuels was shown, the authors could not conclude that there was no effect. The analytical approach implemented did not include an explicit representation of year-to-year meteorological variability, which may have been needed to discern the effect of the oxyfuel program.
Lyons and Fox (1993)	Evaluated the oxygenated fuels program in Denver by using remote sensing measurements at a road location and in parking garages. Measured 20,000 vehicles in each of four periods: (1) five weeks before the start of the oxygenated fuel requirement, (2) three weeks after the start of the requirement, (3) fifteen weeks after the start, and (4) five weeks after the end of the requirement. Compared the data from the measurements in periods (1) and (4) when there was no oxyfuel requirement with the data from periods (2) and (3) when the requirement was in effect.	On-road measurements showed a reduction in average CO concentration from 0.8% during the period with no oxyfuel requirement to 0.6% during the period with the oxyfuel requirement. Measurements in garages showed a similar decrease in CO concentration for vehicles entering the parking garage in the morning which were assumed to be fully warmed. However, vehicles leaving the garages in the evening, which were assumed to be cold, showed an increase in average CO concentration during the period when oxyfuels were required.	The reported data showed an increase from 1.52% to 2.43% under driving conditions reported as "mild acceleration," and an increase from 2.65% to 3.24% during driving conditions described as "level." Although various meteorological data were collected, analysis of these effects on CO concentrations was not considered.

Table 1. Summary of Ambient Air Measurement Evaluation Studies (continued)

Investigators	Approach	Findings	Comments
Effects of Oxygenated Fuels and Reformulated Gasoline (continued)			
Kirchstetter et al. (1995)	Conducted measurements during August and October 1994 of light-duty vehicle emissions in the Caldecott Tunnel located east of San Francisco. In the interval between these two periods, the average oxygen content of gasoline increased from 0.3% to 2.0% by weight.	Observed the following changes in emissions (grams per gallon of fuel): CO — decreased by 21±7%, VOC — decreased 18%±10%, NOx — no significant change, formaldehyde — increased 13±6%, acetaldehyde — no change, benzene — decreased 25%±17% Measured VOC/NOx ratio agreed to within 30% of the value estimated by EMFAC7F for vehicle speeds ranging from 40 to 50 mph; measured CO/NOx ratio was a factor of 1.5 to 2.2 higher than the estimated value.	This tunnel study represents a good example of a controlled experiment to assess the effect of an emission control program. Complications associated with the need to adequately characterize the influence of meteorological variations are significantly reduced.
Main, Roberts, and Ligocki (1995)	Carried out a feasibility study to assess whether VOC speciation measurements could be used to determine the effects of changes in motor vehicle fuel composition in the Los Angeles area. Analyzed 24-hour toxic species samples collected every 12th day and 3-hour samples collected between 0600-0900 PDT at the North Main site near downtown Los Angeles. Calculated the mean, median, standard deviation, and the difference between the median and the 25th (or 75th) percentile values for various individual species and groups of species, weight fractions, and species ratios. Also estimated the expected change in each of these quantities based on available emissions estimates. For the indicator to be useful, assumed that the expected change must be greater than one standard deviation of the current daily mean or outside the current interquartile range.	For indicators based on species concentrations, such as non-methane hydrocarbon, benzene, C7-C8 aromatics, n-butane, etc., only i-butene (which was estimated to increase by 200 percent) was found to be a suitable indicator species. For the species with smaller estimated changes (ranging from 14 to 50 percent), the variability of the daily concentrations was usually much greater than the expected changes in emissions. For weight fraction indicators, many more expected changes may be observable. Potential indicators include: benzene, C9-C10 aromatic hydrocarbons, n-butane, and i-butene. Potentially useful species ratios include: C9-C10 aromatic hydrocarbons to xylenes or toluene, n-butane to i-pentane, and benzene to toluene.	Since the EPA fuel volatility regulations were implemented in 1992, the authors compared VOC speciation data collected in 1990-1991 with that reported in 1992-1993. They found that the associated 0.8 psi decrease in RVP yielded a significant decrease in ambient n-butane concentrations. Various statistical tests were used to confirm that mean and median n-butane concentrations for these two periods were significantly different.

Table 1. Summary of Ambient Air Measurement Evaluation Studies (continued)

Investigators	Approach	Findings	Comments
Vehicle Inspection/Maintenance Programs			
Tiao, Liu and Hudak (1989)	Examined impact of I/M program in Phoenix on ambient CO data. Used a variety of statistical models to fit ambient CO data; postulated a regression equation in which the emission factors from EPA's MOBILE model were included as one of the independent variables; regression equation used the logarithm of the CO concentration (adjusted for traffic volume) and the logarithm of the emission factors; examined two possible regression equations, one with the MOBILE emission factors with I/M and the other using the emission factors for no I/M. Statistical test for assessing the impact of I/M was to hypothesize that the regression coefficient of the emission factor term should be one based on the assumption that the relative change in CO concentrations should be directly proportional to the relative change in emission factors, after accounting for other factors that affect CO.	Coefficient of the emission factor term for wintertime CO data: 0.97±0.21 — with-I/M factors 2.41±0.56 — no-I/M factors For summertime CO data: 0.26±0.18 — with-I/M factors 0.83±0.48 — no-I/M factors; Concluded that the results were "clearly in favor" of supporting the with-I/M factors in the winter months and supported "to a much lesser extent" the use of no-I/M factors for summer months. Final conclusion was that the authors found "some evidence to support the hypothesis that the I/M program has reduced ambient CO levels."	Despite the authors' final conclusion, the statistical analysis is not really conclusive. Even after adding the consideration of MOBILE emission factors to inject the emission model results into the statistical model, the final results depend on the assumption that the coefficient of the correct emission factor term should be one. Even if one accepts the assumption that an emission factor coefficient of one identifies the correct set of emission factors, the statistical results are inconclusive. They support the hypothesis that the coefficient is not different from one for the with-IM results in the winter and the no-I/M results in the summer.
Stedman et al. (1993)	Evaluated the air quality effects of the Colorado I/M program by employing a remote sensing system to measure VOC and CO emissions from on-road motor vehicles. Measured emissions from 11,170 vehicles and also recorded the license plate number for each vehicle.	Found that there was no statistically significant difference in VOC emissions between vehicles participating in the I/M program and those not subject to the program, but did find a significant difference for CO emissions.	None.

Table 1. Summary of Ambient Air Measurement Evaluation Studies (continued)

Investigators	Approach	Findings	Comments
Vehicle Inspection/Maintenance Programs (continued)			
Pollack et al. (1990)	Used three different approaches to describe the impact of the California I/M program on ambient CO data: 1) a purely theoretical exercise, termed the "dispersion model," based on emission and dispersion modeling that provided a direct estimate of improvement in ambient CO peaks attributable to the I/M program; 2) a purely empirical approach, termed the "statistical model," based on statistical analysis of ambient measurements and traffic volume data that attempted to identify an I/M effect despite the recognized effects of other factors; and 3) a hybrid approach, termed the "hybrid model," incorporating emission and dispersion modeling concepts into a statistical model that was used in a separate attempt to identify I/M program effects on air quality. Also examined the feasibility of determining the impact of the I/M program on ozone concentrations.	The dispersion model yielded an estimated reduction in the maximum 8-hour average CO concentration between 6.1 and 7.3 percent. The statistical model analyses using data from 8 to 14 winters (ending with the winter of 1986-1987) at each of the four study sites did not show a statistically significant change in overall trends during the two-year period in which the I/M program was implemented; the variability in year-to-year concentrations that was not statistically explained by traffic and meteorological inputs was too large to allow detection of the projected I/M effect. The hybrid modeling approach was found to provide improved ability to detect changes due to the I/M program. However, the unexplained variability in CO concentrations was still quite large. A statistically significant improvement was detected at only one of the four measurement sites.	The authors attribute the large uncertainties that are carried through in calculations of the I/M program effects to be key factors in limiting the ability of both the statistical and hybrid models to confirm the level of air quality improvement estimated by the dispersion model.

Table 1. Summary of Ambient Air Measurement Evaluation Studies (continued)

Investigators	Approach	Findings	Comments
Vehicle Inspection/Maintenance Programs (continued)			
Scherrer and Kettelson (1994)	Analyzed ambient CO data collected in Minneapolis/St. Paul to determine the effect of implementing an I/M program in that area. Used a regression analysis to develop a relationship for the predicted hourly CO concentration considering (1) the long-term time trend, which incorporates effects of fleet turnover and overall increases in vehicle operation, (2) cyclical variations in vehicle operation over daily, weekly, and annual cycles, (3) ambient conditions (e.g., wind and temperature), and (4) the fraction of the vehicle fleet that has been subjected to at least one I/M inspection. The model was applied to three separate monitoring stations for the years 1986-1992.	Found reductions in ambient CO concentrations of 1.5 and 5.8 percent at two monitoring stations and an increase of 3.4 percent at a third location. The overall change in CO pollutant levels was a decrease of 1.3 ± 1.4 percent.	None.

These studies demonstrate the difficulty in detecting an emission-related effect through statistical analysis of monitored air quality data. One reason for this difficulty is the significant variation in pollutant concentrations that occurs naturally because of the stochastic character of the atmosphere and changes in meteorological variables. In situations where a control measure has only a modest influence on emissions, the resulting change in pollutant level is only one component of the overall variability in ambient concentrations. Even though there may be evidence that emissions are reduced, it may not be possible to show the associated change in ambient air quality to the desired level of statistical confidence.

A second reason for problems in correlating emissions and air concentration data is the influence of outside or uncontrolled events. Such events can have a significant effect on the ambient concentrations, yet this may not be accounted for by the statistical modeling techniques.

Similar difficulties will be encountered in efforts to detect the effects of TCMs on ambient ozone data. Photochemical modeling results, such as those of Michaels and Reynolds (1995), indicate that small changes in precursor emissions are likely to yield correspondingly small changes in ozone concentrations. Evaluating the effects of transportation and other forms of mobile source air quality control measures by using of ambient ozone measurements is a desirable objective, but one which has proven especially challenging to achieve in practice.

Although isolating the effects of particular emission changes through the statistical analyses of monitored air quality data is difficult, these approaches are nonetheless still appealing because of their potential to directly address impacts on ambient air quality. The studies summarized in Table 1 indicate that statistical approaches are likely to be most successful in discerning effects on ambient air quality levels of control measures that result in relatively large reductions in emissions, for example, those greater than 10%. Control measures that have a spatially diffuse effect on emissions, such as many forms of TCMs, will be much more difficult to discern through the statistical analysis of monitored air quality data.

Similarly, these studies indicate that detecting the effects of emission reductions on monitored levels of a secondary pollutant such as ozone is considerably more difficult than detecting changes in primary pollutants such as CO. As pointed out in a number of the analyses described in Table 1, this does not necessarily mean that these measures are not resulting in improved air quality, only that this determination is difficult to demonstrate with the desired levels of statistical confidence.

Achieving air quality goals is likely to require the implementation of several emission control measures. While each of these may have only a modest influence on emissions, the combined influence of these measures may provide the overall required emissions reduction needed to attain the air quality standards. The difficulty in analytically isolating the effects of one or more individual mobile source control measures on monitored air pollutant concentrations should not automatically lead to the conclusion that these measures are not reducing emissions or are not beneficial.

THE KEY GAP IN CURRENT KNOWLEDGE

Achieving the goal of relating the effects of specific transportation control measures and other mobile source air quality control measures to changes in ambient air quality levels remains elusive. While the long-term benefits of the federal motor vehicle emissions control program on CO and ozone levels can be seen by examining several years' worth of air quality monitoring data (Shiftan and Suhrbier 1994), statistically relating changes in air quality to the implementation of specific fuels, vehicle I/M programs, or transportation management programs has been considerably more difficult.

Existing air monitoring practice provides a characterization of local (e.g., near-roadway) and larger neighborhood-scale air quality levels. Using such data to isolate the effects of one or more particular air quality control strategies, though, is significantly complicated by the need to adequately isolate the effects of meteorological variability and other external factors which may be changing simultaneously. This complication is especially apparent with TCMs, where the influence on emissions may be both modest and spatially diffuse.

TCM effects may be most discernible in situations where pollutant levels immediately upwind and downwind of a roadway can be measured. The measurements could be used to directly establish pollutant levels associated with vehicles operating on the roadway of interest. Such an approach to TCM evaluation would require conducting field experiments designed to measure the effects on in-use vehicle emissions and ambient air quality in the roadway environment that result from implementing one or more TCMs. Remote

sensing of vehicle emissions may provide an important tool for developing this approach.

RECOMMENDATIONS

The following analytical approaches can be used to develop an improved understanding of the impacts of air quality transportation control strategies on ambient air quality levels:

- Monitoring a primary pollutant immediately up- and downwind of a source,
- Monitoring to determine local background concentrations,
- Determining the impact of either a single TCM or a program of TCMs through monitoring,
- Supplementing the determination of the TCM impact through modeling or data analysis, and
- Linking the analysis of a primary pollutant to a secondary pollutant of interest through modeling.

As part of the NCHRP Project 8-33, a feasibility study is being conducted to further evaluate the merits and possible limitations of the monitoring aspects of this recommended approach. If the findings of the feasibility study are positive, then a detailed design of an advanced TCM-related monitoring program will be developed.

More information on NCHRP Project 8-33 is available on the Internet's World Wide Web at http://www2.nas.edu/trbcrp. The project is scheduled to be complete in summer 1998. Various interim project documents, including the one from which this digest was drawn, are available for loan from the NCHRP, 2101 Constitution Avenue, N.W., Washington, DC 20418.

REFERENCES

Anderson, L.G. et al., "The Effects of Using Oxygenated Fuels on the Concentration of Carbon Monoxide in Denver." *Paper No. 92-91.07*, Air & Waste Management Association, 85th Annual Meeting, Kansas City, Missouri (June 1992).

Dixon, W.J. and F.J. Massey, Jr., *Introduction to Statistical Analysis*, 4th ed. McGraw-Hill Book Company, New York (1983).

Federal Highway Administration, *Transportation Air Quality Selected Facts and Figures.* U.S. Department of Transportation Publication *FHWA-PD-96-006*, Washington, DC (1996).

Gilbert, R.O., *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold Company, Inc., New York (1987).

Kirchsetter, T.W., B.C. Singer, and R.A. Harley, "Impacts of Oxygenated Gasoline Use on California Light-Duty Vehicle Emissions." *Environmental Science and Technology* (1995).

Lyons, C.E. and R.J. Fox, "Quantifying the Air Pollution Emissions Reduction Effectiveness and Costs of Oxygenated Fuels." *SAE Paper No. 930374*, International Congress and Exposition, Detroit, Michigan (March 1993).

Main, H.H., P.T. Roberts, and M.P. Ligocki, "Assessing the Usefulness of VOC Data as Indicators of Change in Fuel Composition in the South Coast Air Basin (California)." *Paper No. 95-FA113C.02*, Air & Waste Management Association, 88th Annual Meeting & Exhibition, San Antonio, Texas (June 1995).

Michaels, H.M. and S.D. Reynolds, "Southeast Michigan Ozone Study: Urban Airshed Model Results for the 1996 Growth-Only and the 1996 Growth-Only Emissions Scenario with Additional VOC and NO_x Emissions Reductions Using Meteorological Conditions of 4-7 July 1988." Report prepared by Envair for Southeast Michigan Council of Governments, Detroit, Michigan (1995).

Pollack, A.K. et al., "Effects of the California Motor Vehicle Inspection/Maintenance Program on Air Quality." *SYAPP-90/031*, prepared by Systems Applications, Inc., for the California Air Resources Board, Sacramento, California (1990).

Rao, S.T. et al., "Dealing with the Ozone Non-Attainment Problem in the Eastern United States." *Environmental Management*, Air & Waste Management Association (Jan. 1996).

Reynolds, S.D., "Relationships Among Implemented TCMs, Emissions, and Measured Pollutant Levels." Phase I Interim Report prepared by Cambridge

Systematics, Inc., and Envair for NCHRP Project 8-33, Transportation Research Board, Washington, DC (March 1996) unpublished.

Scherrer, H.C. and D.B. Kittelson, "I/M Effectiveness as Directly Measured by Ambient CO Data." *SAE Paper No. 940302*, International Congress & Exposition, Detroit, Michigan (Feb. 28-March 3, 1994).

Shiftan, Y. and J. Suhrbier, "Ozone Trends in Severe and Serious Non-Attainment Areas." Report prepared by Cambridge Systematics, Inc., under subcontract to Jack Faucett Associates, Inc., for the Federal Highway Administration and Volpe National Transportation Systems Center, Washington, DC (June 1994).

Stedman, D.H. et al., "On-Road Hydrocarbon Remote Sensing." *Paper No. 93-WP-102.05*, Air & Waste Management Association, 86th Annual Meeting & Exhibition, Denver, Colorado (June 1993).

Tiao, G.C., L.M. Liu, and G.B. Hudak, "A Statistical Assessment of the Effect of the Car Inspection/Maintenance Program on Ambient CO Air Quality in Phoenix, Arizona." *Environmental Science and Technology*, Vol. 23, No. 7 (1989) pp. 806-814.

Zurbenko, I.G., S.T. Rao, and R.F. Henry, "Mapping Ozone in the Eastern United States." *Environmental Management*, Air & Waste Management Association (Feb. 1995).

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, DC 20418

NON-PROFIT
U.S. POSTAGE
PAID
WASHINGTON, DC
PERMIT NO. 8970

000021-05 *
Robert M Smith
Research & Asst Matls Engr
Idaho DOT
P O Box 7129
Boise ID 83707-1129