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Predicting Changes in PM Exposure Over Time at U.S. Trucking Terminals Using Structural Equation Modeling Techniques

Mary E. Davis[1], **Francine Laden**[2], **Jaime E. Hart**[2], **Eric Garshick**[3], **Andrew Blicharz**[4], and **Thomas J. Smith**[4]

[1]Tufts University, Department of Urban and Environmental Policy and Planning, Medford, Massachusetts

[2]Harvard School of Public Health, Exposure, Epidemiology, and Risk Program, Department of Environmental Health; Harvard Medical School, Channing Laboratory; Harvard School of Public Health, Department of Epidemiology, Boston, Massachusetts

[3]Harvard Medical School, Channing Laboratory, Boston, Massachusetts; VA Boston Healthcare, Pulmonary and Critical Care Medicine, West Roxbury, Massachusetts

[4]Harvard School of Public Health, Exposure, Epidemiology, and Risk Program, Department of Environmental Health, Boston, Massachusetts

Abstract

This study analyzes the temporal variability of occupational and environmental exposures to fine particulate matter in the U.S. trucking industry and tests the predictive ability of a novel multilayer statistical approach to occupational exposure modeling using structural equation modeling (SEM) techniques. For these purposes, elemental carbon mass in PM<1 μm at six U.S. trucking terminals were measured twice during the same season up to 2 years apart, observing concentrations in the indoor loading dock (median EC: period 1 = 0.65 μg/m^3; period 2 = 0.94 μg/m^3) and outdoor background location (median EC: period 1 = 0.46 μg/m^3 ; period 2 = 0.67 μg/m^3), as well as in the truck cabs of local drivers while on the road (median EC: period 1=1.09 μg/m^3 ; period 2 = 1.07 μg/m^3). There was a general trend toward higher exposures during the second sampling trips; however, these differences were statistically significant in only a few cases and were largely attributable to changes in weather patterns (wind speed, precipitation, etc.). Once accounting for systematic prediction errors in background concentrations, the SEM approach provided a strong fit for work-related exposures in this occupational setting.

Keywords

diesel exhaust; elemental carbon; PM; structural equation model; trucking industry

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Address correspondence to: Mary Davis, Tufts University, Department of Urban and Environmental Policy and Planning, 97 Talbot Avenue, Medford, MA 02155; e-mail: E-mail: mary.davis@tufts.edu.

INTRODUCTION

Diesel exhaust particles (DEP) have been linked to increased risk of lung cancer mortality in more than 40 epidemiologic studies.(1,2) Although DEP is considered either a confirmed(3) or probable human carcinogen,(4–6) the remaining uncertainty is driven largely by the difficulty in defining a dose-response relationship between exposure and cancer risk.(1,7,8) Exposure to traffic exhaust in general has also been linked to increased lung cancer risk.(9, 10) The Trucking Industry Particle Study (TrIPS) represents the most comprehensive assessment of the exposure-health link from diesel and other traffic exhaust particles in an occupational setting. The overall goal of the TrIPS study is to build a model of current and historical exposure to DEP and other vehicle exhausts in the U.S. trucking industry and to assess quantitative relationships with mortality using a retrospective epidemiologic cohort of trucking industry workers.(11) This cohort study contains approximately 55,000 people working in 1985 and, in an assessment of mortality through 2000, we have described an overall elevated risk of lung cancer mortality.(12,13)

Assessment of the stability of exposures in this occupational setting and the strength of our current exposure model represents essential parts of the development of a dose-response model for exhaust exposures and lung cancer risk. Previous studies assessing DEP exposure and health risk have not examined this question.(14–16) Therefore, the focus of this article is to assess the strength of our exposure assessment methodology by analyzing variability in exposures across a 1- to 2-year time period. We also test the predictive ability of a novel multilevel exposure model developed for this cohort using structural equation modeling (SEM) techniques.

METHODS

The exposure data used in the current analysis was collected as part of the larger TrIPS study, which consisted of 42 separate 5-day sampling trips (36 initial trips, 6 repeat trips) made between 2001 and 2006 to terminals across the country from four unionized trucking companies. An initial set of 36 trucking terminals was chosen for sampling by random computer generation from the approximate 140 eligible large trucking terminals (>100 persons) in the epidemiologic cohort. Figure 1 provides a map of these locations. The study was conducted with the full cooperation of the International Brotherhood of Teamsters and as such had 100% participation among the terminals chosen for sampling. After completion of the initial 36 sampling trips, a second set of six terminals were chosen out of the original 36 for a repeat visit. The primary goal of the repeat sampling trips was to assess the strength of the exposure assessment methodology and modeling techniques. For this reason, repeat terminals were chosen based on the primary criteria that they be visited during the same season as the initial sampling trip to limit confounding from seasonality. The sampling locations and dates of the six terminals with repeat sampling trips are provided in Table I.

Monitoring Locations

The exposure locations monitored across both time periods included background conditions at the perimeter of the trucking terminal (yard background), the semi-enclosed loading dock work area, and in the truck cabs of local pickup and delivery (P&D) drivers. The initial 36 sampling trips also included monitor placement in the mechanic shop and office work areas, as well as personal sampling. However, the current analysis is limited only to those locations sampled across both time periods, and a full description of these particular monitoring sites is provided below.

The *loading dock* is a semi-enclosed elongated building with a series of large open doors on either side where truck trailers are backed up and loaded/unloaded by dockworkers driving small propane-powered forklifts. Exposures in this micro-environment come from a variety of sources, including background conditions, idling or moving trucks near the dock doors and in the yard, and forklifts operating within the loading dock area. Monitoring locations identified as central to the ongoing operations were chosen, such as a foreman's desk in the center of the loading dock.

Yard background represents the entire area enclosed within the terminal property fence line. Most trucking terminals in our cohort are located within close proximity to major road networks, industrial development, and other trucking terminals, as well as nearby neighborhoods and population centers. Therefore, background concentrations measured at the upwind edge of the terminal yard are largely a function of location, nearby source characteristics, and weather conditions. Background locations were chosen based on an assessment of wind direction to incorporate both upwind and downwind sources using two monitors. During the second round of sampling trips, this monitoring plan was expanded to include crosswinds, for a total of four background monitoring locations during the repeated trips.

P&D drivers drive tractors and smaller single-bodied trucks within cities, suburban, and metropolitan areas and work primarily during the daytime. They are exposed to a range of conditions including rush hour, stop-and-go inner-city traffic and heavy traffic on urban highways, and suburban roads and highways while processing pickup and delivery orders around the terminal location (typically within a 50-km radius).

The particle collectors, their pumps, and a real-time monitor for temperature and humidity (HOBO; Onset Computer Corp, Bourne, Mass.) were mounted in a box housing connected to an external battery. The fixed location samples were collected at consecutive 12-hr intervals over a 5-day period, and therefore represent 12-hr concentration averages at these locations. The driver work area sampling boxes were mounted to the dashboard on the passenger side of the cab prior to the driver's leaving on his assigned route and was retrieved as soon as possible after his return. The average elapsed time for these samples was 10.5 hr. The sampling protocol was approved by the Harvard School of Public Health Human Subjects Committee.

Sampling Methods

Elemental carbon (EC) in particulate matter less than 1 μm in diameter (PM_1) was measured in the work area and background locations described above. The choice of EC as an appropriate exposure marker for diesel exhaust particles is explored in detail elsewhere.(13,16) In short, we were interested in a marker of fresh diesel and other vehicle emissions before they had agglomerated into the larger-sized accumulative atmospheric aerosols, and historically, diesel engines produced more EC mass than spark-combustion engines.(11)

Furthermore, a source apportionment analysis of data collected at our study locations indicated that most (approximately 80% or greater) of the EC was from diesel sources with a smaller percentage from spark-ignition vehicles and lubricating oil.(13) Although cigarette smoke has been shown to contribute only negligible amounts of EC (0.49%),(17) we attempted to sample only nonsmoking drivers to eliminate the potential confounding effect of smoking on EC in truck cabs. Approximately 80% of the driver samples obtained during the repeat visits were from nonsmokers.

EC was measured using the Harvard Field Monitor equipped with a slightly modified Vortex Timer 2 Sampling Pump (Casella, Amherst, N.H.), an SCC1.062 Triplex cyclone pre-selector (BGI Inc., Waltham, Mass.), and a 25-mm Quartz tissue filter (Omega Specialty Instruments Co., Chelmsford, Mass.) with a pore diameter of 1.2 μm. The filters were placed in 25-mm three-piece polystyrene cassettes (Millipore, Bedford, Mass.). The pumps were calibrated to

3.5 L/min, which is the flow rate at which the cyclone conforms to U.S. Environmental Protection Agency (USEPA) PM Standards for a 50% cut point of 1.0 μm. Calibration was performed in the field using field rotometers previously calibrated with a primary calibration device (UltraFlo Electronic Calibrator; SKC Inc., Eighty Four, Pa.).

Flow rates of the pumps were recorded in the field before and after each sampling period. Prior to field sampling, the Quartz tissue filters were pre-fired at 900°C for 5 hr, and the aluminum foil that was used to line the petri dishes for filter storage were pre-fired at 550°C for 15 hr. This was to prevent off gassing from the petri dish material onto the filters. Field blanks were collected during each trip (10% of the total number of filters used per trip) and stored in a petri dish in the field. On returning from the field, the filters were stored at −20°C and analyzed for EC using the National Institute for Occupational Safety and Health (NIOSH) 5040 thermo-optical analyzer method.(18) Duplicates were analyzed for 10% of the samples, and an instrument blank was run at the beginning of each batch analyses. The LOD for the method is 0.2 micrograms/cm^2 of filter.

Statistical Methods

All statistical tests were performed with STATA v. 8.0. The exposure data were not normally distributed, and for this reason, nonparametric comparison tests were used to identify significant differences in concentrations across the two time periods.

A structural equation modeling (SEM) approach was applied previously to predict on-site (nondriver) worker exposures in the trucking industry.(19) Although this was the first application of SEMs to this type of exposure setting, these methods are becoming increasingly popular in environmental epidemiology.(20) In the TrIPS study, the SEM was used to simultaneously predict three exposure settings (personal, work area, and yard background) to identify the specific pathways contributing to worker exposures at the trucking terminals. A pathway diagram is provided in Figure 2 to illustrate the hypothesized directionality of diesel-related particle exhaust exposure contributions in this occupational setting.

The study design of multiple monitors running concurrently at a variety of locations is quite common in exposure assessment. However, this imposes a complex covariance structure on the exposure data and cross-location samples cannot be assumed to be distributed independently of one another. Different sources contribute simultaneously to the measurements observed at different locations within the terminal during the same time periods. Of particular statistical concern is the correlation among the error terms as well as the correlation between the response variables and the error terms. Both of these conditions violate the necessary assumptions for ordinary least squares. Therefore, instead of trying to fit one large model encompassing all covariates simultaneously, we fit three related models using a statistical technique known as three stage least squares (3SLS), a common SEM approach in econometrics.(21,22) The advantage of this particular method is that it provides coefficient estimates for all of the covariates in the model, along with equation-specific R^2 values to individually interpret each level of exposure data. The current analysis utilized the regression estimates from the original SEM(18) that were derived from an analysis of the data collected during the initial 36 trips. This information was used to predict a trip median for EC terminal yard background (Eq. 3 in Figure 2) and loading dock work area (Eq. 2 in Figure 2) for the six repeat sampling trips. Equation 1 has been excluded from the analysis, since personal exposure measurements were not collected on the loading docks during the repeat visits. In contrast to our original description of the SEM, Eq. 2 was also limited to the loading dock work area, since repeat sampling was not conducted in the mechanic shops.

The equations below include the significant coefficients from the SEM relevant to the current application (excluding the mechanic shop):

$$\begin{aligned}&\text{In (WorkAreaEC)} = 0.01(\text{Terminal Size})\\&+0.002(\text{P\&D}) + 0.7\text{In}(\text{YardBackgroundEC})\\&\text{Original model} R^2 = 0.6\end{aligned} \qquad \text{Equation 2}$$

The dependent variable represents the *predicted* concentrations in the loading dock work area; Terminal Size represents the total acreage of the terminal; P&D is the number of P&D drivers assigned to a terminal during the study week (as an index of terminal activity); and YardBackground represents the *predicted* concentration for yard background derived from Eq. 3 below.

$$\begin{aligned}&\text{In}(\text{YardBackgroundEC}) =\\&-0.004(\text{Relative Humidity}) - 0.01(\text{Temperature})\\&-0.11(\text{Wind Speed}) + 0.01(\text{Industrial}) + 0.51(\text{RegMW})\\&+0.84(\text{RegNE}) + 0.68(\text{RegW}) - 0.30(\text{Interstate})\\&\text{Orginal model} R^2 = 0.5\end{aligned} \qquad \text{Equation 3}$$

The dependent variable represents the *predicted* concentrations for yard background; Wind speed is measured in kilometers per hour; Temperature is measured in degrees Celsius; Industrial represents the percent of land uses within a 1-km radius of the terminal that are designated as industrial commercial and transportation by the U.S. Geological Survey (1992 National Land Cover Data); RegMW, RegNE, and RegW represent the location effect defined by the three U.S. Census Bureau regions (Midwest, Northeast, and West) where the data were collected. All three dummy variables are included in the model thereby dropping the constant from the second equation.

In the earlier prediction model of 36 trips, all four census regions were represented (including the South). Interstate represents proximity to an interstate dichotomized at 500 meters: < = 500 meters (value = 0) and >500 meters (value = 1). Finally, although wind direction and upwind source characteristics could also be assumed to be important predictors of exposure, there is no way to incorporate the dynamic nature of these variables at terminals within the current specification of the model. A previous analysis of the effects of wind on occupational exposures at trucking terminals is provided elsewhere.(23)

Because the data was collected as 8- to 12-hr averages to correspond with worker shifts, the previous SEM was developed to predict shift-level EC concentrations as well. However, the current application extends this work by testing the ability of the shift-level model to predict weekly concentrations at these locations. More specifically, this article uses the originally estimated shift-level coefficients to predict the median expected value over the full sampling trip (approximate 1-week period); the coefficients from the original SEM are used along with the weekly median values for each of the predictor variables to estimate median weekly concentrations at each of the locations.

Identifying the flexibility of the exposure model to predict not only shift-level concentrations but weekly, monthly, and even yearly values is relevant to the extrapolation of exposures across time and, more specifically, to the estimation of cumulative exposures to link with the existing epidemiologic database of health outcomes. To test the ability of the model to extrapolate from shift to weekly exposures, the model predictions estimated here are compared with the actual trip medians observed during the sampling trips.

RESULTS AND DISCUSSION

Variability across Time

Table II–Table IV list the summary statistics for EC in the three sampling locations (loading dock, yard background, and P&D drivers). Although median weekly EC values were higher for the loading dock and yard background locations during the second sampling trips when compared with the initial trips for all terminals, they were significantly higher only for the loading dock in Milwaukee and Denver, and for yard background in Columbus and Milwaukee. There were no significant differences in EC levels among nonsmoking drivers.

Although the repeat sampling trips were performed during the same time of year to limit the impact of seasonality, weather differences had a significant impact on observed yard background concentration levels. Table V lists the median values of the terminal-specific variables during both periods, noting where significant differences existed. For example, there were significantly lower wind speeds and humidity levels (less rain) during the second sampling trip to Milwaukee, both of which would support the expectation of higher EC concentrations.

SEM Prediction Model

Table VI and Table VII display the actual median values observed vs. the predicted median values from the SEM by trip, along with their differences in absolute and percentage terms. The distribution of differences from both Eq. 2 (loading dock work area) and Eq. 3 (yard background) are not significantly different than zero. However, interpretation of these results is limited by small sample sizes (only six observations per group), and it is possible that there are differences that went undetected.

The average difference between the actual and predicted values was 35% for the loading dock (Eq. 2) and 38% for yard background (Eq. 3). However, much of the discrepancies between the predicted and observed values in the loading dock were attributable to errors in the yard background predictions used to estimate them. For example, when the actual yard background observations (median value for each trip) were inserted into the model in place of the predicted value, the differences between the predicted and observed values on the loading dock declined dramatically for Phoenix (65% to 1%), Denver (38% to 29%), and Portland (22% to 5%). These changes alone reduce the overall average percent difference in the predicted vs. the observed values in the loading dock to 11%. These results suggest that Eq. 2 provided a very strong fit and accurately categorizes exposures in this work location once background exposures are known. However, the substitution of the observed values in place of the predicted values limits the usefulness of this approach in reconstructing past exposures, one of the primary goals of this study. Therefore, further research is needed to refine the prediction of background estimates at these locations.

For yard background, 7 out of the 12 total sampling trips (including the initial and repeat) showed relatively strong predictions, with less than a 25% difference between the predicted and the actual EC values. The largest discrepancies were observed in Denver, Phoenix, and Columbus, where the percent differences between the predicted and observed values were more than 50%. These differences are likely a result of unique characteristics around each terminal that were not accounted for in the model yet were present during the sampling period. For example, the Denver terminal is located at a high elevation compared with the other terminals in the model and is also within 200 m of a rail line (Phoenix is also in close proximity to a rail line), whereas there is a large landfill along the southeast corner of the Columbus terminal.

These and other site-specific mitigating factors not included in the exposure model may have contributed to the larger prediction errors for these locations. Also, precipitation was not included in the initial SEM due to the lack of variability observed during our sampling trips (almost no rain), although it is certain to have a significant impact on yard background conditions when present. This may explain the lower than expected concentrations in Columbus during the second sampling trip, which did experience some rain during the sampling week. A larger set of sampling sites and more long-term monitoring could have controlled for these less frequent contributing factors, such as precipitation, elevation, and nearby source contributors, and incorporated them into a model with broader applicability. These discrepancies suggest that additional exposure monitoring would be useful to further refine the background exposure model.

CONCLUSIONS

This study uses exposure data on EC in PM_1 collected during a series of repeat sampling trips over 1 to 2 years to six large U.S. trucking terminals to characterize occupational exposure to diesel and other vehicle exhausts at terminal work area and background locations. The results suggest some degree of stability across the two time periods, with relatively few significant differences in the loading dock and yard background monitoring locations, and no significant differences for nonsmoking P&D drivers.

Although the repeat sampling trips were performed during the same time of year to limit the impact of seasonality, weather changes such as lower wind speed, higher precipitation, and higher relative humidity were primarily responsible for significant differences that did exist across time. On average, yard background concentrations tended to be higher during the second time period, which also increased observed exposure levels in the other monitored locations. This suggests that background EC unrelated to exposures generated on site penetrate trucking industry work environments (as evidenced through Figure 1), leading to elevated occupational exposures observed in these settings.

Finally, this work provides evidence to support the broader use of SEM techniques to characterize overall exposure to a pollutant in settings where various levels/sources of exposures (outdoor, indoor, personal, etc.) all contribute to the total exposure and are concurrently monitored for a given subject. These types of sample designs are common in exposure assessment, and the use of SEMs could provide an important tool to improving the accuracy and precision of exposure modeling in complex settings where exposure is not limited to a single pathway or source.

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REFERENCES

1. Bhatia R, Lopipero P, Smith AH. Diesel exhaust exposure and lung cancer. Epidemiology 1998;9:84–91. [PubMed: 9430274]
2. Lipsett M, Campleman S. Occupational exposure to diesel exhaust and lung cancer: A meta-analysis. Am. J. Public Health 1999;89:1009–1017. [PubMed: 10394308]
3. California Air Resources Board. Identification of Diesel Exhaust as a ToxicAir Contaminant, Amendment to Section 93000,Title 17. California Code of Regulations. 1998
4. International Agency for Research on Cancer (IARC). Volume 46 Diesel and Gasoline Engine Exhausts and Some Nitroarenes. Lyon, France: IARC; 1989. IARC

5. Health Effects Institute (HEI). Diesel Exhaust: A Critical Analysis of Emissions, Exposure and Health Effects. Cambridge, Mass: HEI; 1995.
6. U.S. Environmental Protection Agency (USEPA). Health Assessment Document for Diesel Engine Exhaust (EPA/600/8-90/057F). Washington, D.C: National Center for Environmental Assessment, USEPA; 2002.
7. Stayner L, Bailer AJ, Smith R, Gilbert S, Rice F, Kuempel E. Sources of uncertainty in dose-responsemodeling of epidemiological data for cancer risk assessment. Ann. NY Acad. Sci 1999;895:212–222. [PubMed: 10676419]
8. Health Effects Institute (HEI). Research Directions for Improved Estimates of Human Exposure and Risk from Diesel Exhaust. Cambridge, Mass: HEI, Diesel Epidemiology Working Group; 2002.
9. Nyberg F, Gustavsson P, Jarup L, et al. Urban air pollution and lung cancer in Stockholm. Epidemiology 2000;11(5):487–495. [PubMed: 10955399]
10. Nafstad P, Haheim LL, Oftedal B, Gram F, Holme I, Hjermann I, Leren P. Lung cancer and air pollution: A 27 year follow up of 16,209 Norwegian men. Thorax 2003;58(12):1071–1076. [PubMed: 14645978]
11. Health Effects Institute (HEI). Quantitative assessment of lung cancer risk from diesel exhaust exposure in the U.S. trucking industry: A feasibility study. In: Garshick, E.; Smith, TJ.; Laden, F., editors. Research Directions for Improved Estimates of Human Exposure and Risk from Diesel Exhaust. Cambridge, Mass: HEI; 2002.
12. Laden F, Hart JE, Smith TJ, Davis ME, Garshick E. Cause specificmortality in the unionized U.S. trucking industry. Environ. Health Perspect 2007;115(8):1192–1196. [PubMed: 17687446]
13. Garshick E, Laden F, Hart JE, Rosner B, Davis ME, Eisen EA, Smith TJ. Lung cancer and vehicle exhaust in trucking industry workers. Environ. Health Perspect 2008;116:1327–1332. [PubMed: 18941573]
14. Woskie SR, Smith TJ, Hammond SK, Schenker MB, Garshick E, Speizer FE. Estimation of the diesel exhaust exposures of railroad workers: I. Current exposures. Am. J. Ind. Med 1988;13(3):381–394. [PubMed: 3354586]
15. Woskie SR, Smith TJ, Hammond SK, Schenker MB, Garshick E, Speizer FE. Estimation of the diesel exhaust exposures of railroadworkers: II. National and historical exposures. Am. J. Ind. Med 1988;13 (3):395–404. [PubMed: 3281456]
16. Smith TJ, Davis ME, Reaser P, et al. Overview of particulate exposures in the U.S. trucking industry. J. Environ. Monit 2006;8(7):711–720. [PubMed: 16826284]
17. Zaebst DD, Clapp DE, Blade LM, et al. Quantitative determination of trucking industry workers' exposures to diesel exhaust particles. Am. Ind. Hyg. Assoc. J 1991;52:529–541. [PubMed: 1723577]
18. National Institute for Occupational Safety and Health (NIOSH). Diesel Particulate Matter (as Elemental Carbon), Method 5040 by M. Eileen Birch. In: Schlecht, PC.; O'Connor, PF., editors. NIOSH Manual of Analytical Methods (NMAM). Vol. 4th ed.. 1994. DHHS (NIOSH) Pub. No. 94–113
19. Davis ME, Smith TJ, Laden F, Hart JE, Ryan LM, Garshick E. Modeling particle exposure in U.S. trucking terminals. Environ. Sci. Technol 2006;40:4226–4232. [PubMed: 16856739]
20. Sanchez BN, Budtz-Joergensen E, Ryan LM, Hu H. Structural equation models: A review with applications to environmental epidemiology. J. Am. Stat. Assoc 2005;100:1443–1445.
21. Zellner A, Theil H. Three-stage least squares: Simultaneous estimation of simultaneous equations. Econometrica 1962;30:54–78.
22. Goldberger A. Structural equation methods in the social sciences. Econometrica 1972;40:979–1001.
23. Garcia R, Hart JE, Davis ME, et al. Effects of wind on background particle concentrations at truck freight terminals. J. Occup. Environ. Hyg 2007;4:36–38. [PubMed: 17162479]

FIGURE 1.
Map of All TrIPS Sampling Locations.

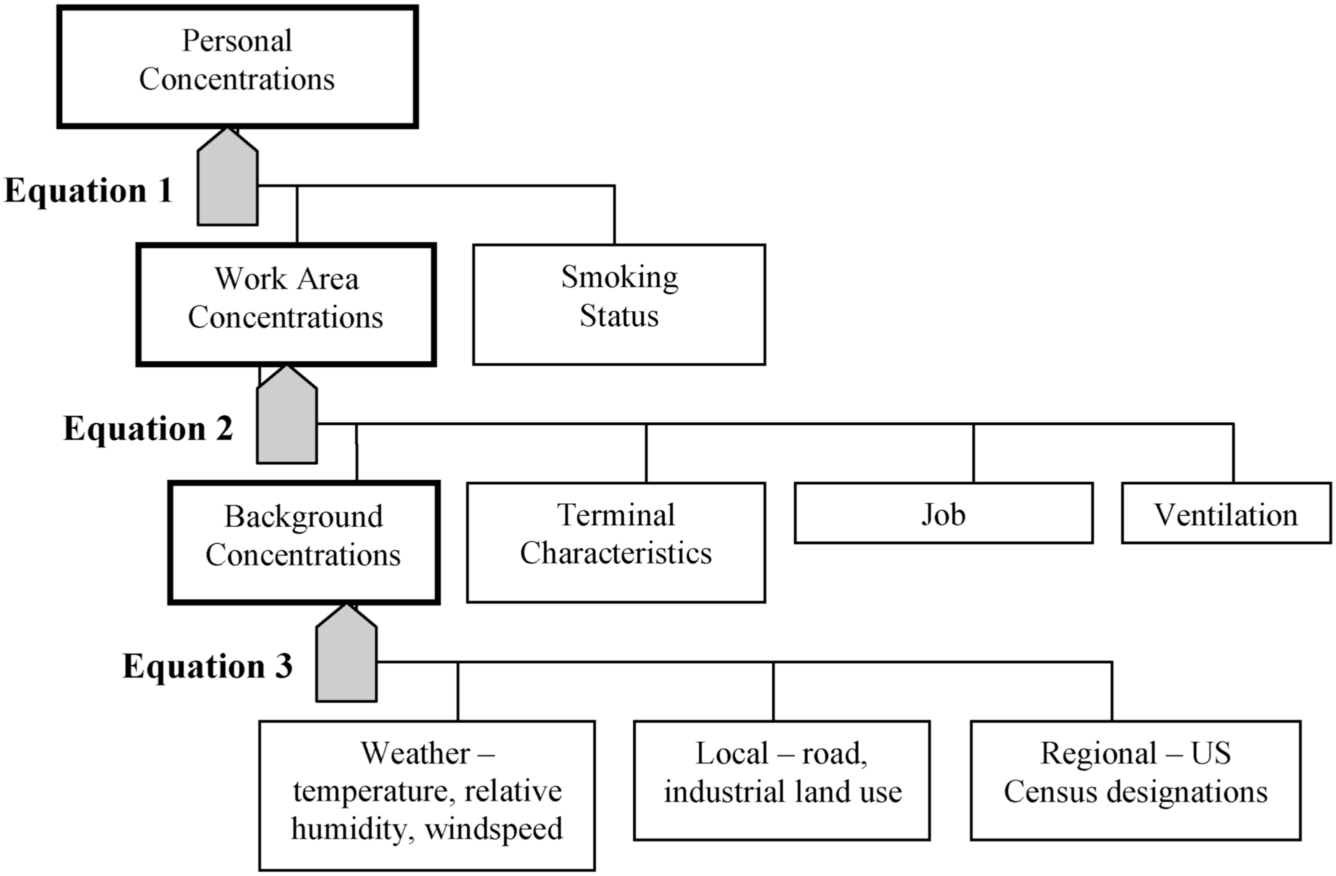

FIGURE 2.
Exposure Pathway Diagram.

TABLE I

Location and Dates of Repeat Sampling Trips

Location	Initial Sampling Trip Date	Second Sampling Trip Date
Columbus, Ohio	March 2004	April 2006
Milwaukee, Wis.	April 2004	May 2006
Phoenix, Ariz.	June 2004	June 2006
Portland, Ore.	July 2004	July 2006
Denver, Colo.	August 2004	August 2006
Philadelphia, Pa.	March 2005	March 2006

TABLE II

Elemental Carbon Summary Statistics for Loading Dock in $\mu g/m^3$

	Initial Visit				Second Visit				Significant Difference[A] and Direction
	Obs.	Mean	Median	Standard Deviation	Obs.	Mean	Median	Standard Deviation	
Philadelphia	20	0.76	0.69	0.37	10	1.28	1.00	1.28	
Columbus	23	0.84	0.72	0.36	9	1.10	0.81	0.76	
Milwaukee	24	0.32	0.24	0.28	17	0.45	0.45	0.19	+[A]
Phoenix	6	1.41	0.88	0.94	9	1.77	2.06	0.57	
Portland	18	0.64	0.63	0.15	10	0.83	0.78	0.35	
Denver	23	0.78	0.71	0.39	12	1.69	1.59	0.63	+[A]
Total	114	0.70	0.65	0.45	67	1.12	0.94	0.74	+[A]

[A] Significant differences ($p < 0.05$) in median values using Wilcoxon Ranksum nonparametric comparison test.

TABLE III

Elemental Carbon Summary Statistics for Yard Background in $\mu g/m^3$

	First Visit				Second Visit				
	Obs.	**Mean**	**Median**	**Standard Deviation**	**Obs.**	**Mean**	**Median**	**Standard Deviation**	**Significant Difference[A] and Direction**
Philadelphia	24	0.63	0.60	0.31	38	1.08	0.70	0.85	
Columbus	20	0.69	0.64	0.44	24	1.46	0.86	1.19	+[A]
Milwaukee	29	0.19	0.13	0.20	31	0.39	0.38	0.24	+[A]
Phoenix	6	1.01	0.77	0.67	36	1.32	1.44	0.63	
Portland	18	0.42	0.38	0.12	36	0.53	0.46	0.37	
Denver	32	0.73	0.60	0.43	32	0.88	0.84	0.47	
Total	129	0.55	0.46	0.42	197	0.93	0.67	0.77	+[A]

[A] Significant differences ($p < 0.05$) in median values using Wilcoxon Ranksum nonparametric comparison test.

TABLE IV

Elemental Carbon Summary Statistics for Nonsmoking Drivers in µg/m^3

	Initial Visit				Second Visit				
	Obs.	**Mean**	**Median**	**Standard Deviation**	**Obs.**	**Mean**	**Median**	**Standard Deviation**	**Significant Difference[A] and Direction**
Philadelphia	12	0.90	0.83	0.46	18	1.11	1.13	0.41	
Columbus	9	1.26	1.16	0.62	11	0.86	0.94	0.38	
Milwaukee	13	0.80	0.66	0.55	17	0.94	0.88	0.52	
Phoenix	10	1.40	1.33	0.46	16	1.29	1.38	0.27	
Portland	13	2.10	1.50	2.02	12	1.17	1.11	0.54	
Denver	16	1.10	1.03	0.70	12	1.09	1.07	0.65	
Total	73	1.25	1.09	1.06	86	1.08	1.07	0.48	

Note: Summary statistics are limited to nonsmoking drivers.

[A] Significant differences ($p < 0.05$) in median values using Wilcoxon Ranksum nonparametric comparison test.

TABLE V

Median Values for Initial and Second Visits of Model Covariates

	Philadelphia		Columbus		Milwaukee		Phoenix		Portland		Denver	
	First	**Second**	**First**	**Second**	**First**	**Second**	**First**	**Second**	**First**	**Second**	**First**	**Second**
Terminal Size[A]	8.0	—	17.9	—	18.2	—	33.0	—	14.0	—	12.0	—
Industrial[A]	24.5	—	23.3	—	25.8	—	12.6	—	37.9	—	27.3	—
P&D Drivers	76	66	36	39	52	51	49	75	52	57	52	61
Relative Humidity (%)	42.7	47.9	79.1[B]	48.6	81[B]	63.3	9.8[B]	18.4	50.5	60.7	52.5	52.4
Temperature (°)	2.8[B]	10.3	0.9[B]	11.3	8.7[B]	14.9	36	33.2	23.9[B]	19.1	20.3[B]	21.1
Wind speed (kph)	12.5[B]	8.4	8.8	12.2	21.2[B]	14.7	13.3	11.3	10.9[B]	12.5	10.6[B]	14.4

[A] Terminal size and industrial land use around a terminal did not change across the two periods.

[B] Significant differences ($p < 0.05$) in median values using Wilcoxon Ranksum nonparametric comparison test.

TABLE VI

Actual vs. Predicted Elemental Carbon Values for Loading Dock in μg/m^3

	First Visit			Second Visit		
	Actual[A]	Predicted	Absolute Difference	Actual	Predicted	Absolute Difference
Milwaukee	0.24	0.26	0.02 (8%)	0.45	0.44	0.01 (2%)
Philadelphia	0.69	0.72	0.03 (4%)	1.00	0.91	0.09 (9%)
Columbus	0.72	0.71	0.01 (1%)	0.81	0.55	0.26 (32%)
Phoenix	0.88	0.59	0.29 (33%)	2.06	0.72	1.34 (65%)
Portland	0.63	0.68	0.05 (8%)	0.78	0.61	0.17 (22%)
Denver	0.71	0.65	0.06 (8%)	1.59	0.49	0.61 (38%)
Average	0.65	0.60	0.08 (12%)	1.12	0.62	0.38 (41%)

Note: The difference as a percentage of the actual value is given in parentheses.

[A] Actual values represent the observed medians for each trip.

TABLE VII

Actual vs. Predicted Elemental Carbon Values for Yard Background in $\mu g/m^3$

	First Visit			Second Visit		
	Actual[A]	**Predicted**	**Absolute Difference**	**Actual**	**Predicted**	**Absolute Difference**
Milwaukee	0.13	0.10	0.01 (8%)	0.38	0.21	0.09 (24%)
Philadelphia	0.60	0.45	0.01 (2%)	0.70	0.65	0.17 (24%)
Columbus	0.64	0.43	0.06 (9%)	0.86	0.30	0.46 (53%)
Phoenix	0.77	0.26	0.42 (55%)	1.44	0.32	1.01 (70%)
Portland	0.38	0.41	0.18 (47%)	0.46	0.35	0.01 (2%)
Denver	0.60	0.40	0.07 (12%)	0.84	0.26	0.49 (58%)
Average	0.52	0.46	0.13 (35%)	0.78	0.47	0.37 (47%)

Note: The difference as a percentage of the actual value is given in parentheses.

[A] Actual values represent the observed medians for each trip.