

UNIVERSITY OF CALIFORNIA

Los Angeles

Characterizing Black Carbon Inside Vehicles:
Implications for Refined Exposure Assessments
for Diesel Exhaust Particulate Matter

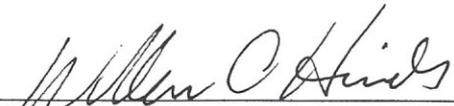
A dissertation submitted in partial satisfaction of the
requirements for the degree
Doctor of Environmental Science and Engineering

by

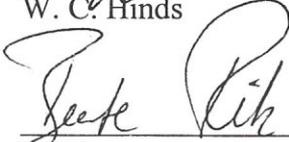
Scott Anthony Fruin

2003

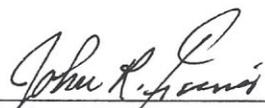
The dissertation of Scott Anthony Fruin is approved.



W. C. Hinds



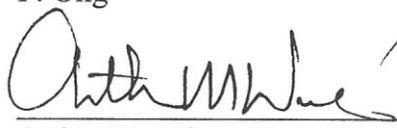
B. Ritz



J. Froines



P. Ong



Arthur M. Winer, Committee Chair

University of California, Los Angeles
2003

TABLE OF CONTENTS

	Page
Dedication	iii
Table of Contents	iv
List of Figures	viii
List of Tables	ix
List of Acronyms	xi
Acknowledgements	xiii
VITA	xiv
ABSTRACT	xvii
1 INTRODUCTION	1
1.1 Importance of Vehicle Emissions To Air Pollution	1
1.2 Diesel Exhaust Health Concerns and Control Measures	1
1.3 Importance of Vehicles Emissions to Exposure	2
1.3.1 Roadside and Near Roadway Concentrations	2
1.3.2 Traffic and Health Effects	4
1.3.3 In-Vehicle Concentrations	6
1.4 Overview of the In-Vehicle Field Study	8
1.4.1 Overview of Reported Results of the Field Study	10
1.5 Exploratory Analysis	12
1.6 Research Objectives	14
1.6.1 Overall Objectives	14

	1.6.2	Specific Research Objectives	15
	1.7	Synopsis of Methods	16
	1.8	Organization of This Work	17
2		METHODS	19
	2.1	Black Carbon and Fine Particle Count Measurements	20
	2.2	Field Measurements Data Processing and Quality Control Procedures	21
	2.3	Additional Data Generation	24
	2.4	Observation Label Assignment Protocol	27
	2.5	Data Analysis Methods	29
	2.6	Traffic Characterization	31
	2.7	Sensitivity and Uncertainty Analyses	32
	2.8	Exposure Modeling	33
3		STATISTICAL ANALYSIS	34
	3.1	Multiple Linear Regression Analysis	35
	3.2	Autocorrelation and Data Grouping Rules	48
	3.3	Averaging Method and Removal of Bias	52
	3.4	Distribution Selection, Procedures for Handling Negative Values, and Tests for Normality	55
	3.5	Distribution-to-Distribution Comparisons	60
	3.6	The Use of Theoretical Distributions in the Exposure Model	61

3.7	Conversion of Black Carbon Concentrations to DPM Concentrations	66
3.8	Summary of Exposure Modeling Distribution Inputs	67
3.9	Summary and Significance of Statistical Testing Results	68
4	REPRESENTING CALIFORNIA DRIVING: DIESEL FOLLOWING TIMES, CONGESTION, AND ROAD TYPE	69
4.1	Linking Traffic Volume and Traffic Density Data to BC Measurements	70
4.2	Statewide Diesel Vehicle VMT Fractions by Vehicle and Road Type	73
4.2.1	Diesel Vehicle-Type Following Rates Observed in the Study	77
4.3	Traffic Density Differences	79
4.4	Arterial versus Freeway Weighting	84
5	EXPOSURE MODELING RESULTS, SENSITIVITY ANALYSIS, AND UNCERTAINTY ANALYSIS	88
5.1	Overview of the California Population Indoor Exposure Model	88
5.2	Overview of Previous DPM Exposure Modeling	92
5.2.1	Outdoor Ambient DPM Concentrations and Estimated Uncertainties	92
5.2.1.1	Uncertainty Propagation	92
5.2.1.2	Derivation of Outdoor Ambient DPM Concentration Uncertainty	93
5.2.1.3	Results of Outdoor Ambient DPM Concentration Derivation	100

5.2.2	Indoor DPM Concentration Calculations and Estimates of Uncertainty for Key Inputs	101
5.3	Sensitivity Analysis for Indoor Concentration Calculations	108
5.4	Results of Uncertainty Testing for Indoor Concentrations	110
5.5	Results and Uncertainty of Overall DPM Exposure Calculations without the In-Vehicle Microenvironment	113
5.6	Results of Sensitivity Tests for Overall DPM Exposures Including In-Vehicle Concentration Distributions	116
5.7	Uncertainty Analysis of the Overall DPM Exposures Including In-Vehicle Concentration Distributions	120
5.8	Exposure Estimates Using New In-Vehicle DPM Distributions	123
6	POLICY IMPLICATIONS AND CONCLUSIONS	129
6.1	Principal Findings	129
6.1	The Relative Importance of On-Road versus Off-Road DPM Emissions and their Implications for Control Measure Priorities	131
6.2	Implications of Multiple Regression Analysis Results	134
6.3	Implications of Uncertainty Analysis Results	136
6.4	Implications for Future DPM Exposure and In-Vehicle Exposure Studies	137
	APPENDIX A	141
	APPENDIX B	147
	REFERENCES	155

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Arthur Winer for guidance provided during this work and for help editing the manuscript. The prospectus committee of Drs. John Froines, William Hinds, and Beate Ritz of UCLA also provided valuable additional guidance.

I would like to acknowledge the work of Steve Hui, Air Resources Board, and Charles Rodes, Research Triangle Institute, for their contributions towards making the original in-vehicle field study possible and successful, which produced the data that this work was based on. The Air Resources Board in general deserves kudos for funding such an intensive field study and in further financially supporting and encouraging my detailed analysis of the results. Also at the Air Resources Board, statisticians Jeff Austen, Hien Tran, and especially Larry Larsen all provided valuable input and guidance regarding the application and interpretation of the many statistical methods used.

Lastly, I would like to thank my wife, LaRonda, for valuable proof-reading and editing of the many revisions that helped make this complicated work as readable as it is.

VITA

1984	B.S. Mechanical Engineering, High Honors University of Minnesota Minneapolis, Minnesota
1985	M.S. Mechanical Engineering University of Minnesota Minneapolis, Minnesota
1985-1988	Mechanical Engineer, Management-Level Bell Laboratories Holmdel, New Jersey
1989-1995	Consulting Engineer RUST Environment and Infrastructure Minneapolis, MN
1995-present	Doctoral Student UCLA, School of Public Health Los Angeles, California
1996	Chancellor's Fellowship UCLA Los Angeles, California
1998	Center for Risk Reduction Fellowship UCLA Los Angeles
1999-2000	Air Pollution Specialist California Air Resources Board El Monte, California.
2000	Switzer Environmental Fellowship
2000-Present	Air Pollution Engineer California Air Resources Board Sacramento, California

PUBLICATIONS AND PRESENTATIONS

Bartz, H., Fissan, H., Helsper, C., Kousaka, Y., Okuyama, K., Fukushima, N., Keady, P.B., Kerrigan, S., Fruin, S.A., McMurry, P.H., Pui, D.Y.H., Stolzenburg, M.R. (1985) "Response Characteristics for Four Condensation Nucleus Counters to Particles in the 3-50 nm Diameter Size Range." Journal of Aerosol Science, 16:443-456.

Fruin, S. "Fine Particle and Black Carbon Concentrations Inside Vehicles." Presented at the International Society of Exposure Analysis Annual Conference, Monterey, CA., Oct. 2000.

Fruin, S. "Reductions in Benzene Exposure in the South Coast Air Basin." Presented at "Issues in the Assessment of Health Impacts of Gasoline Emissions in California." Los Angeles, CA., June, 2001.

Fruin, S.A., St. Denis, M.J., Winer, A.M., Colome, S.D., and Lurmann, F.W. (2001). Reductions in Human Benzene Exposure in the California South Coast Air Basin. Atmospheric Environment, 35:1069-1077.

Fruin, S. "Roadway and Vehicle Pollutant Concentrations and Exposures in California." Presented at the conference "Approaches to Assessing Health Impacts of Gasoline-Related Exposures in California" by the Office of Environmental Health Hazard Assessment, Oakland, CA., June, 2000.

Fruin, S., Elnabarawy, M., and Duffy, D.P. (1994) A Multi-Media Environmental Impact Study for a Manufacturing Facility Incinerator. Proceedings of the Air and Waste Management Association's 87th Annual Meeting and Exhibition, Cincinnati, OH.

Patterson, B.C., Fruin, S., and Elnabarawy, M. (1995) Assessing Ambient Incinerator Impacts Near the Limits of Detection Using Reconciled Dispersion and Receptor Model Techniques. Proceedings of the Air and Waste Management Association's 88th Annual Meeting, San Antonio, TX.

Pui, D.Y.H., Fruin, S., and McMurry, P.H. (1988). "Unipolar Charging of Ultra Fine Aerosols". Aerosol Science and Technology, 8:173-187.

Ritz, B., Yu, F., Chapa, G., and Fruin, S. (2000). "The Effect of Air Pollution on Preterm Birth Among Children Born in Southern California Between 1989-1993." Epidemiology. V11, N5:502-511.

Ritz, B., Yu, F., Fruin, S., Chapa, G., Shaw, G., Harris, J. (2002) "Ambient Air Pollution and Risk of Birth Defects in Southern California." Am. J. of Epidemiology. 1:17-25.

Stevens, J.B., Fruin, S.A., Clark, L.K., and McMurtry, M.G. (1995) "Health Risk Analyses Using Receptor Modeling of Ambient Air Sampling Results." Proceedings of the Air and Waste Management's 88th Annual Meeting, San Antonio, TX.

ABSTRACT OF THE DISSERTATION

Characterizing Black Carbon Inside Vehicles:
Implications for Refined Exposure Assessments
for Diesel Exhaust Particulate Matter

by

Scott Anthony Fruin

Doctor of Environmental Science and Engineering

University of California, Los Angeles, 2003

Professor Arthur M. Winer, Chair

Diesel-powered vehicles are now the most important mobile source of particulate matter and oxides of nitrogen. There is also evidence that diesel exhaust particulate matter (DPM) may be carcinogenic. However, accurate assessments of human exposure to DPM have been lacking. One of the most important routes of exposure, time spent in vehicles, has never been quantified. This thesis research fills this gap by analyzing the real-time black carbon (BC) measurements from a recent large study of in-vehicle pollutant concentrations.

Analysis of video tapes made during the study's driving runs was used to make adjustments for atypical driving. The BC measurements were linked with observable driving factors such as following distance and the type of vehicle

followed. The highest BC concentrations occurred almost exclusively while following diesel vehicles, especially those with visible emissions and those with low exhaust locations. Followed-vehicle type explained a large portion of the variability in the in-vehicle BC concentrations. BC data were grouped by the most important predictive factors that could also be linked to typical driving, such as the type and number of axles of the followed vehicles, roadway type, and relative amount of traffic congestion. Realistic driving was then simulated by sampling from the concentration data groupings via a stochastic exposure model. In-vehicle exposures as well as total exposures were calculated for different regions of California, and an extensive analysis of uncertainty was also conducted.

One-third of total exposures was due to time spent in vehicles, making time spent in-vehicles the most important route of DPM exposure on a per time basis. Based on exposures occurring in vehicles and estimated emissions from on-road versus off-road sources, on-road emissions appeared to be about three times more important, on an equal mass basis, at producing DPM exposures. The uncertainty analysis showed almost all uncertainty in the exposures was due to the uncertainty in the fraction of ambient particulate matter due to diesel vehicles, as estimated from the EMFAC mobile source model. The EMFAC model relies on relatively few tests of diesel vehicles compared to gasoline-powered vehicles.