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1999 Vermont Remote Sensing Study

Final Report

Prepared for:

The State of Vermont
Agency of Natural Resources
Air Pollution Control Division

By:

THE AIR QUALITY LABORATORY

Georgia Institute of Technology
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GLOSSARY

AQL	*Air Quality Laboratory*
CO	*Carbon Monoxide*
CO_2	*Carbon Dioxide*
DEC	*Vermont Department of Environmental Conservation*
DMV	*Vermont Department of Motor Vehicles*
EPA	*U.S. Environmental Protection Agency*
GIT	*Georgia Institute of Technology*
HC	*Hydrocarbons (typical formula,* C_nH_{2n+2}*, but also* C_nH_{2n}*, and* C_nH_{2n-2}*)*
I/M	*Inspection and Maintenance*
IR	*Infrared*
NDIR	*Non-Dispersive Infrared Spectroscopy*
NO_x	*Nitrogen Oxides*
PPM	*Parts-Per-Million by Volume*
RSD	*Remote Sensing Device*
ESP	*Environmental Systems Products, Incorporated*
SDM	*Source Detector Module*
RDB	*Registration Database*
RPM	*Revolutions per minute*
RST	*Remote Sensing Technology*
UV	*Ultraviolet*
VRES	*Vermont Remote Emissions Survey*
VIN	*Vehicle Identification Number*
VOC	*Volatile Organic Compounds (hydrocarbons and carbonyls)*
μm	*Micrometer*
nm	*Nanometer*

EXECUTIVE SUMMARY

During September and October of 1999, the Air Quality Laboratory of the Georgia Institute of Technology conducted a survey of on-road motor vehicle emissions throughout the State of Vermont under contract with the Vermont Agency of Natural Resources. This survey was the second in an annual series of measurements, begun in 1998, to document the emissions characteristics of the motor vehicle fleet operating on the highways of Vermont. In this study, an optical remote-sensing device (RSD) was used on the roadside to measure the exhaust gas concentrations of motor vehicles passing the sensor. Measurements were conducted at eleven locations in eight counties across Vermont. In a total of twenty-four measurement days, 96,603 vehicles passed the RSD. Valid remote sensing readings were recorded for 63,598 (66%) of these vehicles of which approximately 90% had readable license tags. This resulted in 57,024 license tags that could be compared to motor vehicle registration data.

Georgia Tech personnel entered these license tags, along with the accompanying emissions data, into a database in fall of 1999. Approximately 82% of the measured vehicles were found to have Vermont license tags and, of these, about 82% were successfully matched to complete Vermont Motor Vehicle Registration records. The Vehicle Identification Numbers (VIN) returned from the registration data were then decoded to provide information on vehicle type, model year, and a variety of other parameters for use in subsequent data analysis.

Analysis of these data has yielded a number of insights into the emissions characteristics of the Vermont fleet. First, motor vehicle emissions were observed to increase with vehicle age. This effect is due both to differences in vehicle technology (e.g. improvements in fuel control and catalyst technologies in recent years) as well as deterioration and failure of vehicle components as vehicles age. The oldest vehicles are the highest emitting but also tend to be relatively few in number. Newer vehicles are much more numerous but tend to have very low emissions. As a result of these two competing forces (deterioration and number of vehicles) the bulk of total vehicle emissions (>70%) can be attributed to "middle age" cars and light duty trucks (i.e., those between five and fifteen years of age) that exhibit both significant numbers and moderate to high emissions.

A second observation is that the fraction of very high emitting vehicles (i.e. more than three times emissions standards) is very low, approximately 5%, but these vehicles contribute about 40% of total vehicle emissions. Third, comparison of data from 1998 and 1999 indicates that overall vehicle emission factors (grams/mile) for the Vermont fleet declined by about 6% over this period. Most of this decrease could be traced to the retirement of older, higher emitting, vehicles. The extent to which this decrease in emissions rate was offset by increased vehicle activity was not evaluated.

A fourth conclusion of the study was that out-of-state vehicles were observed to have comparable but slightly lower emissions than Vermont registered vehicles and thus these out-of-state vehicles do not contribute disproportionately to overall emissions within the state. Lastly, remote sensing of vehicle emissions in Vermont has proven to be both feasible and highly cost-effective. The emissions measurements in this study were collected, entered into the database, matched with registration data and analyzed for a cost of $1.14 per valid measurement. This cost is approximately one-seventh of the cost of comparable data collected using idle testing and one twenty-fifth of the cost of conducting I/M 240 vehicle emissions testing. Using the most restrictive criteria (i.e. only considering Vermont vehicles for which valid readings were achieved on all parameters and complete registration records could be obtained) still results in a per-vehicle cost of about $1.69.

Recommendations for future studies based on these results include: 1) continuation of the multi-year remote sensing as the value of the data for comparison purposes increases with the length of the study; 2) conducting these additional studies at the same time of year to ensure comparable fleets and minimal changes in motor fuels; 3) modifying the field schedule to account for the fact that rural populations are under-represented in the data; 4) consideration be given to including a study of motor vehicle travel to assess overall emissions trends, and 5) further efforts to improve the matching of vehicle license tags to the Vermont registration database to provide even lower costs-per-vehicle.

1. INTRODUCTION

Emissions of carbon monoxide (CO), reactive hydrocarbons (HC), and nitrogen oxides (NO_x) from motor vehicles adversely impact human health and the environment by contributing to the formation of photochemical smog, acid deposition, regional haze and elevated CO levels. Near the Earth's surface, reactions of NO_x and HC in the presence of ultraviolet light leads to the formation of ozone (a principal component of photochemical smog) and are major contributors to regional haze formation. In most areas, motor vehicles are the dominant source of CO emissions, the largest source of NO_x emissions and are a major source of HC emissions. Carbon monoxide, like ozone and NO_x, is a respiratory irritant regulated as a criteria pollutant by the United States Environmental Protection Agency (EPA) as well as a minor contributor to ozone formation.

In many states, including Vermont, emissions from industrial sources have declined more rapidly over the last decade than have emissions from mobile sources. As a consequence, the control and reduction of on-road motor vehicle emissions is receiving increasing emphasis in Vermont, as in most other states.

Knowledge of the relative contributions of different types of motor vehicles to each type of emission and the sensitivity of these emissions to characteristics such as vehicle age, maintenance, and activity patterns is important to urban and regional air quality control and the protection of human health and the environment. In principle, these data can be gathered either through periodic tail pipe emissions testing (e.g., in a vehicle inspection/maintenance program) or through on-road measurements. In practice, this evaluation is best done on the roadways where the actual emissions take place and modern remote sensing technologies enable these measurements to be made. For this reason, in 1998 the Vermont Agency of Natural Resources embarked on a program of on-road vehicle remote sensing. This program was designed to examine the emissions of the Vermont fleet and to track the changes in the emissions of this fleet over time for purposes of evaluating needs for motor vehicle emissions control and development of effective control strategies. The Georgia Tech Air Quality Laboratory was selected to conduct the studies in both 1998 and 1999. This report summarizes results from the 1999 study.

Remote Sensing Background

Vehicle Remote Sensing systems are based upon the absorption of light by the individual constituents that make up the vehicle exhaust plume. Infrared (IR) spectroscopy is used to measure concentrations of CO and HC while ultraviolet (UV) spectroscopy is used to measure NOx. A schematic diagram of a remote sensing device (RSD) making on-road vehicle exhaust measurements appears in Figure 1 below. Light from a source placed along the roadway is transmitted to a mirror located on the opposite side. The light is reflected back to a co-located detector. The measurement cycle is initiated by the passage of a vehicle that interrupts this beam of light. After the vehicle has passed, the gases in the vehicle's exhaust reduce the amount of light received by the detector compared with that measured immediately before or well after the passage of the vehicle. This reduction in received light (absorption) is used to quantify the concentration of the individual pollutant compounds through a calibration process.

Figure 1 On-Road Remote Sensing Setup.

In addition to the source and detector, remote sensors normally include a camera system to record vehicle license tags to aid in identifying individual vehicle characteristics. The systems are often equipped with meteorological stations and/or vehicle speed/acceleration systems, which can be important in interpreting exhaust measurements due to the influence of vehicle load and environmental conditions. The RSD technology is capable of measuring the CO, HC, and NO_x exhaust emissions of many thousands of vehicles per day and provides a practical approach for routinely characterizing on-road vehicle emissions.

Uses of Remote Sensing

Since remote sensing can make emission measurements "on road", it has several possible regulatory uses. Remote Sensing has been used to determine fleet average emissions for inventory purposes either as a primary tool or as a crosscheck on other methods. It has been used to characterize fleet emissions distributions for evaluation of potential and/or actual emissions control programs and to compare different fleets for benchmarking purposes. Remote Sensing has also been used to evaluate the evolution of fleet composition and emissions over time. In principle, the results of the Vermont studies may be used for any of these purposes.

In addition to the fleet characterization activities described above, Remote Sensing can also be used to identify individual vehicles. Given its ability to identify both very clean and very dirty cars, several states have adopted or are considering adopting remote sensing as a supplement to their vehicle Inspection and Maintenance programs (I/M). Remote Sensing is currently being used to identify high emitters for additional I/M tests in a number of states (e.g. Texas, California, and Georgia) and to excuse clean cars from regularly scheduled tests (e.g. Missouri and Colorado). Both of these applications are based on previous remote sensing studies that have shown that most of the measured on-road emissions (>50%) come from a small percentage of the vehicles (approximately 10%). This is also the case for Vermont, where the 1999 remote sensing data show that 12% of the fleet contributes about 64% of emissions.

Despite these advantages, the RSD approach is not without drawbacks. Most notably, remote sensing measurements are only a snapshot (< 1 sec) of the emissions of a vehicle. Vehicle emissions are highly variable and thus the greatest value of remote sensing is in a statistical sense where numerous observations can be averaged to yield accurate fleet characteristics. Secondly, RSDs have specific siting requirements regarding visibility, single lane operation, absence of maneuvers, no cold-start operations etc. that severely limit the range of locations that can be observed by remote sensing. These factors place a premium on site selection to ensure that the available sites are both suitable for remote sensing operations and are representative of the local operational fleet. These factors will be discussed later in the text. Additionally, in its current form, RSD technology is limited to measurements of tailpipe emissions and provides no information regarding the performance of vehicles in regard to evaporative emissions and running losses.

2. PROJECT DESCRIPTION

As mentioned earlier, during 1998 the Vermont Agency of Natural Resources, Air Pollution Control Division (ANR) undertook a study to evaluate the emissions characteristics of the Vermont fleet statewide. This project had the aim of evaluating the existing Vermont fleet and its evolution over time by a series of annual remote sensing observations. To operate this program, ANR contracted with the Georgia Tech Air Quality Lab (AQL) to conduct the RSD measurements. AQL has extensive experience in remote sensing having conducted more than twenty studies since 1991 and had previously made remote sensing measurements in Burlington, VT for U.S. EPA.

Site selection is perhaps the most important aspect of a successful remote sensing program. Since the RSD senses the emissions of the vehicle for only a brief period (<1 sec), the physical characteristics of the site, traffic conditions, driver behavior, and inherent variability of the vehicle all contribute to fluctuations in the measurements. A favorable site enforces a moderate and constant load on the vehicle to ensure that the vehicle's emissions are as close as possible to their long-term average. Since engine load is a function of vehicle speed, road grade and acceleration of the vehicle, many of the factors influencing vehicle load are controlled by the physical characteristics of the site. The ideal site should have a positive slope of 1 to 3 percent and require that the vehicles pass the site with a slight acceleration rather than coasting or braking. These conditions ensure that the vehicle is operating under moderate load and that emissions are most representative of the vehicle's typical emissions. These conditions cannot always be met at sites needed to achieve good fleet representation and techniques have been developed to use sites having different characteristics.

Preliminary site selection for the Vermont study was conducted in April 1998, in conjunction with the first year of the study. The initial site selection involved identifying major intersections as a means of narrowing the search process. Based on previous experience, the best sites tend to be located on highway entrance ramps where major roads provide a high traffic flow to the highway. Other candidate sites included roads with single lane operations where there is adequate space on the shoulder for setting up equipment and vehicles are traveling at speeds less than 40 miles per hour. Roads having a median sufficient for staging equipment were also evaluated.

Twelve sites were ultimately selected and valid measurements were obtained on eleven of these sites. Two sites were located in Burlington and the remainder were distributed throughout the rest of the state and included representation of most of the remaining major population centers (i.e., Rutland, White River Junction, Montpelier, Brattleboro, Barre, St Johnsbury and Bennington). All of the sites selected for the Vermont Remote Sensing Study had favorable site geometry with zero or positive slopes, limited accelerations and manageable vehicle speeds. Detailed characteristics of each of the sites is provided in the appendix.

The only significant problems associated with the Vermont sites were due to high vehicular speeds that reduced the number of valid readings at several of the sites. This problem lead to adjusting the location of the measurement van at the Brattleboro site during data collection. In no case, however, was the impact sufficiently large to adversely impact data analysis and interpretation.

While small-scale effects, such as site geometry, are important to achieving valid remote sensing readings, the overall distribution of sites is equally important to producing data that can be effectively interpreted. Figure 2 shows a map of several site locations throughout central Vermont focusing on the overall distribution of sites. In Figure 2, triangles locate the measurement sites and show the extent to which good remote sensing sites tend to be associated with Interstate and major arterial highways.

Figure 2 Central Vermont Remote Sensing Sites

As with most other remote sensing studies, the sites used in the 1998 Vermont study tended to focus on the most populous areas. While this approach maximizes the total number of valid remote sensing readings, it also tends to under-represent rural and lower income populations in the collected data. For 1999, these more populous sites were supplemented by additional sites, especially in rural northeastern Vermont, to avoid too substantial a "town and country" sampling bias. Drawing on experience from the 1998 study, three new sites were selected and sampled. Eight of the sites chosen were the same sites used in 1998.

As the most populous urban area, Burlington was treated as a separate "sub-study" and site selection in this area was conducted in consultation with local authorities to minimize the risk of socio-economic bias in the sampling. While a potential problem, the road network and size of the city make this less of a consideration than when sampling in much more populous areas (e.g. New York or Boston).

In summary, the overall experimental design of the 1999 Vermont study was optimized for effective fleet characterization. The intent of this optimization/prioritization was to improve the representativeness of the resulting sample at some cost in terms of sample size. This reduction in sample size will tend to inflate the cost-per-valid-sample by as much as 25% compared to a study aimed at minimizing per-sample costs by focusing only on high volume sites.

3. DATA COLLECTION

A single RSD unit (Environmental Systems Products Accuscan 3000, serial number 532) was used for all remote sensing data collection during the Vermont program. This unit underwent multi-point calibrations both before and after the sampling at AQL's Hopkins Laboratory and underwent field tests immediately prior to deployment at the manufacturer's (ESP) facility in Hartford, Connecticut.

Sampling took place over a one-month period between September 29th and October 29th of 1999. During this period, remote sensing measurements were conducted at twelve sites for a total of 24 sampling days. Poor weather at the Morrisville site resulted in no usable measurements from this site and thus measurements are reported for only eleven sites. For each vehicle sampled, data concerning its speed/acceleration and CO, NOx, and HC emissions were collected and stored along with a license plate image. Daily meteorological data were recorded but not archived or used in subsequent analysis since conditions varied over a relatively narrow range. Puff calibrations were performed every three hours and after realignment of the system.

For the 1999 measurements, the data collection process was enhanced by the use of a newly implemented software package developed by AQL. The software, known as Analyzer, enabled seamless importation of the data generated by the remote sensing instrument directly into a Microsoft Access database. This allowed a preliminary field analysis of the data collected each day. The field analysis included a preliminary evaluation of CO, HC and NOx concentrations, vehicle speed, acceleration and descriptive statistics on measured parameters. These data sets allowed better field evaluation of the efficiency of data collection at each site and improved the ability of the field staff to make adjustments that improved data capture.

Summaries of each of the measurement days' results are presented in Table A-2 of the Appendix. This Table summarizes relevant statistics on vehicle counts and descriptive statistics associated with the measurements made at the site along with the number of valid observations and puff calibrations. These site summary data have been provided in a more complete form on the CD-ROM accompanying this report. A complete description of the data fields used in these analysis files can be found in Tables A3-A5 in the Appendix and on the CD-ROM.

Summary of Program Measurements

Following the field measurements, the entry of license plate information into the emissions records was performed by AQL data entry personnel between November 15, 1999 and December 31, 1999. Tables 1A and 1B summarize the data collection effort for the 1999 Vermont Remote Sensing Study in terms of license plate recognition and emissions measurements (using CO as an indicator), respectively. During the data collection period a total of 96,603 vehicles triggered the RSD. Of these, 63,598 vehicles had valid readings for CO, and 60,094 vehicles had readable license plates. Simultaneous valid CO readings and readable plates were recorded for 57,024 vehicles. Vermont vehicles accounted for 82.2% (46,861) of these fully valid readings. A number of vehicles were seen on multiple occasions, with 8,232 individual vehicles observed two or more times.

The 46,861 Vermont license tags were then matched with the Vermont DMV registration database. As a result of this matching process, a valid Vehicle Identification Number (VIN) was recovered for 38,428 valid measurement records. This represents a data recovery rate of 82.2%, which is well above average performance for this type of matching. Experience in other projects has ranged from values of about 50% to about 90% with most registration database matches in the range of 60-75%. This indicates that Vermont is well positioned to benefit from remote sensing data. We are confident that better coordination between AQL and Vermont DMV on the resolution of ambiguities in the database would yield matching rates equal to or greater than 90%. The VINs were decoded using a commercial VIN decoding package (Radian) yielding information regarding engine parameters, emissions control equipment, vehicle model year, vehicle type and other variables. These data were merged with the remote sensing records to produce the consolidated remote sensing database on the accompanying CD-ROM.

Table 1 Analysis of the Number of Vehicles Triggering RSD (beam blocks)

Part A License Plate Analysis

Beam Blocks of RSD	Readable License Plates	Readable Plates Portion of Beam Blocks	Readable Plates with VT Tags	VT Portion of Total Readable Plates	Readable Plates from other states	Other States Portion of Total Readable Plates
1	2	3	4	5	6	7
96603	60094	62.21%	50485	84.01%	9415	15.67%

Part B CO Measurement Analysis

Beam Blocks of RSD	Valid CO Data	Valid CO Data Portion of Beam Blocks	Valid CO Data with Readable Plates	Portion of Valid CO with Readable Plates	VT Plates with Valid CO	VT Portion of Total Valid CO	Other States Plates with Valid CO	Other State Portion of Valid CO
1	8	9	10	11	12	13	14	15
96603	63598	65.8%	57024	89.7%	46861	82.2 %	10163	17.8%

Geographical Distributions of Measurements

Table 2 gives the distribution of valid CO measurements and the measurement dates for total and VT-registered vehicles observed in each of the eight counties sampled during the 1999 measurement program. Table 3 gives similar information, but references the VT-registered vehicle measurements to county population for comparison of observed vehicles and human population statistics. As can be seen from Table 3, most low population-density areas tended to be under-sampled relative to their populations with Chittenden and Windham counties being somewhat over-sampled. This is a common result in this type of study. Urban areas and larger towns normally exhibit higher densities of both population and commercial enterprises than smaller communities. The higher levels of vehicle activity generated by these people and businesses are routed through a limited number of roadway facilities (roads, ramps, bridges, etc.). Thus urban roads tend to carry more vehicles-per-lane-per-hour than comparable roads elsewhere.. Since sampling takes place on these roads, comparable sampling time tends to over-represent urbanized areas.

With the exception of the over-sampling in Windham county, and the aforementioned under-sampling in the least populous counties, the sample populations are in good agreement with the population statistics. This is a very good result for such a limited sampling program and shows that the general sampling plan was sound and can be adopted, with minor changes (e.g., more emphasis on rural northeastern Vermont) for future measurement cycles.

Table 2 Summary of Measurements by Vermont Counties

County	Number of Sites in County	Valid CO Records Collected in County	Vermont Plates with Valid CO Records Collected in County	Date(s)
Bennington	1	5561	3812	10/16/99, 10/29/99
Caledonia	1	2152	1770	10/22/99
Chittenden	2	23892	17868	09/29/99, 10/05/99, 10/06/99, 10/08/99, 10/24/99, 10/25/99, 10/26/99
Orleans	1	3145	2636	10/21/99
Rutland	1	6898	5367	10/11/99, 10/12/99
Washington	2	6818	5685	10/01/99, 10/02/99, 10/07/99
Windham	1	10802	6825	10/15/99, 10/18/99, 10/19/99
Windsor	2	4330	2898	10/13/99, 10/14/99, 10/27/99, 10/28/99
Total	11	63598	46861	

Table 3 Population and Sample Distribution by County

	Population	% of Total Population	Valid Measurements from County	% of Total Valid Measurements	Difference
Bennington	35968	7.65	5561	8.10	0.45
Caledonia	28,702	6.10	2152	3.64	-2.47
Chittenden	141,591	30.11	23892	38.23	8.12
Lamoille	21,461	4.56	234	0.47	-4.10
Orleans	25319	5.38	3145	5.40	0.02
Rutland	62727	13.34	6898	11.25	-2.09
Washington	56498	12.01	6818	12.94	0.92
Windham	42856	9.11	10802	14.19	5.07
Windsor	55174	11.73	4330	5.79	-5.94

Distribution by Vehicle Type

The vehicle distribution by vehicle type is given in Table 4. Note that not all VIN's could be decoded to yield a vehicle type. The number of vehicles having the registration type of "Car" or "Truck" suggests a sufficient sample set to perform a more detailed statistical analysis.

Table 4 **Vehicle Distributions by the Registration Type**

Registration Type	Vehicle Type	Vehicle Count
A	Automobile	33962
B	Truck	6413
C	Trailer	72
D	Agricultural	11
E	Dealer	344
F	Transport	9
G	Motorcycle	9
H	Highway use permit	6
I	Bus	9
J	Municipal Government	89
K	State Government	47
Not Identified	Not Identified	5890
Total		46861

4. DATA ANALYSIS

Remote sensing data is rich in information and may be used to answer a variety of questions. Remote sensing studies, including this one, routinely make thousands or tens-of-thousands of individual observations and thus have great statistical power. In this discussion we will focus on only a few evaluations. These will be the impact of older vehicles and high emitters on overall emissions, the degradation of vehicles by observing the same vehicle one year apart (i.e. vehicles observed in both 1998 and 1999), the differences between cars and trucks and the differences between in-state and out-of-state vehicles.

Companion CD-ROM:

As mentioned earlier, emissions data collected for each vehicle included vehicle exhaust gas concentrations of CO, CO_2, HC, and NO_x as well as other parameters. The companion CD-ROM to this report contains the final 1999 consolidated remote sensing data from which all of the products in this section have been derived. The CD-ROM also contains the Site Descriptions and Site Summary information given in the Appendix to this report.

As an aid to data analysis, histograms indicating the frequency distribution of emissions in mixing ratio units have been produced for several possible data divisions and are included in the companion CD-ROM. These diagrams are presented as Microsoft Excel™ files and were produced using the Analyzer software package described previously. A listing of these histograms and the remainder of the files on the CD-ROM is given in Table 5.

Table 5 CD-ROM data files and descriptions

1.	Vermont99summreport.doc	This Summary report
2.	Summary Data Collection Report For Vermont99.doc	Summary data collection
3.	Summary Site Report For Vermont99.doc	List of All sites
4.	Data Collection Report Vermont1999.doc	Data Collection report
5.	Working Site Report for Vermont99.doc	List of site selected for remote sensing
6.	Vermont99AllValid.xls	Histogram for all valid reading
7.	Vermont99StateLP.xls	Histogram for state vehicles
8.	Vermont99OutOfStateLP.xls	Histogram for non state vehicles
9.	Vermont99Automobile.xls	Histogram for all vehicles registered as automobile
10.	Vermont99Truck.xls	Histogram for all vehicles registered as truck
11.	Vermont99Rural.xls	Histogram for all vehicles registered outside Burlington area
12.	Vermont99Urban.xls	Histogram for all vehicles registered in Burlington area
13.	Vermont99Sites.xls	Histogram for each site visited
14.	Vermont99County	Histogram combined site for each County visited
15.	Vermont99.mdb	Data base with all table
16.	*.jpg (57 pictures)	All digital pictures
17.	*.bmp (57 sketches)	All digital sketches

Some of the Excel files on the CD-ROM contain more than one worksheet. Each worksheet contains the actual emissions data for the histograms, the descriptive statistics, and the associated charts. The first three sheets in each workbook contain histograms of CO, HC, and NOx emissions respectively. The last sheet provides the descriptive statistics table. The first graph on each page shows the frequency distribution for the corresponding emission components.

High Emitter Influences

A traditional way of viewing remote sensing data is to consider the relative contribution of various portions of the fleet to total fleet emissions (Stedman Plot). Figure 3 below shows the cumulative fraction of vehicles (the cumulative function starts from the maximum value rather than the minimum value) and its contribution to total emissions of this component taken from the 1999 Vermont Measurement Program. The total fraction of pollution is found on the vertical axis, along with the percentage contribution of the vehicles. The top of the graph indicates that 100% of the vehicles and 100% of the CO pollution is from this population of vehicle emissions. The horizontal axis is the percent of CO found in the exhaust plume. The sample interpretation provided is described as follows: 12% of the vehicles (from the vertical axis) are exceeding emission levels of 1.2% of CO (move from the 12% to the lower curve, then down to the axis). At the same time, those vehicles contribute 63.8% of the total vehicle emissions. This value can be found by using the upper curve, and tracing 1.2% upward from the horizontal axis, to the curve, then moving left to the total percent of pollutants. Conversely, one can see that 88% of vehicles have CO emissions of less than 1.2%, only contributing 36.2% of total pollution from this population. The data indicate that only a few vehicles are high polluters, while most vehicles contribute very little to total vehicle pollution.

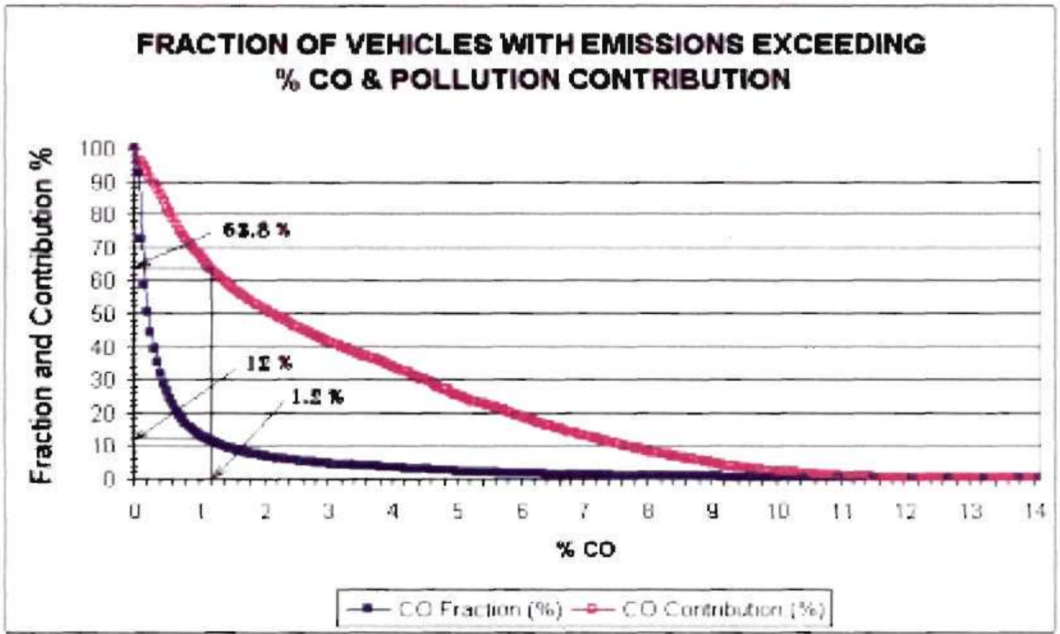


Figure 3. Cumulative Fraction of Vehicles and their Cumulative Contribution to Total CO Emissions

4.1 DESCRIPTIVE STATISTICS

A simple, but effective, way of examining remote sensing data is through simple descriptive statistics. Tables 6, 7, and 8 give summary results for CO, HC and NO_x emissions respectively. These results show that the Vermont-registered (i.e. in-state) vehicles have a higher mean value for emissions than the out-of-state vehicles. This is a somewhat counter-intuitive result but is almost universally observed. This does not imply that Vermont residents operate dirtier vehicles but rather is due to human behavioral tendencies. Vehicles observed operating *near* their home base-of-operations (i.e. most in-state vehicles) tend to be representative of *all* the vehicles available to their drivers. Vehicles observed operating a substantial distance *away* from their home base-of-operations (i.e. most out-of-state vehicles) tend to represent the *best* vehicles available to their drivers. When sampled, the emissions distribution of these "best available vehicles" is almost always cleaner than that of the local "all available vehicles" regardless of differences in I/M and other factors. The results also demonstrate a higher variability of emissions among these out-of-state vehicles (standard deviation of 1.0016 compared to 0.8397) than for in-state vehicles. Tables 6-8 also confirm the hypothesis that trucks have higher levels of emissions than cars.

Table 6 **CO Emissions Descriptive Statistics (in percent)**

Descriptive Statistics	All Valid Vehicles in sample 1999	Vermont Registered Vehicles sampled 1999	Vermont Registered Vehicles sampled 1998	Non Vermont Registered Vehicles sampled 1999	Vermont Registered Cars sampled 1999	Vermont Registered Trucks sampled 1999
Mean	0.361478	0.362823	0.4170	0.283916	0.346735	0.457108
Standard Error	0.005145	0.004627	0.0061	0.008328	0.005328	0.015556
Mode	0.02	0.02	0.0200	0.01	0.02	0.02
Standard Deviation	1.006651	1.00166	1.07	0.839711	0.951453	1.205652
Range	12.71	12.72	13.44	12.67	12.69	12.42
Count	38281	46861	30637	10167	31889	6007

Table 7 **HC Emissions Descriptive Statistics (in PPM)**

Descriptive Statistics	All Valid Vehicles in sample 1999	Vermont Registered Vehicles sampled 1999	Vermont Registered Vehicles sampled 1998	Non Vermont Registered Vehicles sampled 1999	Vermont Registered Cars sampled 1999	Vermont Registered Trucks sampled 1999
Mean	64.0505	66.35245	98.23	49.739	62.24942	82.88842
Standard Error	1.123337	1.098859	1.44	2.12379	1.109996	4.194305
Mode	2	2	23	1	1	2
Standard Deviation	219.7868	233.8351	250.51	211.197	195.3466	316.413
Range	11259	11259	12277	12095	11259	7105
Count	38281	45283	30271	9889	30972	5691

Table 8 **NOx Emissions Descriptive Statistics (in PPM)**

Descriptive Statistics	All Valid Vehicles in sample 1999	Vermont Registered Vehicles sampled 1999	Vermont Registered Vehicles sampled 1998	Non Vermont Registered Vehicles sampled 1999	Vermont Registered Cars sampled 1999	Vermont Registered Trucks sampled 1999
Mean	454.0213	458.8758	450.73	387.4965	450.6776	513.2487
Standard Error	3.658053	3.535177	4.83	7.015962	4.228598	10.57186
Mode	19	19	28	45	19	21
Standard Deviation	715.7176	724.4785	735.63	665.7774	721.5183	747.0944
Range	7074	7074	7101	5539	7074	5065
Count	38281	41998	23222	9005	29114	4994

4.2 STATISTICS RELATED TO VEHICLE AGE.

Figures 4 and 5 show a comparison of the sampled vehicles distributed by age for both the 1998 and 1999 studies. The average CO for Vermont vehicles decreased in 1999 compared with 1998 by about 15 %. The distribution of vehicles by model year (Figure 4) shows a 4% increase in the number of new (less than 6 years old) vehicles from 1998 to 1999. At the same time, the number of vehicles in model years 1989 through 1991 has decreased. The decrease in the number of vehicles in the 10-year or older category suggests that these vehicles may have become too expensive to repair and maintain and are no longer part of the general fleet. This hypothesis is supported by the overall youth of the fleet with the average Vermont vehicle being almost two years younger than that measured for Atlanta, GA, the reference fleet for all AQL studies. The relative youth of the Vermont fleet may be due to the harsh winter conditions prevalent in Vermont that tend to increase vehicle deterioration rates.

Figure 6 represents the average CO for vehicles versus vehicle age. Figure 6 also displays the fraction of the total vehicle fleet represented by each vehicle age and its contribution to the total pollution for all sampled vehicles. This chart clearly shows a decrease in average CO in 1999 for vehicles that are 10 to 15 years old. However, those vehicles still have average CO levels below the accepted limit of 1.2%. The fluctuation in average CO values for vehicles more than 15-years old suggests an insufficient number of samples for this age group. Based on these data, 17% of 10 to 15 year old vehicles create 34% of the CO pollution related to vehicle emissions, while 20% of vehicles older than 10 years create 56% of CO related to vehicle pollution.

Figures 7-9 compare emissions versus model year for both cars and trucks for the three primary pollutants. In all cases trucks, on average, have higher emissions.

Distribution of Vehicles in the Sample and the Registration Database (RDB) by Model Year

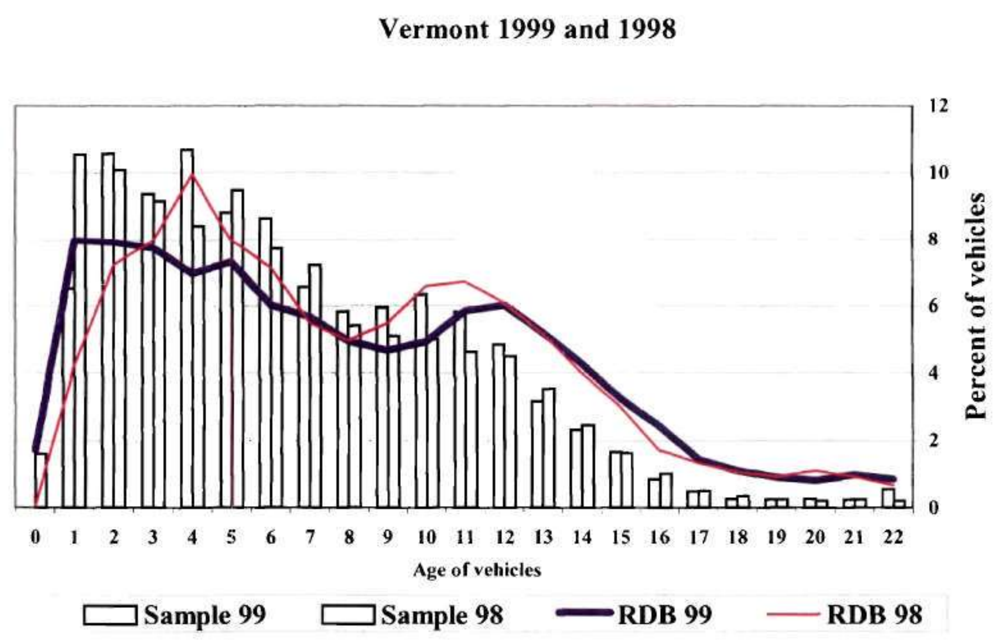


Figure 4 **Percentage of vehicles in sample and registration database: dependence on age for 1999 and 1998 sampling.**

Contribution to Total CO Pollution of Vehicles by Model Year 1999 vs. 1998

Vermont 1999 and 1998

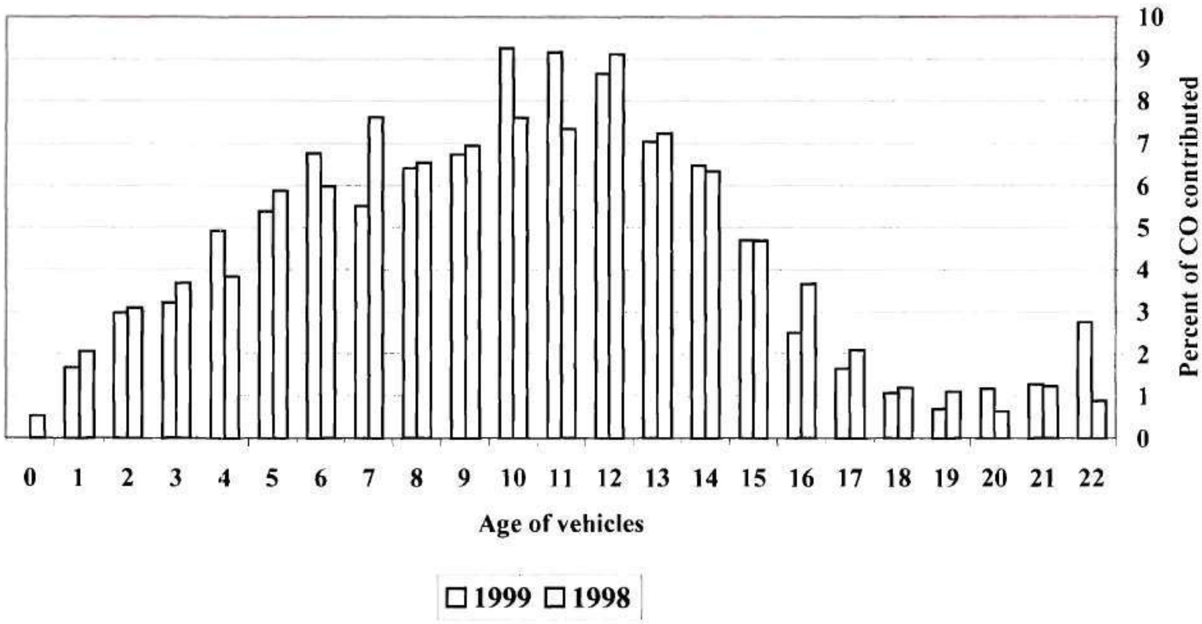


Figure 5 **Contribution to Total Emissions by Vehicle Age**

Average CO by Model Year - Sample Year 1999 versus Sample Year 1998

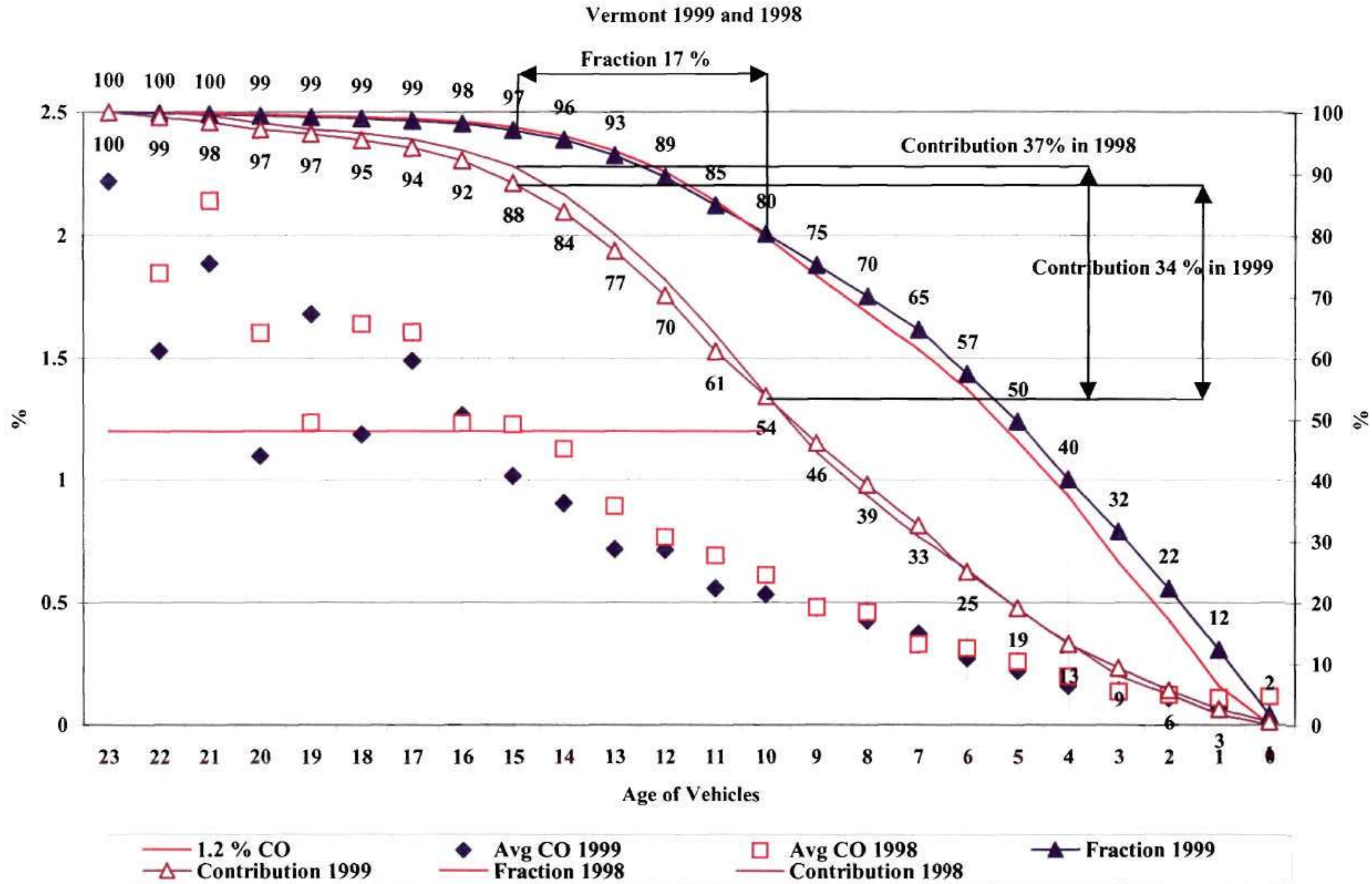


Figure 6 Average CO for vehicles: dependence on age and calculated cumulative distribution of vehicles in sample 1998 and 1999. Lower lines give calculated cumulative total emission for each year given in upper lines.

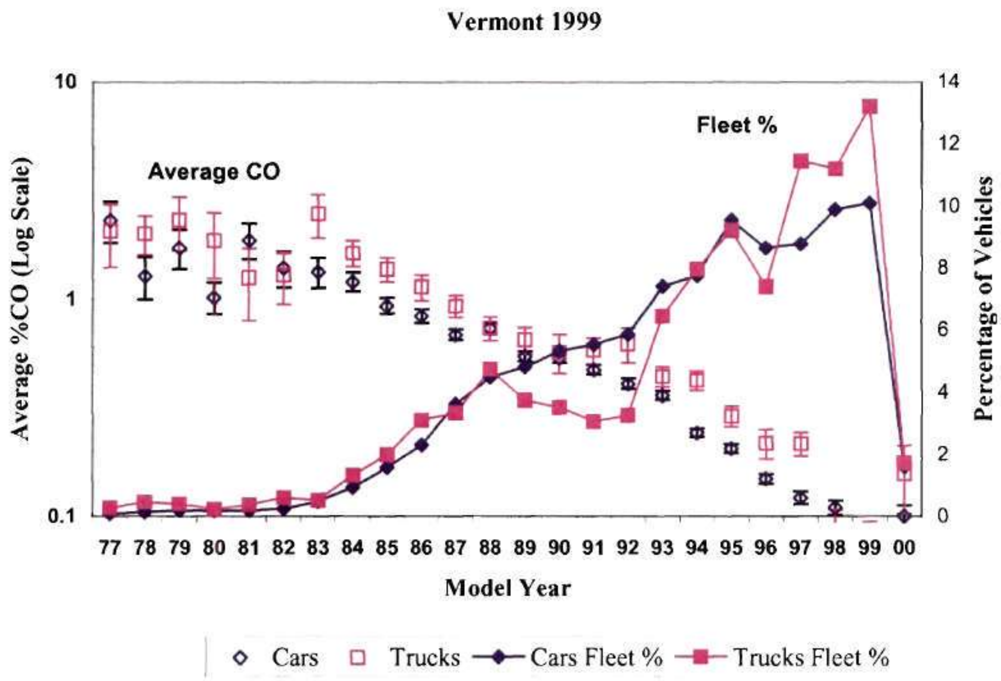


Figure 7 Average CO by Model Year: Cars versus Trucks

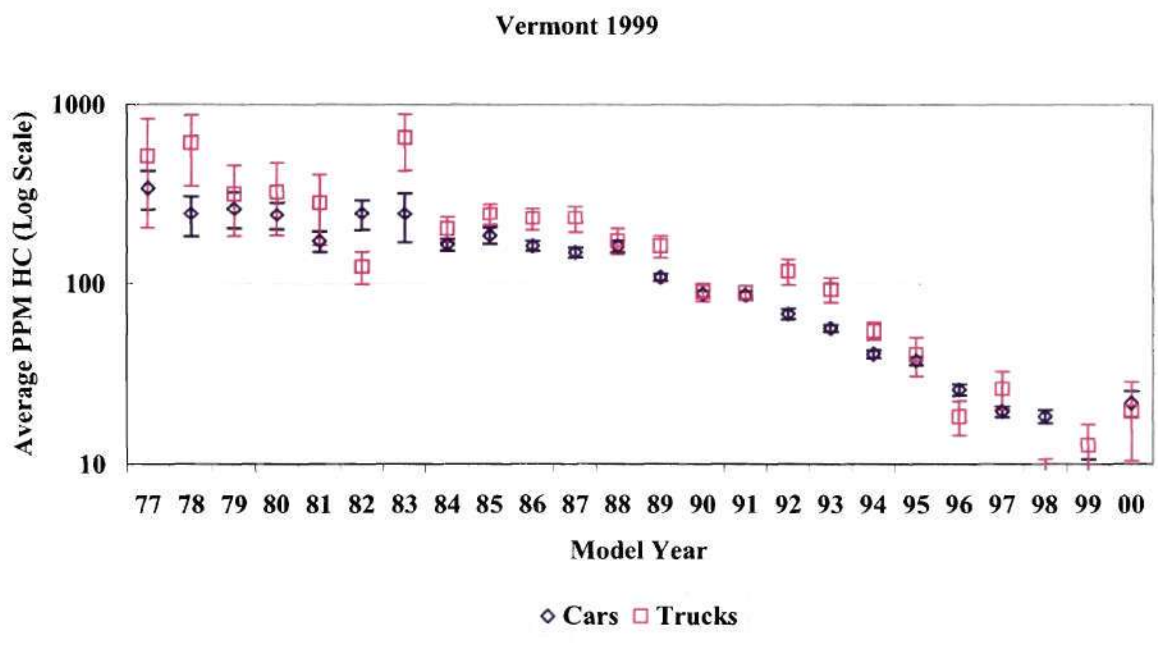


Figure 8 Average HC by Model Year: Cars versus Trucks

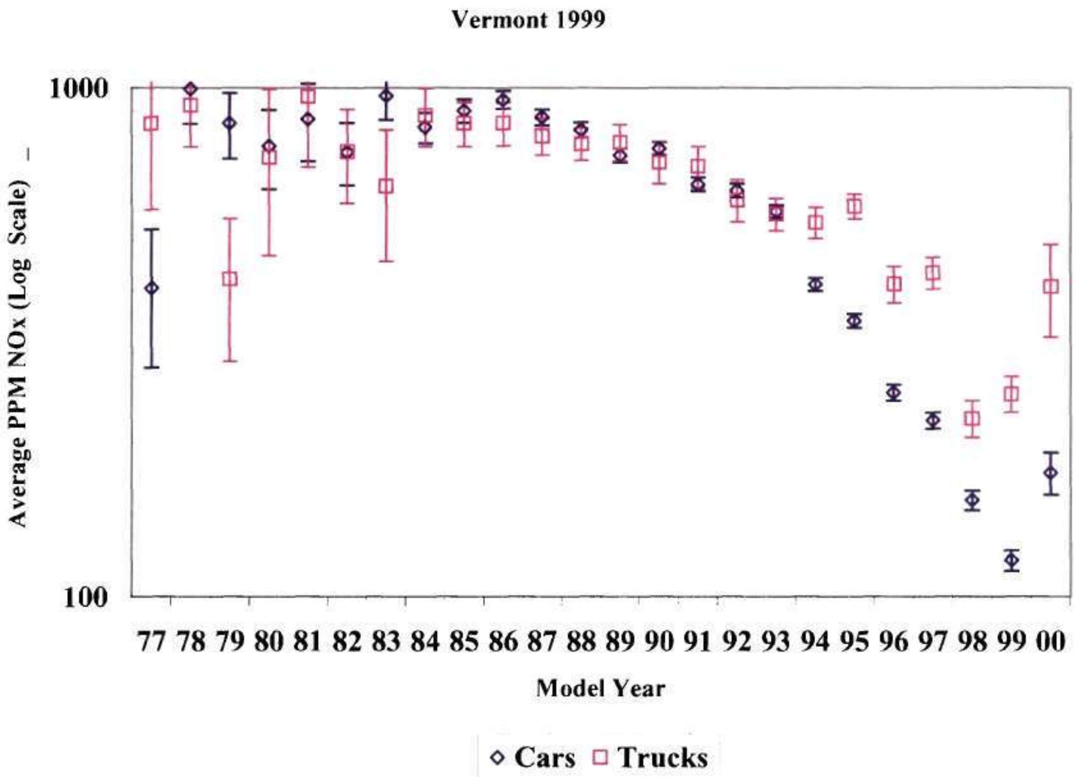


Figure 9 **Average NOx for Model Year: Cars versus Trucks**

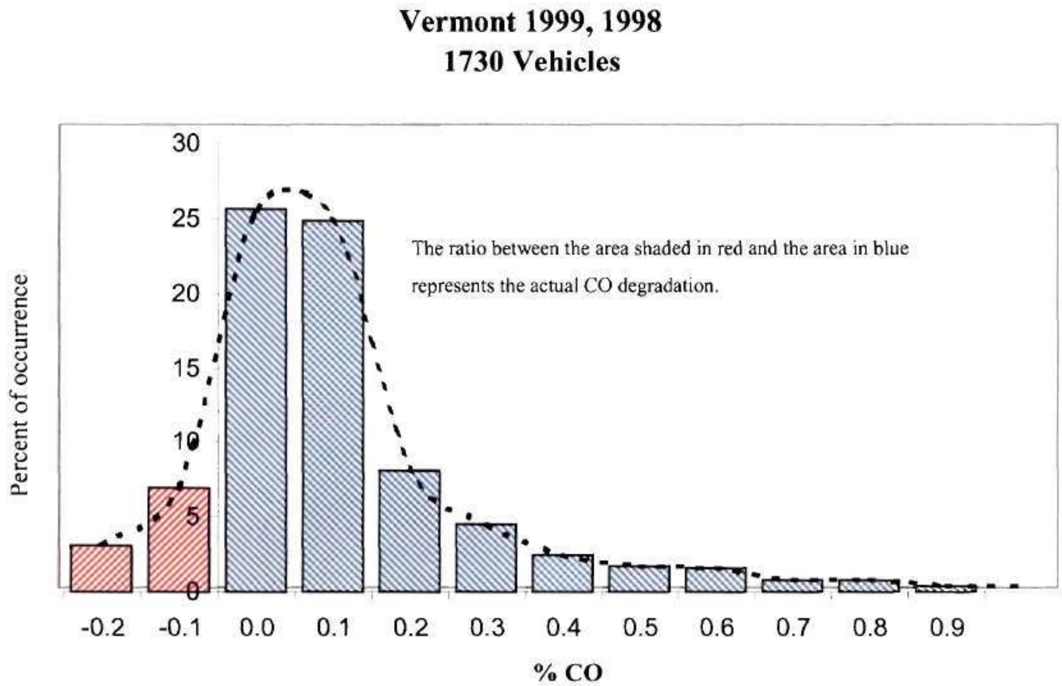
4.3 REPEAT VEHICLES IN 1998 AND 1999

The most reliable method of evaluating in-use deterioration is to continually sample the same population of vehicles and observe how their emissions evolve over time. Remote sensing offers such an opportunity since vehicles are often observed at the same site under similar conditions a considerable time apart. A total of 1730 vehicles having valid readings were sampled in both the 1998 and 1999 sampling programs. The vehicles in this group had model years from 1974 through 1998 and an average age of six years. The difference in emission levels between the two sampling programs (1998 and 1999) can be seen in Figures 10 through 12. An increase in emissions was observed for CO and NOx as well as a slight decrease for HC.

Figure 13 shows the change in average concentrations of CO when various age groups are compared. The groups compared are: relatively new vehicles (model years 1995-1998), vehicles of average age (model years 1990-1994) and older vehicles (model years 1985-1989). It is interesting to note that the most significant increase in CO is observed for vehicles having an average age as reflected on Figure 6.

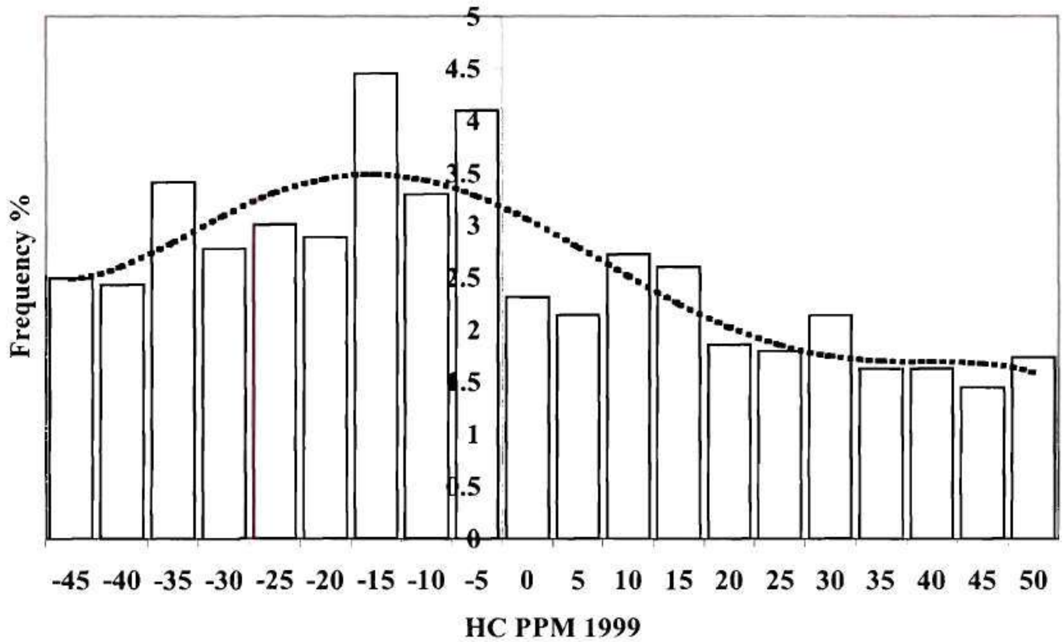
A hypothesis to explain these results is that when a vehicle is new, initial degradation occurs slowly. At an intermediate age a vehicle begins a rapid deterioration and average emissions increase accordingly. Older vehicles begin to show less deterioration over time because annual mileage accumulation has decreased. The reason why HC emissions remain more stable than CO rates is unclear at this time. However, catalysts that are ineffective for CO can still retain good HC performance and it is possible that the vehicles have not deteriorated sufficiently for changes in HC emissions to be observed.

Figure 10 **Histogram of CO differences for same vehicles. (1999-1998)**



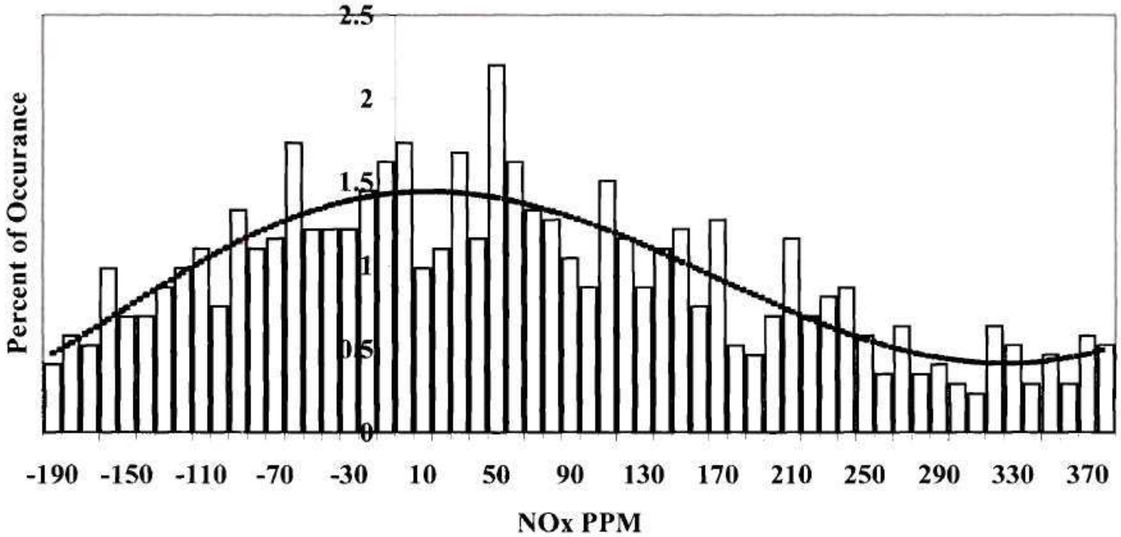
Mean	0.050
Standard Error	0.023
Median	0.010
Mode	0.000
Standard Deviation	0.954
Kurtosis	30.947
Skewness	0.084
Range	19.070
Count	1730

Figure 11 **Histogram of Differences in HC for Same Vehicles (1999-1998).**



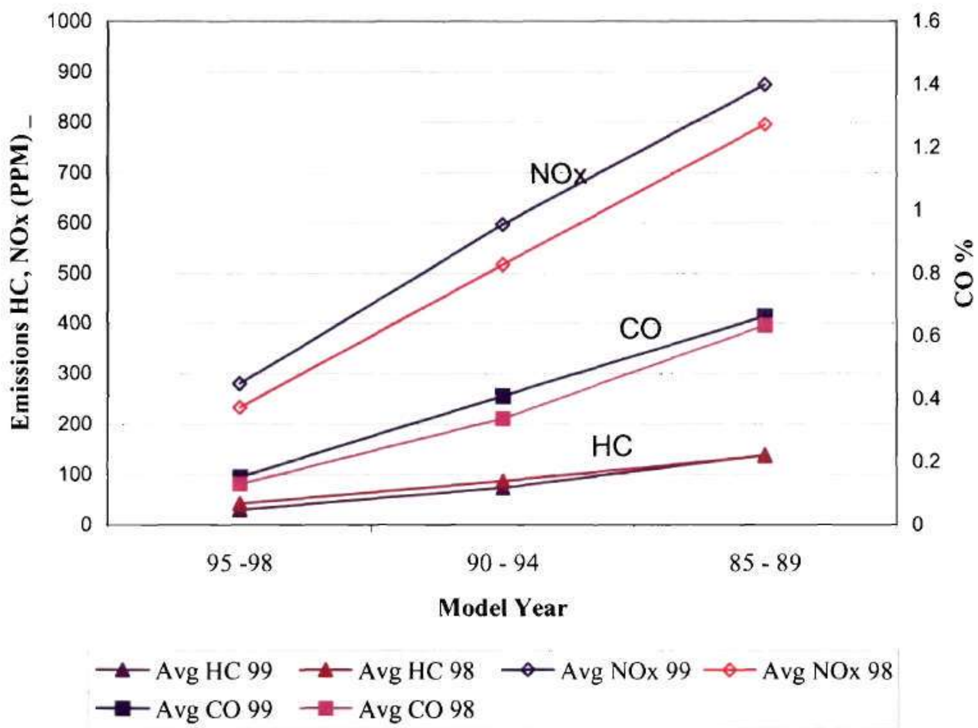
Mean	-12
Standard Error	6
Median	-15
Mode	-5
Standard Deviation	260
Kurtosis	110
Skewness	-4
Range	7325
Count	1730

Figure 12 **Histogram of Differences in NOx for Same Vehicles (1999-1998).**



Mean	64
Standard Error	21
Median	45
Mode	58
Standard Deviation	890
Kurtosis	7
Skewness	0
Range	11424
Count	1730

Figure 13 **Changes in Average CO, HC and NOx for Various Age Groups (1999-1998)**



5. CONCLUSIONS

Remote sensing technology is a proven tool in general fleet evaluation. Continuous or annual remote sensing data collection over a four or five year period has been useful in identifying trends in the general fleet as well as estimating the effectiveness of I/M programs in other parts of the country. The results of this study, in conjunction with the pilot project conducted in 1998, clearly indicates that this technology is an effective method of fleet evaluation in the State of Vermont. The following is a list of conclusions resulting from this project, some of which underscore the effectiveness of annual remote sampling,

1. A comparison between the results of this study and the 1998 Vermont study suggest a "cleaning" of the Vermont fleet from 1998 to 1999. This is interpreted as a consequence of changing fleet composition, that is, the turn-over of the fleet from year-to-year and the removal of older vehicles with inefficient emission control systems. However, the level of uncertainty in this measurement is relatively high. Future measurements will significantly reduce the uncertainty in this evaluation as the measured effect should increase with time.

2. Analysis of the data indicates that the emissions from the Vermont fleet continue to be in line with the observations made in other areas of the country on a model year specific basis with the exception of the oldest vehicles being cleaner than those observed in non I/M areas. The emissions of the oldest part of the Vermont fleet are comparable to those of the inspected Atlanta fleet. The fleet is also relatively young with an average age almost two years younger than the reference (Atlanta) fleet.

3. This study found that the same vehicles had less deterioration in HC emissions between 1998 and 1999 than for NOx and CO.

4. Emissions from light duty trucks are higher than emissions from cars.

5. The number of high emitters in Vermont is relatively low and the main contribution to pollution is from vehicles that are between 5 and 15 years old.

6. There were no observed difficulties in operations of the RSD systems in Vermont. Environmental and road conditions appear to be well within operational limits and the available sites appear to be reasonably representative of the vehicle population.

7. The DMV database for Vermont is of sufficient quality to conduct an in-depth analysis of the remote sensing records.

Recommendations

The following recommendations are intended to increase the overall understanding of mobile source emissions and to improve the effectiveness of future remote sensing activities in Vermont.

1. Annual remote sensing studies in the State of Vermont should be continued. Remote sensing has proven to be an effective means of identifying trends in air pollution caused by mobile source emissions. The value of any monitoring program increases with the length of record, thus allowing clearer identification of time-dependent trends.

2. While the data suggest that the overall fleet is producing less emissions, consideration should be given to implementing a VMT study to augment an annual remote sensing program. This type of study could be used to confirm whether or not the fleet in Vermont is actually producing less pollution over time. This could potentially be done in concert with the annual vehicle safety inspection records.

3. Annual studies should be conducted in the same season of the year, preferably at the end of spring or summer, to reduce the influence of weather conditions such as temperature, humidity, and variations in seasonal wind. No studies should be conducted during any transitions between summer and winter fuels.

4. Urban and rural populations are not proportionally represented in the current study. Future studies should concentrate a greater effort in rural areas. However, this may result in additional field time since traffic flow in rural areas is typically much lower than in urban areas. This will raise the cost per record.

5. While license plate match rates to the Vermont vehicle registration are relatively high, closer cooperation between the Vermont DMV and AQL information technology personnel may produce even higher match rates.

In summary, since vehicle lifetimes are increasing, the durability of the emissions control systems within these vehicles may determine the status of on-road mobile source emissions in the future. This study has proven that the use of remote sensing technology on an annual basis provides an effective means of tracking the deterioration of these systems and uncovering important trends in vehicle pollution. This study, along with other studies conducted in different regions of the country, has also shown that remote sensing is a cost-effective method of analyzing these trends.

6. APPENDICES

Table A-1 **Site Summary Reports**

Site ID: 5 Abbreviation: 7BB
Location: 7 SB just south of Bartlett Bay Road
Grade: 0 Speed: 31 Traffic: 1062 Rating: 9
Site Type: 3
City: Burlington County: Chittenden State: VT
Evaluated By: N. Vescio
Evaluated Date: 09/17/1999 Evaluated Time: 07:03 PM

Site ID: 24 Abbreviation: SS134
Location: Near 134 State Street along State Street
Grade: 0 Speed: 21 Traffic: 320 Rating: 7
Site Type: 3
City: Montpelier County: Washington State: VT
Evaluated By: P. Klochko
Evaluated Date: 09/17/1999 Evaluated Time: 07:08 PM

Site ID: 25 Abbreviation: RT302
Location: Route 302 from Montpelier to Barre just past Sixth Street near Johnson and Dix Company
Grade: 0 Speed: 24 Traffic: 580 Rating: 9
Site Type: 3
City: Barre County: Washington State: VT
Evaluated By: P. Klochko
Evaluated Date: 09/17/1999 Evaluated Time: 07:10 PM

Site ID: 28 Abbreviation: RT5AH
Location: Route 5 NB from St. Johnsbury near Aubuchon Hardware
Grade: 2 Speed: 33 Traffic: 340 Rating: 8
Site Type: 3
City: St. Johnsbury County: Caledonia State: VT
Evaluated By: P. Klochko
Evaluated Date: 09/17/1999 Evaluated Time: 07:13 PM

Site ID: 29 Abbreviation: RT100
Location: Route 100 SB just south off Route 15 near Northgate Street
Grade: -1 Speed: 39 Traffic: 360 Rating: 7
Site Type: 3
City: Morrisville County: Lamoile State: VT
Evaluated By: P. Klochko
Evaluated Date: 09/17/1999 Evaluated Time: 07:16 PM

Site ID: 32 Abbreviation: 91RT5
Location: Route 5 SB under bridge I-91 NB
Grade: 0 Speed: 31 Traffic: 340 Rating: 8
Site Type: 3
City: White River Junction County: Windsor State: VT
Evaluated By: P. Klochko
Evaluated Date: 09/17/1999 Evaluated Time: 07:18 PM

Site ID: 36 Abbreviation: RT5B
Location: Route 5 SB across-from Sunoco Fuel and in front of Kipling Cinema
Grade: 1 Speed: 28 Traffic: 500 Rating: 10
Site Type: 3
City: Brattleboro County: Windham State: VT
Evaluated By: P. Klochko
Evaluated Date: 09/17/1999 Evaluated Time: 07:23 PM

Site ID: 2 Abbreviations: SPSW
Location: Shelburne St. and S. Willard St. SB Junc.
Grade: 0.5 Speed: 28 Traffic: 588 Rating: 9
Site Type: 3
City: Burlington County: Chittenden State: VT
Evaluated By: N. Vescio
Evaluated Date: 09/28/1999 Evaluated Time: 08:54 PM

Site ID: 37 Abbreviation: NP
Location: Intersection of Rt.191 and US 5, 105 just south of Intersection (about 30 ft) in Newport.
Grade: 0 Speed: 25 Traffic: 275 Rating: 7
Site Type: 4
City: Newport County: Orleans State: VT
Evaluated By: P. Klochko
Evaluated Date: 10/02/1999 Evaluated Time: 09:00 AM

Site ID: 38 Abbreviation: RT4N
Location: Rt. 4 E just East of empty building opposite ATM bank facility and sight "Carris Reels" building 439
Grade: 2 Speed: 28 Traffic: 400 Rating: 9
Site Type: 3
City: Rutland County: Rutland State: VT
Evaluated By: P. Klochko
Evaluated Date: 10/03/1999 Evaluated Time: 10:43 AM

Site ID: 39 Abbreviation: BND
Location: Northside Dr. Intersection of Benmont Ave and US 7.
Grade: 0 Speed: 25 Traffic: 450 Rating: 9
Site Type: 6
City: Bennington County: Bennington State: VT
Evaluated By: P. Klochko
Evaluated Date: 10/03/1999 Evaluated Time: 12:43 PM

Site ID: 40 Abbreviation: SPF
Location: Intersection of Rt. 10, 106 and 11on Springfield Plaza
Grade: 3.5 Speed: 25 Traffic: 250 Rating: 7
Site Type: 6
City: Springfield County: Windsor State: VT
Evaluated By: P. Klochko
Evaluated Date: 10/03/1999 Evaluated Time: 05:28 PM

Table A-2 **Preliminary Statistics and Data Collection Reports**

Site ID: 5 RSD Unit Number: 532 Date: 09/28/1999
Start: 08:06:48 End: 18:06:15 Operator: Prokofiy and Juanita
Notes: Mirror and electronics board cleaning during morning setup.

Calibrations Performed: 13		Average Traffic: 531	Beam Block: 5195
License Plate-	Visible: 4099	State: 3714	Matched RDB: 2678
Speed-	Average: 25	St. Dev.: 5.0386	Count: 4253
Acceleration-	Average: 0.44	St. Dev.: 0.7878	Count: 4221
CO-	Average: 0.23	St. Dev.: 0.7624	Count: 3393
HC-	Average: 50	St. Dev.: 178.30	Count: 3180
NOx-	Average: 250	St. Dev.: 496.80	Count: 3055

All Valid Data = 2452

Site ID: 2 RSD Unit Number: 532 Date: 09/29/1999
Start: 11:33:54 End: 18:06:12 Operator: Prokofiy and Juanita
Notes: Cleaning board at morning. CO2 channel fluctuation and low voltage.

Calibrations Performed: 4		Average Traffic: 548	Beam Block: 3569
License Plate-	Visible: 2793	State: 2465	Matched RDB: 2110
Speed-	Average: 21	St. Dev.: 4.2148	Count: 2851
Acceleration-	Average: 1.35	St. Dev.: 1.1166	Count: 2828
CO-	Average: 0.29	St. Dev.: 0.8186	Count: 3086
HC-	Average: 41	St. Dev.: 121.50	Count: 3061
NOx-	Average: 499	St. Dev.: 741.39	Count: 2989

All Valid Data = 2405

Site ID: 25 RSD Unit Number: 532 Date: 10/01/1999
Start: 12:18:05 End: 18:18:01 Operator: Prokofiy and Juanita
Notes: Problem with CO2 channel in morning. Start after 12 PM.

Calibrations Performed: 6		Average Traffic: 678	Beam Block: 4054
License Plate-	Visible: 2219	State: 2063	Matched RDB: 1549
Speed-	Average: 22	St. Dev.: 5.1578	Count: 3833

Acceleration-	Average: 0.31	St. Dev.: 0.8316	Count: 3824
CO-	Average: 0.39	St. Dev.: 1.1146	Count: 2213
HC-	Average: 80	St. Dev.: 374.12	Count: 1998
NOx-	Average: 321	St. Dev.: 596.22	Count: 1914

All Valid Data = 1707

Site ID: 25 RSD Unit Number: 532 Date: 10/02/1999
Start: 08:17:24 End: 18:23:22 Operator: Prokofiy and Juanita
Calibrations Performed: 9 Average Traffic: 522 Beam Block: 5255

License Plate-	Visible: 2601	State: 2382	Matched RDB: 1905
Speed-	Average: 25	St. Dev.: 5.1327	Count: 5130
Acceleration-	Average: 0.12	St. Dev.: 0.7604	Count: 5127
CO-	Average: 0.35	St. Dev.: 1.0580	Count: 2263
HC-	Average: 87	St. Dev.: 329.78	Count: 2181
NOx-	Average: 283	St. Dev.: 551.59	Count: 1818

All Valid Data = 1771

Site ID: 2	RSD Unit Number: 532		Date: 10/05/1999
Start: 08:24:01	End: 17:59:39	Operator: Prokofiy and Juanita	
Calibrations Performed: 12		Average Traffic: 500	Beam Block: 4769
License Plate-	Visible: 3484	State: 3029	Matched RDB: 2614
Speed-	Average: 22	St. Dev.: 3.9638	Count: 4533
Acceleration-	Average: 1.39	St. Dev.: 1.0402	Count: 4531
CO-	Average: 0.30	St. Dev.: 0.8220	Count: 3953
HC-	Average: 50	St. Dev.: 132.17	Count: 3880
NOx-	Average: 644	St. Dev.: 913.72	Count: 3562
All Valid Data = 3377			

Site ID: 5	RSD Unit Number: 532		Date: 10/06/1999
Start: 07:56:22	End: 08:18:01	Operator: Prokofiy and Juanita	
Notes: Rain after 8:18AM.			
Calibrations Performed: 2		Average Traffic: 1110	Beam Block: 396
License Plate-	Visible: 259	State: 229	Matched RDB: 206
Speed-	Average: 23	St. Dev.: 4.6274	Count: 334
Acceleration-	Average: 0.60	St. Dev.: 0.7719	Count: 331
CO-	Average: 0.27	St. Dev.: 1.0213	Count: 252
HC-	Average: 49	St. Dev.: 148.92	Count: 243
NOx-	Average: 333	St. Dev.: 606.22	Count: 223
All Valid Data = 192			

Site ID: 24	RSD Unit Number: 532		Date: 10/07/1999
Start: 08:18:05	End: 17:48:50	Operator: Prokofiy and Juanita	
Calibrations Performed: 18		Average Traffic: 337	Beam Block: 3183
License Plate-	Visible: 2313	State: 1961	Matched RDB: 1626
Speed-	Average: 19	St. Dev.: 4.9706	Count: 3028
Acceleration-	Average: -0.28	St. Dev.: 0.9695	Count: 3019
CO-	Average: 0.39	St. Dev.: 1.1230	Count: 2342
HC-	Average: 94	St. Dev.: 330.39	Count: 2277
NOx-	Average: 287	St. Dev.: 562.37	Count: 1863
All Valid Data = 1775			

Site ID: 5	RSD Unit Number: 532		Date: 10/08/1999
Start: 08:09:15	End: 17:29:23	Operator: Prokofiy and Juanita	
Calibrations Performed: 8		Average Traffic: 906	Beam Block: 8437
License Plate-	Visible: 4570	State: 3931	Matched RDB: 2816
Speed-	Average: 25	St. Dev.: 5.0416	Count: 7410
Acceleration-	Average: 0.42	St. Dev.: 0.8041	Count: 7363
CO-	Average: 0.32	St. Dev.: 0.9161	Count: 4943
HC-	Average: 59	St. Dev.: 188.47	Count: 4844
NOx-	Average: 377	St. Dev.: 670.85	Count: 4198
All Valid Data = 3837			

Site ID: 38	RSD Unit Number: 532		Date: 10/11/1999
Start: 07:54:42	End: 17:54:21	Operator: Prokofiy and Juanita	
Calibrations Performed: 6		Average Traffic: 508	Beam Block: 5072
License Plate-	Visible: 3318	State: 2904	Matched RDB: 2315
Speed-	Average: 29	St. Dev.: 4.6550	Count: 4663
Acceleration-	Average: 0.31	St. Dev.: 0.7776	Count: 4652
CO-	Average: 0.38	St. Dev.: 1.1146	Count: 3422
HC-	Average: 54	St. Dev.: 272.93	Count: 3368
NOx-	Average: 462	St. Dev.: 703.13	Count: 3033
All Valid Data = 2819			

Site ID: 38	RSD Unit Number: 532		Date: 10/12/1999
Start: 08:10:25	End: 17:51:27	Operator: Prokofiy and Juanita	
Calibrations Performed: 9		Average Traffic: 534	Beam Block: 5160
License Plate-	Visible: 3010	State: 2670	Matched RDB: 2281
Speed-	Average: 28	St. Dev.: 4.6674	Count: 4947
Acceleration-	Average: 0.15	St. Dev.: 0.7265	Count: 4946
CO-	Average: 0.37	St. Dev.: 1.0931	Count: 3476
HC-	Average: 56	St. Dev.: 178.63	Count: 3419
NOx-	Average: 485	St. Dev.: 725.46	Count: 3101
All Valid Data = 3011			

Site ID: 32	RSD Unit Number: 532		Date: 10/13/1999
Start: 07:51:09	End: 17:24:14	Operator: Prokofiy and Juanita	
Calibrations Performed: 10		Average Traffic: 313	Beam Block: 2980
License Plate-	Visible: 1645	State: 1083	Matched RDB: 911
Speed-	Average: 29	St. Dev.: 4.8967	Count: 2807
Acceleration-	Average: 0.22	St. Dev.: 0.7790	Count: 2803
CO-	Average: 0.28	St. Dev.: 0.9076	Count: 1954
HC-	Average: 44	St. Dev.: 155.30	Count: 1936
NOx-	Average: 474	St. Dev.: 722.45	Count: 1703
All Valid Data = 1655			

Site ID: 40	RSD Unit Number: 532		Date: 10/14/1999
Start: 08:27:30	End: 08:58:48	Operator: Prokofiy and Juanita	
Calibrations Performed: 1		Average Traffic: 181	Beam Block: 94
License Plate-	Visible: 0	State: 0	Matched RDB: 38
Speed-	Average: 18	St. Dev.: 5.7051	Count: 70
Acceleration-	Average: -0.18	St. Dev.: 1.5708	Count: 66
CO-	Average: 0.29	St. Dev.: 0.6910	Count: 62
HC-	Average: 170	St. Dev.: 687.34	Count: 58
NOx-	Average: 482	St. Dev.: 752.34	Count: 51
All Valid Data = 35			

Site ID: 37	RSD Unit Number: 532		Date: 10/21/1999
Start: 08:25:24	End: 18:05:08	Operator: Mikhail and Juanita	
Calibrations Performed: 15		Average Traffic: 514	Beam Block: 4943
License Plate-	Visible: 2949	State: 2696	Matched RDB: 2220
Speed-	Average: 22	St. Dev.: 4.4644	Count: 4751
Acceleration-	Average: 8.31	St. Dev.: 0.8462	Count: 4746
CO-	Average: 0.40	St. Dev.: 1.0976	Count: 3145
HC-	Average: 67	St. Dev.: 328.47	Count: 2913
NOx-	Average: 286	St. Dev.: 490.86	Count: 2733
All Valid Data = 2589			

Site ID: 28	RSD Unit Number: 532		Date: 10/22/1999
Start: 08:03:17	End: 17:41:45	Operator: Mikhail and Juanita	
Calibrations Performed: 8		Average Traffic: 339	Beam Block: 3241
License Plate-	Visible: 2049	State: 1804	Matched RDB: 1529
Speed-	Average: 31	St. Dev.: 5.1470	Count: 3054
Acceleration-	Average: -0.16	St. Dev.: 0.6646	Count: 3049
CO-	Average: 0.31	St. Dev.: 0.8850	Count: 2152
HC-	Average: 60	St. Dev.: 156.11	Count: 1900
NOx-	Average: 468	St. Dev.: 718.53	Count: 1937
All Valid Data = 1731			

Site ID: 5	RSD Unit Number: 532		Date: 10/24/1999
Start: 10:30:33	End: 17:23:43	Operator: Mikhail and Juanita	
Calibrations Performed: 22		Average Traffic: 625	Beam Block: 4246
License Plate-	Visible: 1498	State: 1248	Matched RDB: 1133
Speed-	Average: 29	St. Dev.: 5.2980	Count: 4001
Acceleration-	Average: 0.24	St. Dev.: 0.7045	Count: 4000
CO-	Average: 0.23	St. Dev.: 0.7608	Count: 1646
HC-	Average: 41	St. Dev.: 155.45	Count: 1510
NOx-	Average: 341	St. Dev.: 573.07	Count: 1454
All Valid Data = 1337			

Site ID: 2	RSD Unit Number: 532		Date: 10/25/1999
Start: 09:50:12	End: 17:55:06	Operator: Mikhail and Juanita	
Calibrations Performed: 5		Average Traffic: 516	Beam Block: 4168
License Plate-	Visible: 3101	State: 2774	Matched RDB: 2439
Speed-	Average: 22	St. Dev.: 4.1313	Count: 3802
Acceleration-	Average: 0.98	St. Dev.: 1.0932	Count: 3779
CO-	Average: 0.31	St. Dev.: 0.8527	Count: 3412
HC-	Average: 55	St. Dev.: 154.84	Count: 3330
NOx-	Average: 615	St. Dev.: 877.68	Count: 3221
All Valid Data = 2933			

Site ID: 36	RSD Unit Number: 532		Date: 10/15/1999
Start: 08:00:19	End: 17:50:33	Operator: Prokofiy and Juanita and John	
Calibrations Performed: 21		Average Traffic: 623	Beam Block: 6100
License Plate-	Visible: 3360	State: 2271	Matched RDB: 1884
Speed-	Average: 26	St. Dev.: 5.6525	Count: 5833
Acceleration-	Average: 1.86	St. Dev.: 0.8171	Count: 5831
CO-	Average: 0.39	St. Dev.: 0.9882	Count: 3552
HC-	Average: 79	St. Dev.: 308.59	Count: 3468
NOx-	Average: 536	St. Dev.: 741.50	Count: 3019
All Valid Data = 2918			

Site ID: 39	RSD Unit Number: 532		Date: 10/16/1999
Start: 09:23:20	End: 17:27:28	Operator: John Hughes and Juanita Lewis	
Calibrations Performed: 9		Average Traffic: 196	Beam Block: 1574
License Plate-	Visible: 1241	State: 820	Matched RDB: 708
Speed-	Average: 16	St. Dev.: 5.6697	Count: 1299
Acceleration-	Average: -0.51	St. Dev.: 1.6726	Count: 1290
CO-	Average: 0.48	St. Dev.: 1.1598	Count: 1107
HC-	Average: 86	St. Dev.: 224.37	Count: 1074
NOx-	Average: 294	St. Dev.: 566.68	Count: 863
All Valid Data = 689			

Site ID: 36	RSD Unit Number: 532		Date: 10/18/1999
Start: 07:33:04	End: 18:17:55	Operator: John Hughes and Juanita Lewis	
Calibrations Performed: 27		Average Traffic: 570	Beam Block: 6073
License Plate-	Visible: 4127	State: 2949	Matched RDB: 2371
Speed-	Average: 27	St. Dev.: 5.5447	Count: 5387
Acceleration-	Average: -6.26	St. Dev.: 0.7955	Count: 5354
CO-	Average: 0.38	St. Dev.: 1.0506	Count: 4217
HC-	Average: 76	St. Dev.: 249.39	Count: 4174
NOx-	Average: 542	St. Dev.: 769.48	Count: 3825
All Valid Data = 3436			

Site ID: 36	RSD Unit Number: 532		Date: 10/19/1999
Start: 09:42:27	End: 17:56:44	Operator: MIKHAIL AND JUANITA	
Calibrations Performed: 8		Average Traffic: 542	Beam Block: 4445
License Plate-	Visible: 2618	State: 2311	Matched RDB: 1471
Speed-	Average: 28	St. Dev.: 5.2452	Count: 4147
Acceleration-	Average: 2.50	St. Dev.: 0.7746	Count: 4144
CO-	Average: 0.40	St. Dev.: 1.0324	Count: 3033
HC-	Average: 71	St. Dev.: 165.91	Count: 2986
NOx-	Average: 588	St. Dev.: 780.29	Count: 2771
All Valid Data = 2562			

Site ID: 5	RSD Unit Number: 532		Date: 10/26/1999
Start: 08:28:24	End: 15:46:57	Operator: Mikhail	
Calibrations Performed: 5		Average Traffic: 724	Beam Block: 5279
License Plate-	Visible: 2669	State: 2361	Matched RDB: 2023
Speed-	Average: 29	St. Dev.: 5.1377	Count: 4169
Acceleration-	Average: 0.57	St. Dev.: 0.8257	Count: 4148
CO-	Average: 0.37	St. Dev.: 1.0618	Count: 3207
HC-	Average: 47	St. Dev.: 238.73	Count: 2930
NOx-	Average: 504	St. Dev.: 796.99	Count: 2922
All Valid Data = 2287			

Site ID: 40	RSD Unit Number: 532		Date: 10/28/1999
Start: 09:07:37	End: 17:56:40	Operator: Mikhail	
Calibrations Performed: 9		Average Traffic: 245	Beam Block: 2106
License Plate-	Visible: 1556	State: 1326	Matched RDB: 1136
Speed-	Average: 23	St. Dev.: 3.5389	Count: 1894
Acceleration-	Average: 0.70	St. Dev.: 0.8673	Count: 1889
CO-	Average: 0.41	St. Dev.: 1.0333	Count: 1788
HC-	Average: 65	St. Dev.: 168.49	Count: 1724
NOx-	Average: 674	St. Dev.: 886.13	Count: 1683
All Valid Data = 1506			

Site ID: 39	RSD Unit Number: 532		Date: 10/29/1999
Start: 08:54:11	End: 16:58:10	Operator: Mikhail	
Calibrations Performed: 6		Average Traffic: 707	Beam Block: 5674
License Plate-	Visible: 4124	State: 3094	Matched RDB: 2668
Speed-	Average: 20	St. Dev.: 4.6459	Count: 5332
Acceleration-	Average: 0.49	St. Dev.: 1.0648	Count: 5326
CO-	Average: 0.47	St. Dev.: 1.1048	Count: 4454
HC-	Average: 91	St. Dev.: 302.44	Count: 4326
NOx-	Average: 486	St. Dev.: 718.70	Count: 4158
All Valid Data = 3918			

Site ID: 40	RSD Unit Number: 532		Date: 10/27/1999
Start: 09:41:07	End: 17:54:26	Operator: Mikhail	
Calibrations Performed: 9		Average Traffic: 186	Beam Block: 590
License Plate-	Visible: 491	State: 400	Matched RDB: 340
Speed-	Average: 21	St. Dev.: 4.2330	Count: 536
Acceleration-	Average: 0.69	St. Dev.: 0.9680	Count: 531
CO-	Average: 0.32	St. Dev.: 0.7730	Count: 526
HC-	Average: 56	St. Dev.: 189.48	Count: 517
NOx-	Average: 561	St. Dev.: 751.12	Count: 505
All Valid Data = 459			

Total for All 24 Work Days			Beam Blocks: 96603
License Plate-	Visible: 60094	State: 50485	Matched RDB: 40971
CO-	Average: 0.35	St. Dev.: 1.0110	Valid: 63598
HC-	Average: 64	St. Dev.: 238.06	Valid: 61297
NOx-	Average: 464	St. Dev.: 729.98	Valid: 56601
All Valid Data = 51401			
All Valid Data Mean: CO, HC, NOx, Speed and Acceleration is Valid			

Table A-3 "Sites" Table Data fields, Format, and Description

Field Name	Format	Description
1. SiteID	Text	Represents Unique Identifier Number or Letter Without space.
2. Abbreviation	Text	Represents optional abbreviation
3. Location	Text	Represent description of site location in local road and highway naming convention.
4. ZIP	Number	Optional ZIP code for location
5. Memo	Text	Automatically enters number of cars, vans, truck and pickups and may have any additional data such as itinerary or direction or traffic condition.
6. Grade	Number	Slope grade in percent measured by grade master (see description below.)
7. Speed	Number	Average speed for site measured by Laser Gun (see description below.)
8. Traffic	Number	Vehicle counts for site.
9. Rating	Number	Rating of site on a scale from 0 to 10.
10. Latitude	Text	Latitude of site in Degree and Minutes with two digits after decimal.
11. Longitude	Text	Longitude of site in Degree and Minutes with two digits after decimal.
12. City	Text	Name of City
13. County	Text	Name of County.
14. State	Text	Name of State.
15. Country	Text	Name of Country
16. SiteTypes	Number	Number represents the site type 1 to 6 see description below.
17. EvaluatedName	Text	Name of person who evaluated this site.
18. EDate	Text	Date of evaluation.
19. ETime	Text	Time of Evaluation
20. Picture	Text	File name in same directory w/ database; digital picture of site.
21. Sketch	Text	File name in same directory w/ database; digital sketch of site.
22. Checked	Boolean	Check box checked for printing options.
23. SFR	Number	Single line operation coefficient 0 or 1. 1 - for single line.
24. SER	Number	Coefficient of space requirement. 1 for sufficient space.
25. DSR	Number	Site observation coefficient. 1 for good site.
26. TIR	Number	Traffic Light and intersection allocation. 1 for remote allocation.
27. DAR	Number	Driver behavior coefficient. 1 for not too defensive or aggressive.
28. ST	Number	Site Type coefficient. 1 for ramp entrance and middle of road.
29. GR	Number	Geographic location suitable for fleet evaluation is 1.
30. DR	Number	Fleet composition coefficient for mixed traffic, vans and pickups.
31. DPT	Number	Diurnal pattern of traffic. 1 for whole days traffic.
32. DBR	Number	Break-in or Idle traffic coefficient. 0 for breaking or idle.
33. SLR	Number	Road slope coefficient calculated based on Grade input.
34. RT	Number	Total rating for site.

Table A-4 **"Remote Data" Table Data fields, formats, and descriptions**

Field Name	Format	Description
1. RSDUnitNumber	Integer	SDM detector identification number
2. VehicleSequence	Long Integer	Sequence Vehicle number on the jazz disk
3. Date	Date, DD/MM/YYYY	Date of Remote Sensing Measurement
4. Time	Time, hh:mm:ss	Time of Remote Sensing Measurement
5. CO	Double	Remote Sensing CO Measurement in %
6. COFlag	Text	CO measurement validation: V – valid, S – suspect, X – invalid, E – insufficient plume, N – data does not exist
7. CO2	Double	Remote Sensing CO2 Measurement in %
8. CO2Flag	Text	CO2 validation (same as above for CO)
9. MaxCO2	Double	Maximum of CO2 concentration in the volume of air covered by IR beam, as related to calibration
10. CO2Volume	Double	Integrated in time CO2 concentration in the beam
11. HCppm	Double	Remote Sensing HC Measurement in PPM of Hexane
12. HCFlag	Text	HC validation (same as above)
13. NOxppm	Double	Remote Sensing NOx Measurement in PPM
14. NoxFlag	Text	NOx validation (same as above)
15. Opacity	Text	Exhaust plume opacity as measured in reference channel
16. OpacityFlag	Text	Opacity validation (same as above)
17. ColdStart	Boolean	Estimation of cold start probability from absorption in H2O vapor channel, not functioning
18. Speed	Double	Vehicle speed in mph
19. SpeedFlag	Text	Speed validation (same as above)
20. Acceleration	Double	Vehicle acceleration in mph/sec
21. AccelerationFlag	Text	Acceleration validation (same as above)
22. SpeedAcceleration	Text	Units of measurement of Units speed/acceleration, E–means English, see above
23. LicensePlate	Text	License Plate of the vehicle
24. LicensePlateFlag	Text	See below separate paragraph
25. LicensePlateType	Text	See below separate paragraph

Table A-5 "Data Collection" Table Data fields, formats, and descriptions

Field Name	Format	Description
1. SiteID	Text	Unique Identifier Number or Letter W/Ospace
2. RSDUnitNum	Number	SDM detector identification number
3. MDate	Text	Date of data collecting
4. StartTime	Text	First measurement time
5. EndTime	Text	Last measurement time
6. Operator	Text	Operators name
7. Notes	Text	Memo for helpful notices
8. CalibrationsPerforme	Number	Num of calibrations performed
9. CalibrationOverrides	Number	Number of calibrations overrides
10. AverageTraffic	Number	Hourly traffic on base triggered vehicles
11. AverageSpeed	Number	Average speed for captured traffic
12. StDevSpeed	Number	Standard Deviation of speed
13. SpeedCount	Number	Count of captured speed reading
14. AverageAcceleration	Number	Average acceleration for captured traffic
15. StDevAcceleration	Number	Standard Deviation of acceleration
16. AccelerationCount	Number	Count of captured acceleration reading
17. BeamBlock	Number	Number of triggered vehicles
18. Valid	Number	Num of readings w/ 4 gases and speed,accel
19. StateLP	Number	Number of visible License Plate belong to State
20. LPVisible	Number	Number of visible License Plate
21. ValidLP	Number	All Data Valid and State License Plate
22. MatchedRDB	Number	Num License Plate matched w Data Base
23. MeanCO	Number	Average CO
24. StDevCO	Number	Standard Deviation CO
25. ValidCO	Number	Number of valid reading CO
26. MeanHC	Number	Average HC
27. StDevHC	Number	Standard Deviation HC
28. ValidHC	Number	Number of valid reading HC
29. MeanNOx	Number	Average NOx
30. StDevNOx	Number	Standard Deviation NOx
31. ValidNOx	Number	Number of valid reading NOx

Table A-6 "Report Calibration" Table Data fields, formats, and descriptions

Field Name	Format	Description
1. RSDUnitNum	Number	SDM detector identification number
2. Mdate	Text	Date of remote sensing
3. CalNum	Number	Calibration Identification number for this Day.
4. StartTime	Text	Time when measurement stop for calibration
5. EndTime	Text	Exact time of calibration is performed.
6. CObefor	Number	CO before calibration
7. COafter	Number	CO after calibration
8. CO2befor	Number	CO_2 before calibration
9. CO2after	Number	CO_2 after calibration
10. HCbefor	Number	HC before calibration
11. HCafter	Number	HC after calibration
12. NOxbefor	Number	NOx before calibration
13. NOxafter	Number	NOx after calibration

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