1991

Remote Sensing Enhanced Motor Vehicle Emissions Control for Pollution Reduction in the Chicago Metropolitan Area: Siting and Issue Analysis

Carol E. Lyons

Donald H. Stedman

ILENR/RE-AQ-91/15

REMOTE SENSING ENHANCED MOTOR VEHICLE EMISSIONS CONTROL FOR POLLUTION REDUCTION IN THE CHICAGO METROPOLITAN AREA: SITING AND ISSUE ANALYSIS

Illinois Department of Energy and Natural Resources

Jim Edgar, Governor
John S. Moore, Director

Printed by the Authority of the State of Illinois

ILENR/RE-AQ-91/15
Printed: October 1991
Contract: AQ 30
Project: 90/009

REMOTE SENSING ENHANCED MOTOR VEHICLE EMISSIONS CONTROL FOR POLLUTION REDUCTION IN THE CHICAGO METROPOLITAN AREA: SITING AND ISSUE ANALYSIS

Final Report

Prepared by:

University of Denver
Atmospheric Science Center
University Park
Denver, CO 80208-0179

Principal Investigators:

Carol E. Lyons
Donald H. Stedman

Prepared for:

Illinois Department of
Energy and Natural Resources
Office of Research and Planning
325 W. Adams, Room 300
Springfield, IL 62704-1892

Jim Edgar, Governor
State of Illinois

John S. Moore, Director
Illinois Department of
Energy and Natural Resources

NOTE

This report has been reviewed by the Illinois Department of Energy and and Natural Resources (ENR) and approved for publication. Statements made by the author may or may not represent the views of the Department. Additional copies of this report are available through ENR Clearinghouse at 800/252-8955 (within Illinois) or 217/785-2800 (outside Illinois).

Printed by the Authority of the State of Illinois.

Date Printed:	October 1991
Quantity Printed:	400
Referenced Printing Order:	IS 66

One of a series of research publications published since 1975. This series includes the following categories and are color coded as follows:

Energy Resources	- RE-ER	- Red
Water Resources	- RE-WR	- Blue
Air Quality	- RE-AQ	- Green
Environmental Health	- RE-EH	- Grey
Insect Pests	- RE-IP	- Purple
Information Services	- RE-IS	- Yellow
Economic Analysis	- RE-EA	- Brown

Illinois Department of Energy and Natural Resources
Office of Research and Planning
325 W. Adams, Room 300
Springfield, Illinois 62704-1892
217/785-2800

Printed on Recycled Paper

ACKNOWLEDGEMENTS

Robert D. Melvin, Andrew Burt, Roger E. Salters and Gary A. Bishop formed the study team. These authors thank Donna Gilmore and her colleagues at the Denver Research Institute for patient assistance with tables and figures, Elizabeth Van Kirk for typing (and retyping) significant portions of the text, and Cindy Hanna and her colleagues for expert short-notice design services.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report describes three specific scenarios for implementation of remote sensing to enhance inspection and maintenance (I/M) programs for controlling motor vehicle emissions. Three scenarios are presented which describe the range of potential applications of a Fuel Efficiency Automobile Test (FEAT) remote sensor to motor vehicle emissions control. A combination of two or three of the scenarios would be most effective in identifying high mileage gross polluting vehicles. The preliminary implementation framework of each scenario is described for the purpose of discussion to develop future pilot studies and implementation plans. The ultimate purpose of this work is to contribute to the development of acceptable plans for the further reduction of emissions from automobiles in the Chicago metropolitan area.

All of the scenarios and accompanying details presented in this report are preliminary in nature. The proposed plans can be revised and modified to address current conditions and regulatory requirements.

The important message of this report is that remote sensing of vehicle emissions to identify the small percentage of vehicles responsible for most of the motor vehicle pollution can contribute to an efficient and effective air pollution control strategy that can be implemented.

This report is written with the understanding that the centralized Illinois Vehicle Emission Test (VET) I/M testing program will continue in its current form or be modified to accommodate FEAT screening, at least through the initial years of implementation of on-road remote sensing. Thus a comparative baseline of VET testing of all cars will continue while actual FEAT implementation is started.

The three scenarios presented in this report are:

1. <u>FEAT Screening at Centralized Stations</u>

FEAT is used to instantly screen emissions as vehicles enter the centralized VET stations for annual or semi-annual tests. Only vehicles which emit CO or HC above a certain cut point are required to proceed further for the standard VET test. Approximately 70 to 80% of vehicles, emitting less than the CO and HC cut points, would be allowed to leave immediately, with no further testing required.

2. Mobile Sensors

A small fleet of mobile vans are equipped with FEAT and set up for 5 days at a time at varying locations throughout the VET program area. High mileage gross polluters are identified using remote sensing of emissions and license plate records.

3. Modular Fixed Sensors

Using locations of particular interest with very high traffic volumes, identified through the use of mobile sensors, reusable roadside bunkers are constructed where FEAT sensors can be installed for long term monitoring. Modular FEAT units would be constructed for easy installation and removal. High mileage gross polluters would be identified by the same system as used by the mobile sensors.

Procedures for Data Transmission and Processing applicable to each of the above scenarios are presented following the scenario descriptions. In each case video information is transmitted to a central processor in which automated license plate reading is carried out. This automatic reader is backed up by a human operator, and by direct access to State motor vehicle records. Mobile units will probably detect 1,400 unique vehicles (112 gross polluters) per day. Used 200 days per year, each sensor would detect 280,000 vehicles per year. Modular fixed units will detect at least 12,000 readings on at least 7,000 unique vehicles (560 gross polluters) per week. Based on a detailed analysis of Cook County traffic patterns and sensor placement it is estimated that the five county VET program area could be adequately monitored with twenty remote sensing units. The program would emphasize measurements of high mileage vehicles which can be disproportionate contributors to pollution, if not properly maintained. Fleet Coverage, Trip Distribution, and Other Issues are discussed in subsequent sections. Finally, Conclusions and Recommendations are presented.

This report is part of a larger effort under the direction of Dr. Donald H. Stedman at the University of Denver and sponsored by the Illinois Department of Energy and Natural Resources to test and analyze the application of on-road remote sensing as a tool for automobile emissions control. The initial report published for this project was "An Analysis of On-Road Remote Sensing as a Tool for Automobile Emissions Control" (Stedman and Bishop, March 1990).

1. General Introduction

With initial support from the Colorado Office of Energy Conservation in 1987, the University of Denver (DU) developed an infra-red (IR) remote monitoring system for automobile carbon monoxide (CO) exhaust emissions. Significant fuel economy results if rich-burning (high CO emissions) vehicles are tuned to a more stoichiometric and more efficient air/fuel (A/F) ratio. Therefore, the University of Denver CO remote sensor is named Fuel Efficiency Automobile Test (FEAT). The basic instrument measures the carbon monoxide to carbon dioxide ratio (CO/CO_2) in the exhaust of any vehicle passing through an IR light beam transmitted across a single lane of roadway. An additional channel to measure hydrocarbon emissions has been tested successfully. Figure 1 (page 6) shows a schematic diagram of the instrument.

The IR source sends a horizontal beam of radiation across the lane, 10 inches above the road. This beam is picked up by the detector on the opposite side and split into four wavelength channels, CO, CO_2, HC, and reference. Data from all four channels are fed to a computer for analysis. The calibration gases are used as a daily quality assurance (Q/A) check on the system.

The instrument determines the CO/CO_2 ratio (Q). Q is a useful parameter to describe the combustion system. Most vehicles show a Q of zero. When $Q > 0$, the engine has a fuel rich air/fuel ratio, and the emission control system is not fully operational. With a fundamental knowledge of combustion chemistry, many parameters of the vehicle and its emissions system can be determined, including the instantaneous air/fuel ratio, grams of CO emitted per gallon of gasoline (gm CO/gallon), and the %CO.

The mechanism by which FEAT measures Q is explained in Bishop et al (1989). Q can be determined by remote sensing, independent of wind, temperature, and turbulence in 0.7 seconds per passing car. Other publications describing remote sensing are listed in the References.

The detector operates continuously once it is turned on. The exhaust gas analysis routines are triggered by the beam being blocked (for instance by a vehicle or pedestrian). If the beam is blocked and less than a preset minimum increase in the concentration of CO [0.04 cm at one atmosphere (atm)] or CO_2 (0.01 atm cm) is observed, then the computer gives a 990 XCL (eXceeds Confidence Limits) error code or an invalid (X) status code. This code is generated by the wheels of large trucks or tractor trailers, pedestrians, etc. If CO_2 and/or CO are observed, the computer plots delta-CO versus delta-CO_2 where delta indicates the increase in

CO or CO_2 above corresponding measurements of the air just in front of the vehicle. The slope of the delta - CO/delta CO_2 line is Q. The computer also calculates the standard deviation of the slope, σQ. For most vehicles, Q is close to zero and an XCL code of 991 arises if σQ is larger than 0.02. For vehicles where Q is > 0.1, the same error code arises if $\sigma Q > 0.2*Q$.

FEAT has measured over 250,000 vehicle CO emissions. In a one week study of 20,200 beam blocks at a freeway on-ramp (Bishop and Stedman, 1989), exhaust gas measurements were reported for 18,510 vehicles, a 990 code for 655 vehicles, and a 991 code for 1035 vehicles. A total of 11,818 successful exhaust CO and license plate measurements were made involving 7,456 unique vehicles.

The remote sensing measurement of Q is independent of instrument temperature. Wind and turbulence serve to dilute the exhaust behind the vehicle. This dilute exhaust is the material detected by the remote sensor and its further dilution is a necessary part of the measurement. The computer program is written so that only valid data are accepted. If wind, turbulence, or other factors such as exhaust from another vehicle were to perturb or eliminate the CO/CO_2 slope, then an XCL code is generated.

Recent testing at the University of Denver involved a stationary pre-catalyst vehicle idling with various A/F ratios. The remote sensor used a rotating ventilated exhaust beam chamber to measure the exhaust and to generate measurements using the exact program also used to measure vehicles on the road. Out of 486 measurements at one A/F ratio, six generated an XCL error (990 code); the other 480 all fell within a total range of Q of 0.13 to 0.15. This demonstrates that FEAT's precision of $\pm$20% is very conservative. The actual observed relative standard deviation of the data was < 7%. This estimate of precision includes any drift in emissions from the parked vehicle.

In 1990, an additional detector was added to the FEAT system to measure the concentration of hydrocarbons in exhaust gases. The new IR detector monitors infra red transmissions at 3.3 microns, characteristic of the absorption frequency of the carbon-hydrogen interatomic stretch. This is the same frequency used by analyzers in standard government I/M programs.

As with standard analyzers, the detector is calibrated using propane gas. The FEAT detector measures the total concentration of hydrocarbons, plots the results against the total concentration of carbon dioxide, and calculates the HC/CO_2 ratio. The absolute percentage concentration of HC in the exhaust is then obtained by multiplying the $\%CO_2$ by the HC/CO_2 ratio. Results are reported in the equivalent percentage of propane.

FEAT can measure the CO and HC emissions in all vehicles, including gasoline and diesel-powered vehicles, as long as the exhaust plume exits the vehicle toward the ground. Due to the current height of the sensing beam, FEAT will not register emissions from exhausts which exit from the top of vehicles. Carbon monoxide emissions from diesel vehicles are usually negligible. Moreover, diesel vehicles are exempt from the Illinois VET program.

FEAT is effective across traffic lanes of up to 40 feet in width. However, it can only operate across a single lane of traffic in order to positively identify each vehicle with its exhaust. FEAT operates most effectively on dry pavement. Rain, snow, and wet pavement cause interferences with the IR beam. These interferences cause the rate of invalid readings to increase, ultimately to the point that all data are rejected as being contaminated by too much "noise".

The FEAT beam is accompanied by a video system when license plate information is required. A video camera is coupled directly into the data analysis computer so that the image of each passing vehicle is frozen onto the video screen, over which the computer writes the date, time and the CO, HC and CO_2 concentrations. These images are stored on videotape, although current digital storage media are fast enough to be used for this purpose.

The purpose of this report is to present potential configurations of remote sensing technology applied to measurement of motor vehicle exhaust to enhance the current State of Illinois Vehicle Emission Test (VET) automobile Inspection and Maintenance (I/M) program in the Chicago metropolitan area. On-road remote sensing and analysis of pollutants in vehicle exhaust has been shown to be a highly effective and efficient means to identify the small percentage of cars which emit the majority of automobile pollution.

The current State of Illinois VET program was implemented in 1985 as part of the state's plan to meet the National Ambient Air Quality Standard for ozone, as required under the federal Clean Air Act.

> I/M is a process whereby the exhaust of operating vehicles is analyzed using standardized test procedures at an emissions inspection station to determine the

amount of carbon monoxide and hydrocarbon emissions present. These measured exhaust emissions are then compared to [locally] established exhaust emission standards to determine compliance with the law. (IEPA, 1986)

In this report, the terms: motor vehicles, vehicles, cars, and automobiles, are all used to refer to light and heavy duty vehicles, including cars and trucks, powered by internal combustion engines using gasoline fuel. These are essentially all the vehicles currently affected by the Illinois VET program. However, for this report, we do not exclude vehicles based on age, ownership, or location of registration (unless otherwise specified). The application of the program described in this report would be in the geographic area in and around Chicago in which the current or future VET program is applied.

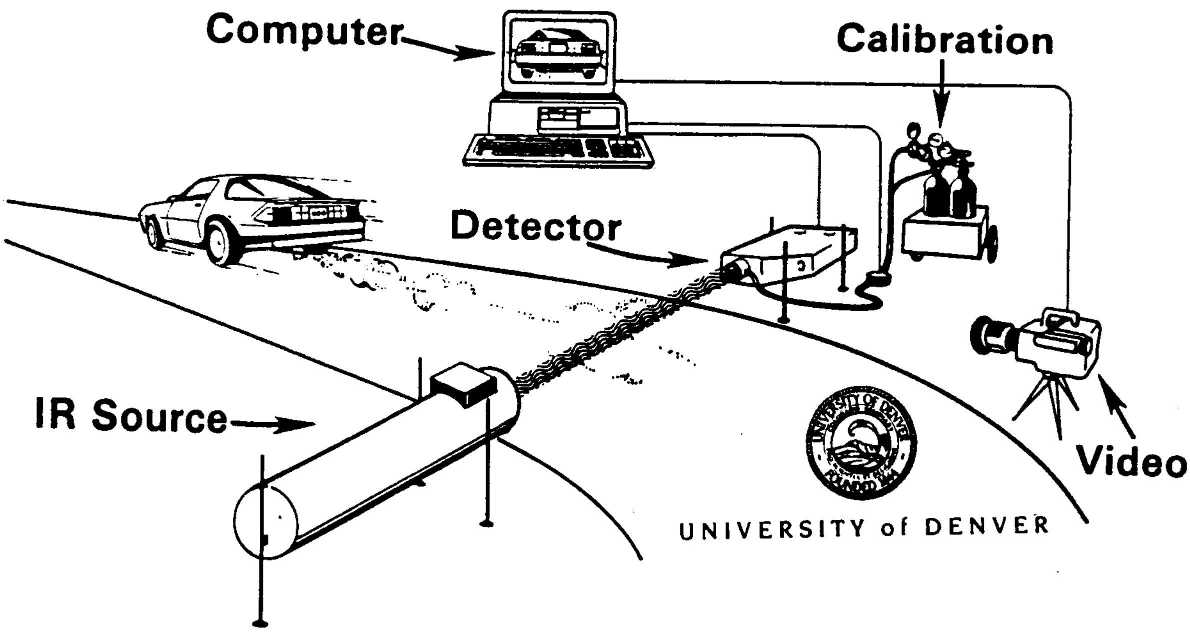
As outlined above, the University of Denver's remote sensing technology, called the Fuel Efficiency Automobile Test, or FEAT, accurately measures gaseous pollutant emissions from motor vehicles driving by on the road. By means of non-dispersive infra-red detection, FEAT's current capabilities include analysis of carbon monoxide (CO) and total hydrocarbon (HC) concentrations in vehicle exhaust.

Accurate measurement of on-road vehicle exhaust emissions under normal driving conditions (under load) are very important in the effort to control ambient air pollution. FEAT measurements of emissions from each vehicle are taken over a short time span (usually less than one second); and the analytical results are probably better correlated to lengthier analyses (such as the Federal Test Procedure, or FTP) than is idle testing. Neither correlation is very good because each measures a different mode or mix of driving modes, which, for some vehicles, show very different emissions.

To address the goals of reducing air pollution, a remote sensing based system can be the most effective approach to controlling motor vehicle emissions, because of the specific characteristics of this pollution source. A small percentage of vehicles contribute most of the emissions. These vehicles are called gross polluters. A small percentage of vehicles are responsible for a high percentage of miles driven. These vehicles are called high mileage. The pollution contribution from high mileage gross polluters is so great that the contribution from the remaining vast percentage of vehicles is almost irrelevant. Remote sensing is designed to identify the high mileage gross polluters at no inconvenience or delay and almost no cost to most vehicles.

FEAT uses commonly-available technology in a configuration which can be replicated and implemented widely. Legal and regulatory practices which identify undesirable violators comparable to high mileage gross polluters are currently used in other applications such as to catch people who exceed the speed limit, people who drive drunk, or people who go through a toll booth without paying the toll. Similarly FEAT can be implemented to identify high mileage gross polluters. If those vehicles are then tuned or repaired to fix the problem causing high emissions, air pollution can be reduced significantly at a cost much lower than other known control measures.

Figure 1. University of Denver FEAT



2. FEAT Screening at Centralized Stations

A. Introduction

FEAT remote sensing units can be installed in an entrance lane to each existing state centralized VET test station to screen vehicle emissions. A conservative cutpoint for CO and HC emissions would be applied to assure that vehicles which might exceed the state standards for VET tests would be identified. Vehicles with emissions above the cutpoint for either CO or HC would be sent on to the standard test; the remaining vehicles could exit immediately. Since a large majority of vehicles pass the standard test AND are not gross polluters, a large majority of vehicles would be spared the standard test, allowing cost and time savings for drivers and for the state.

This system would conform to the former state practice of requiring annual tests for every car in the program area. It would be highly attractive to the regulated public, providing most drivers with a time savings over the current program, thereby providing a reward or incentive to drivers for maintaining their cars. Passing vehicles would go through the annual test in less than a minute, without waiting in line.

B. Reasoning

A remote sensing-based universal screening program would be the easiest to implement, since it would be a modification of the established VET program, thereby reducing costs and saving time.

From the standpoint of investment by the state, the purchase and installation of approximately 20 to 30 FEAT units would be the only major cost. Existing facilities would be used for a testing lane, electric power, and security. Although many current state VET stations are built in very close quarters with no room to spare, the substantial reduction in the number of vehicles which would require the standard test would allow a reduction in the number of testing lanes and corresponding space requirements at each VET station. Thereby, a single lane of space required for FEAT screening would be readily available. Due to the tight quarters at some facilities, installation of FEAT would require changes to some VET stations.

In addition, FEAT screening would accommodate expansion of the VET I/M program to cover more cars. As the geographic coverage of the VET program expands, it will be desirable to build new VET stations to serve the additional area. If FEAT screening were an integral part of the design of new VET facilities, they could be built at a lower cost.

Moreover, the state recently modified the requirement for annual testing, waiving testing for the first two years after a new car is purchased, testing once in the third, fifth and seventh years, and then requiring annual testing. The addition of FEAT screening to centralized testing could avoid the need for this reduction in test frequency and maintain the benefit of identifying the small percentage of late model gross polluters, while expediting testing for the vast majority of vehicles.

Mandatory FEAT screening provides an expedient, low-cost means to assure that all cars are tested periodically. While it is more effective from a pollution reduction standpoint to test vehicles on the road to locate high mileage gross polluters, it may be important from a regulatory compliance standpoint to maintain periodic testing of all vehicles.

C. Description

A diagram of a potential site layout for FEAT screening at centralized test stations is shown in Figure 2 (page 13).

Every car entering the station activates FEAT by stopping at a mechanical gate with the driver pushing a START button on a post located next to his/her window. This is similar to the procedure followed at a parking lot where one pushes a button, takes a ticket, and activates an entry gate. When the START button is pushed, FEAT video cameras in front of and behind the vehicle instantly record the front and rear license plates of the car. [Both front and rear recording is done to double the success rate of obtaining a legible reading of the license plate.] The entry gate lifts, the driver gets a green light to proceed, and the car is driven a straight-forward distance of about 175 feet to a second mechanical gate. The remote sensing analysis of the car's emissions are completed while the car drives that distance. At least 150 feet of driving run is needed for the car to accelerate, pass by FEAT, and stop again.

At the second gate, a ticket box (similar to the kind found at a parking lot) level with the driver's window produces a dated Red or Green Ticket depending on the results of the FEAT analysis. Cars with emissions below the CO and HC cutpoints receive a Green Ticket while cars with emissions above the CO or HC cutpoints receive a Red Ticket.

The cutpoints will be determined based on the existing emissions of vehicles continuously measured in the Chicago metropolitan area in order to assure that at least 95% of all vehicles which would have failed the VET idle test would receive a Red Ticket. The 95% level can be achieved by appropriate setting of the FEAT HC and CO cutpoints.

When the driver takes the ticket from the machine, the mechanical gate is activated and opens. There is a fork in the road. A sign in front of the vehicle directs the car out of the VET station (GREEN Ticket) or to an interior lane for additional testing (RED Ticket). To assure that the driver makes the correct choice, the exit out of the station and the entry to the VET test area can also be controlled by mechanical gates, one or the other activated by the results of the FEAT analysis. Accordingly, it may not be necessary to have a gate at the point where the driver receives the test results. Rather a traffic signal could be used. The signal is red until the driver arrives and takes the results ticket. A green arrow pointing in or out would then light up, depending on the test results, along with the appropriate gate opening.

Vehicles with emissions below the cutpoint will be automatically issued a dated printout (Green Ticket) containing its license plate number and the CO and HC levels. The Green Ticket will indicate that the vehicle has passed the test and no further testing is required. This document could be kept with the car and a dated tear-off coupon portion used for annual license plate renewal. Green ticketed vehicles will follow signs to exit the station immediately. At the exit, a sign will include instructions to the driver to check the license plate on the printout. "If it is not YOUR license plate, return for re-test, and notify the operator of the error." The traffic flow at each station should be designed to accommodate a return to the FEAT screening lane by cars receiving a Green Ticket but which have the wrong license plate number recorded on the ticket.

Vehicles with emissions above either cutpoint will automatically receive a printout (Red Ticket) with measured CO and HC levels recorded at the bottom. The Red Ticket will NOT say "You failed," to avoid being threatening or negative; rather, it should read "Additional testing needed" or something similar. [Assistance from speech communications experts in preparing written and other visual communication material is advised.] The appropriate green arrow light and gate would be activated instructing the driver to proceed to a standard VET test lane.

Operators of the VET test will enter the FEAT test results in the VET data base so that they will be stored along with the VET test results. Vehicles which pass the VET test will receive a dated Green Ticket with correct corresponding license plate number. Parallel with current procedures, for vehicles failing the VET test, two options are possible. One, requiring the owner to promptly tune up and/or repair the vehicle and then return soon to the FEAT/VET station to be retested. Or, two, given the vehicle's emission test history, an inspection waiver could be issued for reasons permitted by law.

For enforcement purposes owners should be required to submit one of the following dated documents to renew their vehicle's license plates: green ticket with appropriate license plate number; or waiver certificate, issued only after prior repair efforts have proven ineffective.

The enforcement process could also include the requirement that one of the above documents must be kept with the vehicle registration in the car. If inspected by a police officer for whatever reason, and the license plate on a Green Ticket does NOT correspond to the vehicle registration, or is more than one year old, a ticket could be issued. Lacking either a valid Green Ticket or waiver also would constitute a ticketable violation.

In short, enforcement in the field will involve the requirement that drivers produce current VET inspection documentation for the vehicle as well as registration if stopped by a police officer. Failure to have proper documentation will result in enforcement procedures similar to those currently in effect, such as ticketing, fine, loss of license, etc. In this scenario, receiving by mail the current Secretary of State's forms for the annual renewal of vehicle license plates could also simultaneously serve as notification to drivers to now take their car into the local FEAT/VET station for its annual emissions testing.

Two alternatives to this overall scheme are possible.

<u>Alternative 1</u>: Instead of videotaping the front and rear of the car, an operator enters the license plate number into the station computer system while the car is stopped at the first gate. He also verbally confirms the recorded plate number with the driver. The Green Ticket will

include a large bold printout of the license plate and the test results. The same warning as described above would be posted at the exit.

This system would have the advantage of providing direct recording of the license plate with the emissions measurements, eliminating the need for any subsequent use of video recordings. Further, it could bypass the requirement for vehicle owners to carry documentation of the test because enforcement authorities would have a positive centralized computer record of results of vehicles. However it will add additional labor and time costs.

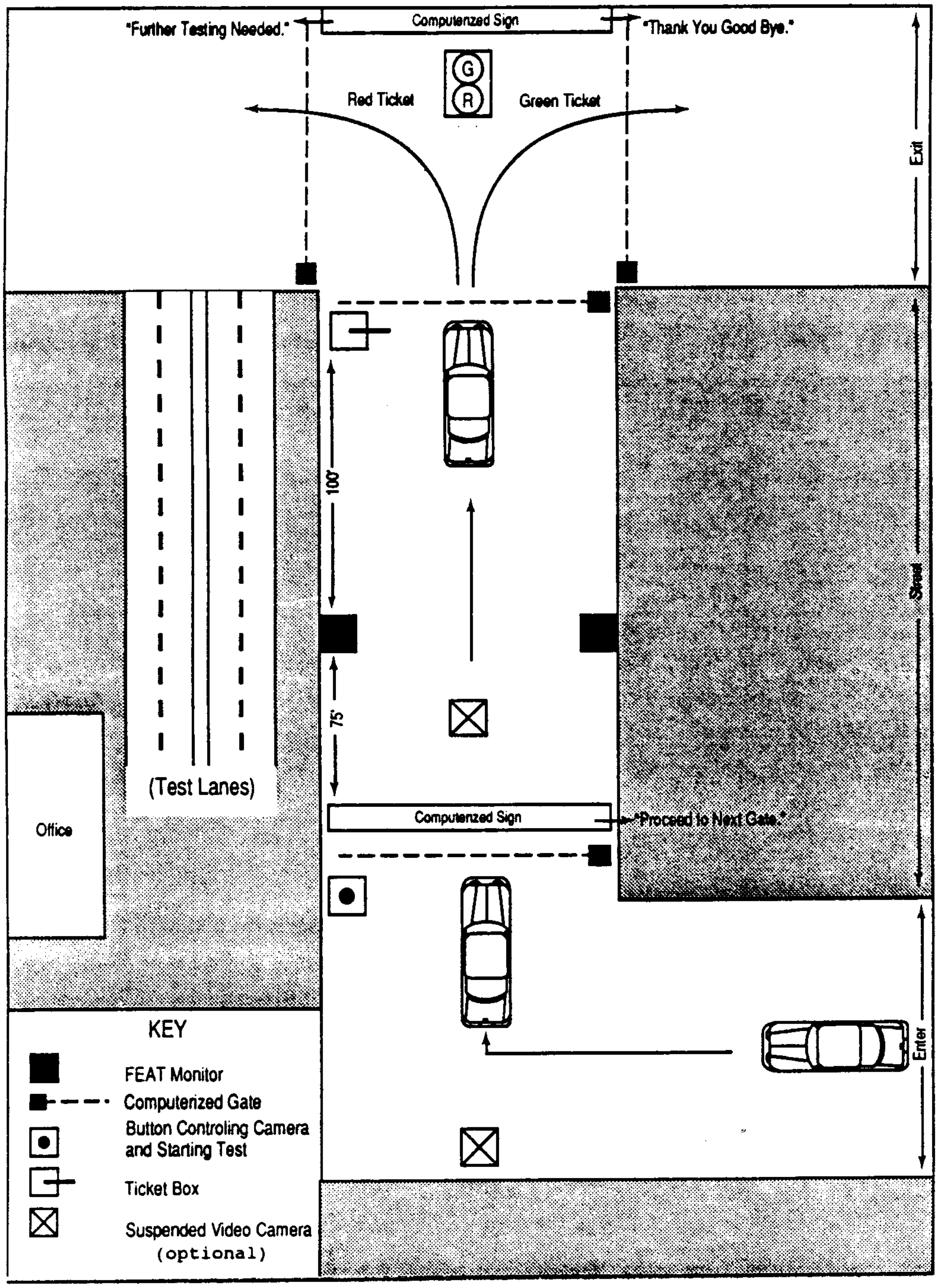
Alternative 2: Automatic license plate scanning software could be employed to read license plates. A promising preliminary version of this software has been developed by Perceptics Corporation (Knoxville, Tenn.). Improvements in this automatic scanning software as well as its application to controlled and narrow vehicle lanes would contribute significantly to the successful reading of a large majority of license plates. If the software successfully reads the plate (and the car is clean), the Green Ticket is printed with the license plate number and test results. If the software misses the plate OR the car is not clean, a Red Ticket is printed.

This system enjoys the same digital recording advantages of Alternative 1, without the additional labor costs of an operator to type in the license plate number. However, initially, this alternative may send more cars to the standard VET test due to an inability to read license plates rather than due to actual high emission readings. But other side benefits are possible. If the software cannot read the license plate, it may be due to dirty, mangled, or otherwise illegible plates, which should be fixed anyway.

Use of Alternative 1 or 2 could eliminate the driver's paperwork requirement by transmitting the license plate number and test results (FEAT or VET) directly to a central computer and to the Department of Motor Vehicles (DMV). Annual vehicle license plate purchases could not be completed without DMV records of a recent successful annual test.

Finally, some cars could be sent by FEAT to the centralized VET test lanes even though their emissions may be below the cutpoint, due to any problem reading the license plate or for a FEAT error reading or temporary malfunction. This will provide an avenue of quality control, with somewhat random testing of a small percentage of clean cars. This can also serve as a deterrent to drivers who may try to switch license plates in order to beat the test. Because of this, the program must be carefully designed to prevent the impression that all cars sent for centralized testing are "failures." Again, well-prepared educational programs for consumers, agency personnel, and operators is essential to make sure the correct message is communicated.

Figure 2. FEAT Screening at Centralized Test Stations



D. Logistics, Siting Requirements, Staffing

A full-time FEAT operator at each site will be responsible for quality assurance and instrument calibration at least three times a day. The operator will maintain printer and video supplies, perform routine daily and weekly maintenance on the equipment, and provide assistance to drivers who have problems going through the screening test. In addition, the clear presence of an operator may alleviate motorists' feelings that the procedure is dehumanized and that they are being judged by a heartless machine without any possible human appeal or recourse.

What if someone drives in to the screening test lane by mistake? (They were really looking for the Burger King drive-through lane.) The operator will have a blank option to allow a car to pass through without testing or recording results.

Based on an approximate population of three million vehicles to be tested each year at the eighteen circa 1990 stations, each station could process an average of 900 cars per day. Peak locations at peak times might experience 2,000 cars per day or 200 per hour. Thus FEAT could analyze and print results for about 4 cars per minute, which is well within its current capability.

Depending on the selection of the cutpoint levels for screening vehicles, 70 to 80 percent of all vehicles would pass FEAT and leave the station. The remaining 20 to 30% of the total population (or 700,000 to 1,050,000 vehicles per year out of 3,500,000) would require VET testing.

Given the current (1990) VET program, in addition to 18 full time operators (one per site), two additional full time FEAT technicians would be required to provide specialized service, quality control, fill in for vacations and sick leave, and perform basic data analysis. One supervising engineer would be responsible for system operations, quality assurance, and data analysis (described below).

E. Data Processing

Initially, for legal backup, recordings of all testing by FEAT will be kept on video tape. These records should be maintained at a secure location for a period of about 18 months, after which the tapes could be reused.

Data analysis programs could be set up to compute summary measures of emission characteristics for the entire Chicago area vehicle fleet. Fleet characteristics could be analyzed according to various parameters, such as emissions by make and model year. Intensive analysis could be done initially to determine other vehicle characteristics of interest. Vehicles at each centralized site could also be characterized according to daily, monthly, and annual emissions. Ongoing trends could be calculated. Other more immediate analyses could be based on average emissions measurements only, without including make and model year information.

Additional short-term or long-term intensive studies could be implemented as requested by state officials, agency personnel and cooperating researchers. Variations according to hour of the day, day of the week, month, season, year, or other parameters could be analyzed. Changes in fleet characteristics could be analyzed by selected data analysis of all tested vehicles at appropriate intervals, such as a given week's worth of tests each year at each location or selected locations. A well identified sample of the entire vehicle fleet can be selected for more detailed analysis (e.g., one percent of the fleet or approximately 30,000 tests per year) on a year-by-year basis.

In the initial several months of operation, FEAT and standard VET test results for a random portion of the Red Ticket vehicles (the vehicles which undergo the standard VET test) could be analyzed and correlated. The following information should be compiled and analyzed:

- Develop statistics for FEAT vs. VET measurements for all Red Ticket cars;
- Assess the effectiveness of increasing VET emissions cutpoints by model year;
- Percentage of Red Ticket cars that have been tampered with;
- Model year distribution of Red Ticket cars.

In cases where data analyses require make and model year information, selected video tapes may be analyzed using Perceptics automatic scanning software to record license plates. Since the data set will be large, the portion of plates which are not successfully read automatically can be ignored for overall statistical analyses. [If data analysis efforts require reading of video tapes for license plates, additional labor costs would be involved. However, if Perceptics software is used to automatically scan plates, these costs would be significantly less.]

F. Advantages

The main advantages of implementing FEAT screening at centralized VET stations are:

- reduction in time required for testing for 70 to 80% of all car owners;
- reduction in costs to the state to test the same or a greater number of vehicles;
- potential reduction in staff and data processing requirements of the state VET system;
- reduction in space and facility requirements for testing;
- all vehicles could be tested annually despite additional demands put on VET due to other program changes (e.g. anti tamper checks);
- implementation of a loaded-mode emissions test (not a static idle test).

Tracking and enforcement in this program will be tied to annual vehicle license plate renewal in order to significantly reduce current data processing and mailing burdens. Each driver will receive dated documentation of inspection, either by FEAT or by VET, and be required to produce current documentation to purchase plates for the vehicle. If other more automated alternatives (described above) are implemented, which include positive entry of every license plate number, the requirement for drivers to produce documentation can also be eliminated. Test results can be stored centrally for use in the vehicle licensing process. From a public relations standpoint, the state may wish to consider using some of these advantages to illustrate to the public its efforts to reduce paperwork, energy consumption and the exploitation of scarce natural resources.

FEAT remote sensing cannot operate in rainy, snowy, or otherwise wet conditions. However, the permanent centralized screening setups could include overhead protection of the drive-through lane at the critical measurement area, thereby largely eliminating this problem. Large canopies such as at gasoline stations only cost $10,000 to $15,000.

G. Limitations

Vehicle owners and operators could cheat on a FEAT/VET inspection process by registering their vehicles in areas not covered by mandatory VET testing. An independent assessment of the magnitude of this problem could be completed and evaluated to determine the relative impact of this group on pollution emissions. In addition, registration cheaters still risk being caught by the current vehicle licensing enforcement system. Also, a centralized FEAT/VET mandatory screening program would miss the marginally polluting cars that currently get away with cheating by using fuel additives or other temporary "fixes" to reduce emissions. As outlined in this scenario, there is no anti-tampering inspection of the pollution control devices of cars which pass the FEAT screening. However, this limitation is probably unimportant to the pollution problem because tampered vehicles would likely not "pass" FEAT screening.

The major limitation of this centralized screening program is that it would still be periodic (e.g., annual), missing the high mileage gross polluters that operate in that condition from one to 364 days a year. This is a serious limitation, especially in light of recent findings of the magnitude of the number of such vehicles on the road (Lawson et al, 1990). If a centralized FEAT/VET screening program is conducted in concert with additional on-road remote sensing, those vehicles which contribute significantly to pollution also could be identified continuously. These repeat gross polluters would be required to submit to a FEAT/VET test even though they had passed one less than twelve months previously. This would then significantly enhance the effectiveness of the state's mobile source pollution control program and perhaps catch some licensing cheaters at the same time.

H. Discussion, Recommendations

The primary impact of centralized screening by remote sensing is to reduce waiting time for drivers and operating costs for the state without reducing the effectiveness of the current program. The parameters of the program are known--sites, construction requirements, percentage of passing vehicles, number of vehicles to be processed, data processing requirements, etc. The potential for cost savings and pollution reduction benefits is high. It is a program that can be implemented and would deliver results almost immediately.

3. Mobile Sensors

A. Introduction

The initial and current application of remote sensing for the measurement of motor vehicle emissions utilizes mobile units which can operate at a wide range of locations. All the necessary equipment can be transported in a station wagon or small van. By operating a few units at selected locations for 5 days at a time, it is likely that nearly all the high mileage gross polluting vehicles in a large metropolitan area could be identified within months.

B. Reasoning

Approximately ten fully-equipped, completely mobile FEAT units could assure fairly widespread coverage of vehicle emission monitoring for the Chicago metropolitan area. (The later addition of modular fixed units, described below, likely could insure complete coverage.) A mobile application of remote sensing would provide true on-road emission measurements, decrease the rate of successful cheating, and focus control efforts on the small percentage of vehicles that contribute most of the pollution. Each unit could operate 1-5 weekdays at each selected location. Since drivers would not know in advance where monitoring was taking place, attempts to avoid the test would be minimal.

By monitoring at high traffic locations, use of mobile units allows for a high volume of emission measurements, broad geographic coverage and economical monitoring at lower density sites. The monitoring is also effective in identifying persistent gross polluters that drive in the VET enforcement area but are not registered therein.

Variations in fleet pollution characteristics could be uncovered by global analysis of all emissions at each site. Locations with significantly higher than normal emission measurements probably would indicate higher concentrations of dirty cars and/or, less likely, stagnant air or problem driving conditions. Such information would be useful for future pollution control and vehicle emission research and enforcement efforts.

C. Description

Ten vans would be equipped with FEAT and all the necessary support equipment, including mobile phone or radio, generator, calibration supplies, etc. The monitoring program would be a five days per week, 8 hours per day operation with each FEAT unit staying at its assigned location for five days in a row. Each unit would be staffed by one technician.

The operation schedule would vary in a prescribed manner in order to include early morning as well as late afternoon and evening drive times. In short, morning and evening rush hours are prime monitoring times. Two shifts in one day could be scheduled to obtain 16 hours of measurements in one day. Overall, weekends frequently involve lower volume traffic flows. However, weekend monitoring could be scheduled according to specific targets of interest with significant traffic, such as busy shopping areas, sporting events, concerts, or likely driving routes of holiday travellers.

Allowing for vacations, maintenance, and bad weather, each unit could operate approximately 40 weeks per year. Thus, with 10 units, monitoring could occur at 400 separate locations per year. Moreover, each unit can be expected to measure emissions from at least 7,000 different cars at each site each week, measuring most cars multiple times. Therefore, a minimum of about two million different cars could be monitored a number of times each year. Moved every day and used 200 days per year ten units would record about 4.8 million measurements in one year, with the high mileage vehicles measured repeatedly. [At the Central Avenue on-ramp to the Eisenhower Expressway in Chicago, in the summer of 1989, one FEAT unit collected approximately 12,000 successful measurements including legible liscense plate numbers, involving approximately 7,000 unique vehicles, during 5 days of monitoring, 7 hours per day.]

Most repeat measurements of the same car will be obtained at the same location, since many commuters drive in a repetitive pattern. Some cars will be measured at different sites; the frequency of this will depend both on how close together sites are. Traffic volumes vary widely, of course. A typical main road in Chicago can average a volume of 16,000 vehicles per day including all lanes in both directions. Therefore, if this typical road is 4 lanes, there are about 4,000 cars per day per lane. Monitoring for 5 days in one of these lanes, including one or both weekend days, would provide about 20,000 measurements; about 4,000-5,000 different cars; and approximately 2,500 valid repeat measurements.

Mobile FEAT will be set up specifically to identify gross polluters. The CO and HC cutpoints to define gross polluters will be set according to the approach described above for the centralized FEAT/VET program. A vehicle could be classified as a gross polluter if its emissions exceed the cutpoint for either CO or HC a number of (say, three) times in any 60-day period. [The numbers 3 times and 60 days are not definitive, and can be modified as required.] Once a gross polluting vehicle is identified, the state regulatory agency can determine the appropriate follow-up to achieve the goal of isolating and fixing the car's pollution problem, thereby reducing overall mobile source pollution. One approach would be to mail the vehicle owner a notice reporting the mobile test results and issuing a citation requiring a visit to an identified permanent FEAT/VET testing location to confirm the results. FEAT/VET procedures for the visit would be identical to the FEAT/VET process previously described. If the vehicle is confirmed as a gross polluter, appropriate repairs could be required by law. The vehicle owner would have 30 days from the notice date to take the FEAT/VET test. If the vehicle was identified again within the next two months as a gross polluter, an additional level of enforcement could be applied. [The numbers 30 days and 2 months are also not final, and can be modified as needed.] This second level of enforcement could include the requirement that the vehicle report for a more thorough form of centralized test including an anti-tampering inspection, and perhaps a dynamometer loaded-mode emissions test. Repair requirements could also be more stringent. Additional levels of enforcement could follow. In any case, annual license plate renewal would require either no record of mobile FEAT exceedances, an appropriate certificate of vehicle emission "cleanliness" or a waiver of the requirement.

Permanent Test Locations

To support the mobile testing program, at least 10 permanent FEAT/VET test locations could be retained to provide voluntary drive through testing. These locations would be widely publicized so that drivers could have their vehicle(s) tested voluntarily in order to avoid any pollution problems. The fixed locations would also provide mandatory retesting services for gross polluters identified by the mobile FEAT units. FEAT/VET stations could be established at some of the sites currently used by the present VET program. Hours of operation would be similar to those currently used by these centralized VET stations.

Each fixed location would be equipped with one FEAT and one VET operator. The total number of operators should be about 30% above the number of locations, to cover for vacations and sick leave. One full-time supervising technician would serve these stations' maintenance and repair needs. Administration could be handled by the personnel administering the mobile program.

Again, a setup similar to that described above for centralized FEAT/VET stations would be used. Drivers would be directed by signs and gates. A button would activate a gate and the vehicle would drive through the test. At the end of the lane, the driver would receive a Green Ticket, if clean, or a Red Ticket, requiring a VET test, if dirty. Each dated ticket would show the license plate number and the emission test results. The FEAT video would also record license plate numbers and the emission results. This data would be stored for 6 months, then the video tapes could be reused.

The number of needed stations would be less than the current number, due to the use of other (mobile) FEAT units, the overall efficiency of FEAT screening and the fact that only 10% (and at most 20%) of vehicles are gross polluters. Again, the fewer centralized FEAT/VET stations would also serve as voluntary testing locations.

D. Logistics, Siting Requirements, Staffing

Mobile FEAT will be housed in a standard light-duty van equipped with one built-in generator and one portable generator. A custom-built push-out panel will lower the FEAT sensor to the proper level above the roadway. The light source and video camera will be set up individually near, but safely off, the roadway.

Inside the van, a personal computer with digital tape drive and video monitor will be installed. The PC will store the FEAT measurement data base. The tape drive (or digital media) will collect vehicle data on video tape. The tapes(s) will be delivered to a central processing unit once a week. The van would also be equipped with an appropriate environment to provide optimal working conditions for the operator. For security, each unit will be constantly staffed and equipped with a two-way radio and/or cellular telephone.

Staffing for this mobile aspect of the program will involve about 20 people. Ten operators will staff the mobile units. Two supervising technicians will provide backup to unit operators, do maintenance and trouble shooting, conduct quality control checks, and respond to technical emergencies. Two administrators will scout for locations, obtain necessary siting permissions, and assure proper program operation. One technical specialist will conduct the quality assurance program. The technical data handling, data analysis, and program analysis will be handled by 3 data technicians, one program scientist or engineer and one statistician or computer specialist.

Site selection: One of the crucial tasks of this program will be site selection and preparation. The first criteria in locating sites for monitoring will be the safety of staff for setting up, taking down, and operating FEAT. A wide shoulder is desirable to park the van and set up equipment.

Moreover, it will be necessary to find locations where FEAT can monitor passing vehicles across one single lane of traffic. Traffic patterns should reflect representative driving conditions (i.e. cars at moderate speed and load). A stoplight would not be a suitable FEAT site. It will be necessary to obtain permission from authorities having jurisdiction over the road and the site.

1. One effective approach to finding suitable monitoring sites is through regular (weekly or monthly) contact with road maintenance departments, utility companies, and others who might do road work that creates single lane traffic. In this way, a schedule could be compiled of road work which provides the opportunity to set up FEAT on multiple lane roads experiencing forced lane closures.

2. Using detailed county road maps, staff members would look for well-travelled roads, commuter routes, delivery routes, major circulation routes, and similar ideal monitoring conditions. In particular, maps would be examined for single lane opportunities where cars do not stop (such as on and off-ramps to limited access roads), toll booths, and two-lane divided roads. For example, there are many high-volume single lanes in the Chicago area, such as I-88 east merging into I-290 east.

3. To assure complete regional coverage, it also will be necessary for the two administrators to get in a car and start driving around. In the case of multi-lane roads, they would look for wide areas where temporary islands (for a FEAT light source and generator) can be created without restricting traffic flow.

E. Data processing

Each mobile unit will average approximately 4,000 vehicle measurements per day. Since this program is designed to identify gross polluting vehicles, roughly 10% of all measurements will indicate gross polluters. Thus the ten mobile units will measure about 4,000 gross polluters per day. An automatic license plate scanning program (Perceptics) at the central processing unit (CPU), with a mini-computer, will successfully read at least 3,000 of the 4,000 gross polluter license plates; the data technicians will read about 1,000 per day. The data recorded for each gross polluting vehicle will include: license plate number, date of measurement, time, location, HC, CO, CO_2, make of car, and model/year of car. These files will be recorded at the CPU. Computer programs will scan all data to generate the information necessary for further action (i.e., when multiple gross polluting readings of the same car are compiled).

Site specific data summaries for each site stay (e.g., 5 days) will be tabulated. Data summaries will include vehicle emission distribution characteristics, number and level of gross polluters, and an overall pollution summary for future assessment of program impact. During each site stay, the mobile unit technician could complete a site description log including photographs, maps, road descriptions, and detailed comments about installation, operation, traffic characteristics, and other parameters. The site information could be tabulated in the administrators' data file. The notebooks with photos and maps could be maintained indefinitely to provide comparisons for future monitoring at the same as well as other locations.

F. Advantages

As mentioned earlier, mobile remote sensing of vehicle emissions is the optimal use of the FEAT technology. At least two million vehicles, probably more, could be monitored multiple times each year. The high mileage vehicles are the most likely to be monitored, thereby allowing the most effective means of identifying the high mileage gross polluters who are responsible for most vehicle emissions.

This mobile FEAT application is low in cost due to the relatively low capital investment and minimal administration required. It is very high in flexibility. The program can be started with one unit, and gradually expanded as funding and opportunity permit. Ongoing modification, improvement, and optimization of the motor vehicle emission control program can be accomplished in a timely fashion. For example, since detailed data analysis is rapidly available and FEAT monitoring cutpoints for gross polluters can be changed as the data dictate, program adjustments can be made continuously in order to achieve pollution reduction goals. Finally, implementing use of mobile units provides a foundation in order to begin the modular fixed program which will be described below. It allows for extensive testing of the modular fixed program concept before any substantial investment is undertaken.

G. Limitations

The mobile monitoring program will require a lot of siting work. The siting technicians (two administrators) will be continually busy finding suitable sites and obtaining necessary permits. However, after the first year or two, the program should have a repertoire of several hundred good sites (and probably a lot of bad sites also). Effective siting techniques will likely evolve after the first several months. Sites selected independently (i.e., not dependent on tracking street repair or utility crews) and found to be good could be used repetitively, reducing the siting and permission effort. In addition, the program could continue to take advantage of road work siting opportunities while continuing to search out new sites.

Ongoing analysis of the effectiveness of the repertoire of sites regarding fleet coverage, trip distribution, varying geographic/ economic conditions and appropriate vehicle operating conditions will be maintained to ensure that an accurate understanding of fleet emission levels within the entire test area is achieved.

Although the mobile approach provides a lot of flexibility, it entails a nontrivial amount of time setting up and taking down the equipment. In many or most cases, equipment will have to be taken down at the end of each monitoring day. Security for the personnel and equipment will have to be maintained at every site every day.

It is conceivable that some motorists might take great pains to avoid these mobile tests. Perhaps enterprising individuals would try to follow the units and announce their locations over CB radios. However, both possibilities are unlikely or of extremely marginal effectiveness. Since the units are only sited at a location for a few days, it is unlikely that motorists will change ingrained commuting patterns to avoid a mobile FEAT unit. Those few that do will probably be monitored at another site on another day.

H. Discussion, Recommendations

Implementation of remote sensing with this mobile approach takes greatest advantage of the FEAT technology's capabilities. Before full scale implementation, the program can be started, tested, and proven with one unit, which would allow for identification and removal of most hardware and software difficulties as well as unforseen problems. For example, the selection of CO and HC tailpipe emission cutpoints could be determined by several factors including: regulatory agency requirements; the correlation of on-road emission levels to standard idle emission measurements; specific pollution reduction goals; data reduction capabilities; and other factors. According to FEAT testing in Chicago in 1989, using a flat cutpoint of 4% CO to select gross polluters regardless of vehicle age would mean that FEAT would identify the same percentage of cars by model year which fail current VET testing.

However, current Illinois regulatory model year pollution cutpoints in the centralized VET test program allow many older cars which might be considered as gross polluters to pass. While a FEAT regulatory system could be geared to vehicle age, the on-road remote measurements themselves do not discriminate by the model year of gross polluters. Future regulatory modifications could be accommodated in order to phase in control of older vehicles which are gross polluters. This system flexibility does not preclude effective implementation of remote sensing to identify gross polluters on the road. Exemptions for older vehicles could take place during the data analysis phase of the raw FEAT measurements. Since on-road emissions are often double the concentration of idle emissions, a cutpoint of approximately 2% CO and 200 ppm HC could be set. This would identify ALL vehicles which exceed the TIGHTEST emission standards currently applied to new cars in the centralized VET program. Roughly 20% of all vehicles would fall into this polluter category via FEAT measurements. Or, since FEAT measurements will be routinely analyzed by model year, a sliding scale could be applied according to model year prior to naming a vehicle as a gross polluter and proceeding with enforcement.

For example, a targeted sliding scale by model year could be applied whereby the 10% (or any other percent) highest polluters of EACH model year are identified as gross polluters. In this approach, it would be necessary to first determine emission profiles for each model year to find the cutpoint of the 10% dirtiest vehicles. This cutpoint for each model year could also be revised periodically (say once a year) as vehicles get older, some retire, and the current dirtiest 10% are located and fixed. This approach would require a careful selection of data subsets for analysis or a very large amount of data collection and analysis. Another effective approach would be to determine a pollution reduction goal, and back calculate the number or percentage of gross polluters which must be identified and fixed in order to fulfill that pollution reduction goal.

Site specific statistics can be determined from the first 1,000 vehicles which pass any given mobile FEAT location. In order to generate these statistics, all the vehicles, not only the gross polluters, would be recorded on the video system. These site-specific fleet statistics would also be useful for the fleet monitoring aspects of the program.

The lower the initial FEAT emission cutpoint, the greater the number of identified gross polluters, the higher the demand for data processing. Data processing demands also would rise with the complexity of any set of sliding scale cut-points. Additional data processing personnel and costs could be invested most effectively in the initial year of the program in order to establish comprehensive baseline information and allow maximum flexibility for needed adjustments. Once the program parameters are established, data processing demands would be consistently high but lower than initially.

Initial program pilot testing and analysis, using at least 5 mobile units and corresponding staff for six months, is recommended prior to public announcement. Actual enforcement would come even later. This would permit development of the most effective and desirable protocols to resolve the issues discussed above. Education and communication programs could be developed and tested concurrently, to assure successful implementation of the new program. Program implementation should incorporate dedicated educational programs for the public and for all involved parties (automobile mechanics, automobile dealers, regulatory personnel, centralized VET test personnel, environmental advocacy groups, media, etc). This would be the stage at which objections along the lines of fairness (or lack thereof) could be raised and answered.

Appendix A includes a proposed format for a cost and benefit analysis of this mobile approach as well as a proposed protocol for the necessary communications program.

4. Modular Fixed Sensors

A. Introduction

To monitor vehicles at locations which are not convenient or conducive to parking a mobile van, modular FEAT units can be built to fit into small, permanent bunkers. The locations considered for this type of monitoring would be high volume, possibly high speed, highway interchanges, toll plazas, and congested urban locations.

The purpose for this approach would be to supplement the mobile FEAT monitoring by collecting even larger numbers of vehicle measurements. These modular units would particularly target high mileage vehicles, and likely obtain repeat measurements of high mileage gross polluters over fairly short periods of time. Rapid identification of high mileage gross polluters is most important in reducing significantly overall vehicle emissions.

In addition, modular units could operate unattended, thus conveniently obtaining night time, weekend, and holiday data. Units could operate at each location for about a month at a time. The most ideal locations for bunkers would be identified via the routine operations of the mobile FEAT units. Enforcement procedures could be identical to those described for mobile FEAT units.

B. Reasoning

Traffic loads on main commuter roads in the Chicago area are huge. It may be impractical for mobile FEAT units to operate at such high volume locations for long periods, due to the challenges of security, ambient pollution concentrations, inclement weather, and space limitations. However, there is usually enough room to install a FEAT sensor, light source, computer, tape drive, and video camera in any roadway situation, with adequate protection, for unstaffed operation.

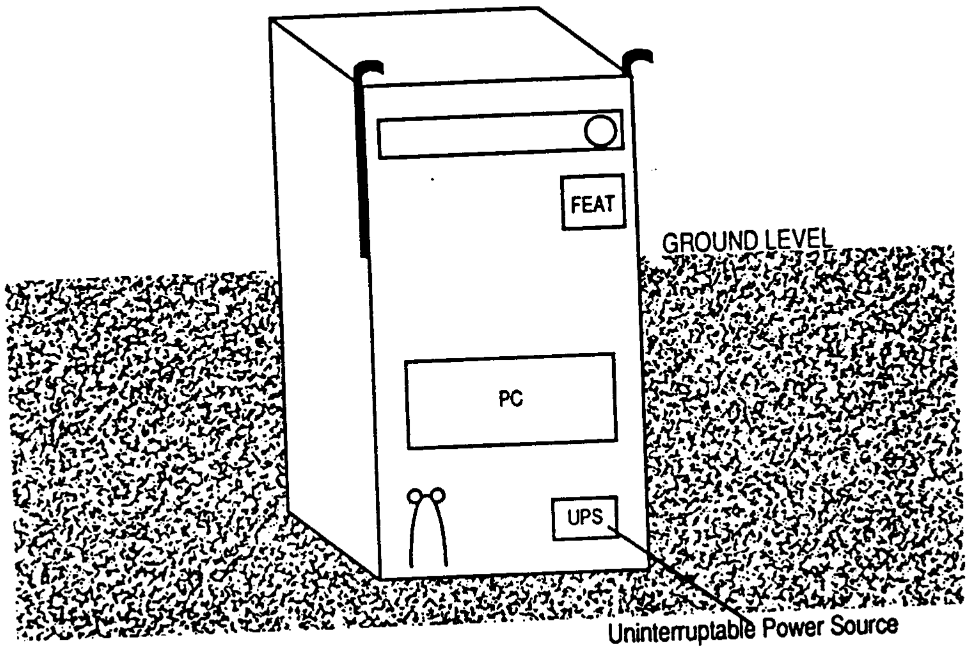
A single lane on a high traffic roadway, ramp, toll lane, or interchange can easily yield 12,000 FEAT measurements per week. Therefore, dispersing modular FEAT sensors at ten appropriate locations throughout the enforcement area could yield 120,000 measurements per week, 480,000 per month. Given recent FEAT experience, each location would successfully measure about 7,000 unique vehicles, the balance being repeat measurements of the same vehicles. Ten sensors would measure at least 70,000 unique vehicles per week, 280,000 per month. Allowing a generous margin for repeat measurements among modular FEAT sites, ten units staying at various locations for one week at a time and operating ten months a year could provide at least two million unique vehicle measurements per year.

Moreover, the prime target of monitoring in high volume locations is to find the high mileage gross polluters. The total potential for at least 4,800,000 FEAT measurements provides for multiple measurements of the same (potentially gross polluting) vehicles. Also since the initial 12,000 measurements per week estimate is a conservative one, the potential of this approach is probably even greater. Accordingly, a full-fledged Chicago area modular program could involve as little as 5 to 10 FEAT units and 50 to 100 permanent bunker sites.

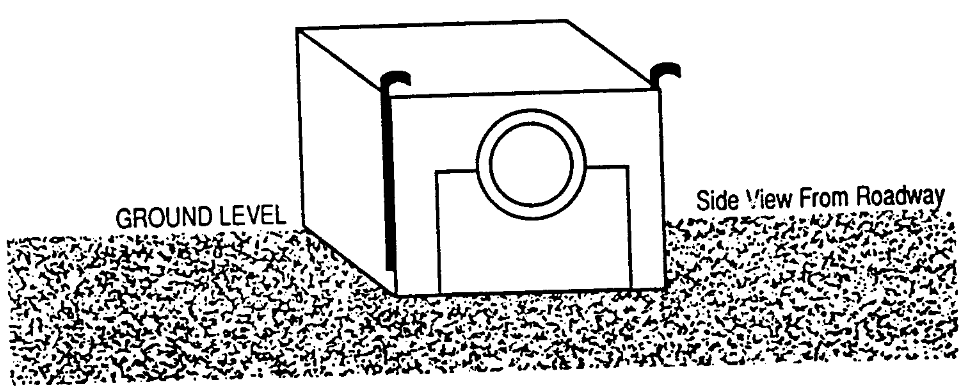
C. Description

A schematic of a potential modular FEAT layout is shown in Figure 3 (page 29). Modular units will consist of a rack mounted detector combined with a computer and disk storage system. This will be inserted into a bunker on one side of the road lane. An infrared light source module will be deposited in a similar but smaller bunker located on the other side of the lane. An established light pole will be used or a permanent pole will be installed for the video camera mounting. The video camera should be enclosed in vandal and weather proof shielding and securely mounted. Electric (110v) power and a telephone line will be installed for the detector bunker; power will be routed to the camera and the source bunker. The bunkers can be constructed out of metal and concrete or similar sturdy, secure material. The modules will be locked in the bunkers and all of the transmission or communication lines (such as from the camera to the computer) will be buried. The units operate without staffing, except for weekly maintenance (pickup of data on digital media and Q/A check), or unless a problem is transmitted by telephone. The telephone lines are not used for data transmission, only for rapid notification of any trouble codes to the technical service center.

Figure 3. Modular Fixed Sensors



Detector Unit



Source Unit

D. Logistics, Siting Requirements, Staffing

Sites could be identified by staff of the mobile monitoring units. Modular fixed sites should be selected for a high traffic volume, acceptably low congestion characteristics and modal driving conditions at moderate speeds. Safe short-term access to the site would be necessary for installing and servicing the units. Again, a high volume of traffic is crucial. To assess the suitability of sites prior to bunker construction, mobile units could operate on nearby accessible highway ramps and other roads. Suitability would be a function of the potential sites physical characteristics and the overall emissions behavior of traffic in the general but immediate area.

As always with FEAT, it is necessary to operate across a single lane of traffic. However, modular FEAT units can be installed in order to operate across a single lane, even if the relevant road has multiple lanes. Highway ramps and interchanges are generally ideal. Toll plazas also provide excellent sites. Fixed toll lanes funnel traffic into temporary singe lane streams, while overall plaza layouts make installation and servicing of modular units fairly easy. Even on crowded downtown streets, there are frequent opportunities for installing modular units by using existing traffic islands, turn lanes, and other separations. All locations would require access to 110v electric power as well as a hard-wired dedicated phone line for status checks.

It is recommended that the modular program be implemented only after a mobile program is operating smoothly. Like the mobile program, the modular program should start small and build gradually. Moreover staffing assignments could overlap and personnel requirements for the modular program could be drawn from the mobile program. Staffing for a full 10-unit program would involve ten people. Two full time technicians would install and service the modular units. One supervising technician could provide service backup to the technicians and conduct a unit-by-unit quality assurance program. One technical specialist/administrator will conduct a system-wide quality assurance program and maintain smooth program operation. The technical data handling, data analysis, and program analysis of FEAT measurements can be handled by four data technicians, one program scientist or engineer and one statistician or computer specialist.

E. Data processing

Data processing would be conducted identical to that for the FEAT/VET and mobile programs described above. A technician could pick up data tapes at each unit about once a week and take them to the CPU for processing. Alternatively, data may be transmitted over dedicated telephone lines.

F. Advantages

The advantages of the modular approach include the ability to acquire huge volumes of vehicle measurements without constant human attention. From an enforcement perspective it opens up many useful (high traffic) locations to FEAT monitoring by using secure bunker installations. Labor costs per vehicle measurement would decrease and routine operating costs would be relatively low. Moreover, the most desirable modular locations can be constantly monitored for extended periods, providing useful data for long term analysis and evaluation of Chicago area fleet emissions. Discovered changes could provide objective measures of the effectiveness of the overall vehicle emissions control system as well as progress toward pollution reduction goals. Finally, modular fixed units can run on weekends, holidays, and nights, when mobile FEAT monitoring may have a very low cost effectiveness. A bunker unit will not be effected by very hot, very cold, or very windy weather.

G. Limitations

The modular approach will have higher initial capital costs than mobile units, but, if properly constructed to withstand weather and road conditions, maintenance costs in subsequent years should be minimal. Even though electric power and telephone operating requirements may offset some of the lower operating costs, if the total program expenditures are averaged over a number of years, the investment in modular FEAT units could be favorably compared with the costs of other control options.

The size of the bunkers may raise question regarding obstruction of traffic. However, many productive sites can be selected and bunkers installed so that there is absolutely no obstruction to traffic. Generally, in many roadway situations, especially those outlined, plenty of space is available so that no obstruction will occur. Construction of the bunkers and video camera installations should be as secure as any standard roadway installation in order to prevent damage by weather, vehicles, or vandals. The bunkers are not very large. Current FEAT units utilize a light source sixteen inches in accross-lane dimension (length) and seven inches wide. The detector is ten inches wide and the same "length".

H. Discussion, Recommendations

High mileage gross polluters could be rapidly identified using FEAT at high volume traffic locations. The modular approach is recommended to provide the advantages of fixed location monitoring without the disadvantage of diminishing returns of monitoring at only one place.

The exact level of fixed monitoring needed to cover the Chicago metropolitan area could be determined and adjusted by the gradual installation of bunker sites and the operation of fixed units. It is expected that between 5 and 10 units operating one week at a time at a total of 50 to 100 sites could find the overwhelming majority, if not all, of the high mileage gross polluters in the area. A modular unit is expected to monitor at least 12,000 vehicles per week, at least 7,000 of which are unique vehicles. If ten modular units were moved only once per month, and were operated for ten months per year then 4.8 million readings will lead to the identification of 224,000 gross polluters, mostly measured multiple times. The actual in-use statistics would be built up as the program developed. It is more likely that ten modular sensors would be needed for the monitoring program presuming that the locations are well chosen. Freeway interchanges and the busiest on and off ramps are certainly the locations which would receive initial emphasis.

For example Figure 4 (page 38) shows a diagrammatic map of Cook County. With the aid of traffic maps, and toll authority information, potential sites have been indicated by various letters and numbers. Capital letters indicate potential tollway locations. The indication of a potential site does not necessarily mean that single lane operation is necessarily available. Numbers indicate surface streets for which a lane closure would be required. A major reason why such high rates of return are available is that the preliminary studies at Central and Eisenhower were operated for a single shift. Mobile units could operate double shifts, while modular units can operate around the clock.

Toll Plazas

This scenario involves the placement of a single FEAT unit at a toll plaza. The unit would be mounted inconspicuously and in a way that vehicles would be monitored as they exit from a toll lane. The unit could be easily moved between various automated or manned toll booths. This arrangement would be in cooperation with the toll authority, since the goal here is to monitor at the booths which are used 24 hours per day. This placement at a multi-lane toll plaza has the useful property that a very large number of different vehicles will be monitored, provided that the unit is located appropriately. For instance the River Road interchange plaza on I-90 just East of O'Hare carries 65,540 vehicles daily through eleven lanes (according to data from Illinois toll authority). Further discussions with the toll authority indicated that an automated automobile-only lane collects tolls from about 650 vehicles per hour, whereas a manned lane tolls about 450 vehicles per hour. The most used lanes can operate at that rate for twenty hours per day. The two lanes above would toll 13,000 and 9,000 vehicles respectively during the twenty hours of high traffic. More would be collected during the quietest four hours, but not at the high hourly rates. We estimate that a lane which stays open at all times will monitor at least 1.5*65,540/11 = 8,900 vehicles per day, where the factor of 1.5 was estimated to take into account the fact that the sensor would be located on the lanes which received the most traffic. A monitor which stayed at the site for twenty days would make 178,000 measurements of passing vehicles. Many multiple measurements of the same vehicle would occur, up to a maximum possible of 20 times. However, the latter would be very unlikely since the FEAT unit would be moved randomly between automatic and manual toll lanes. At Central and Eisenhower, we observed about 7,000 different vehicles in five days compared to about 4,000 different vehicles in one day. If these statistics hold up at River Road, then over 100,000 (65,540*7/4 = 114,000) different vehicles would be monitored by the 178,000 measurements in twenty days.

There are many possible tollway placements. The map shown in Figure 5 (page 38) indicates by letters five locations which would be used first, namely River Road (R), Deerfield Road (D), Cermak Road (C), Army Trail Road (A) and York Road (Y). They were chosen in order to monitor all the major commuter toll routes into Chicago. The analysis which was discussed above for River Road was carried out for each of the above locations. The results are tabulated below.

Location	Lanes	Vehicles	Days	Different Vehicles
River Road	11	65,540	20	114,000
Deerfield Road	10(S)	58,460	20	102,000
Cermak Road	12(N)	56,420	20	98,000
Army Trail Road	6(N)	25,920	10	45,000
York Road	10(N)	54,660	20	96,000
TOTALS	49		100	445,000

Shown above is a conservative calculation for a single FEAT sensor which spends 100 days rotating around various toll plazas. This single sensor is capable of monitoring more than 10% of the total Chicago area vehicle fleet, with most of the vehicles monitored more than once.

Surface Streets

The map of Cook County also shows ten strategically located potential surface street sampling sites indicated by the numerals 0-9. These sites are indicated as examples of surface street placement. Traffic map data gave the number of vehicles passing, but not the number of lanes. We therefore estimated the number of lanes based on similar traffic count maps from Denver for which the lane and the vehicle count are known.

Single lane sampling of surface streets can be carried out in one of two modes. In the Los Angeles basin both modes have been utilized. In the first mode one lane was closed so that two lanes were forced into one. The FEAT unit then monitored the total two lane traffic although only across one lane. In the second mode no lane was closed. The traffic passed around a "PASS EITHER SIDE" lane divider in which the light source was located. The FEAT unit could sample either the inside or outside lane depending on whether the detector was on the median or the shoulder of the road. If lane closures are present, the traffic count doubles and more vehicles are detected in a single day. If lane closures are not available (in one case in LA the lane closure was for FEAT, in another it was already in place for the gas company) then only a single lane count will be measured in a single day. For a conservative calculation we assume that no lane closures will be available and therefore multi lane sites will need to be monitored for twice as long as single lane sites (note that in every case only one direction is monitored). The site characteristics are tabulated below.

Site #	Name	Location	Daily Vehicles per lane	#lanes assumed	days
1	Lincoln	at US 14	5,000	4	10
2	North Ave	at Pulaski	6,000	4	10
3	Illinois 21	at Dempster	6,000	6	15
4	Waukegan	at Willow	5,000	4	10
5	Roosevelt	at First	5,500	4	10
6	Ogden	at California	4,000	4	10
7	Archer	at Willow Springs	6,000	2	5
8	Cicero	at 95th	5,000	8	20
9	Halstead	at Riverdale	5,400	4	10
0	Calumet	North of I-80	6,000	4	10
TOTALS			53,900	44	110

If we again assume the 7/4 ratio of different vehicles over and above the different vehicles encountered on one day, then the table above shows that a single remote sensor working a 24 hour day for 110 days at ten sites could be expected to monitor at least 94,000 different vehicles, mostly monitored more than once. In view of the fact that traffic counts are highly peaked, we believe that many of these sites would achieve the vehicle counts listed above with as little as eight hours of monitoring, four hours for the morning commuter rush and four for the evening rush "hour".

Freeway On-off Ramps

The Chicago area is liberally supplied with freeway ramps whose characteristics are not significantly different from the on-ramp studied at Central and Eisenhower. At that ramp, five days of study yielded 7,000 unique vehicles, many monitored more than once. In 100 days, a mobile FEAT unit operating only one eight hour shift could service 20 such sites for a total of 140,000 vehicles.

Freeway Interchange Ramps

Given available highway traffic maps it is not possible to determine traffic counts on freeway interchanges, nor whether interchange ramps narrow down to single lanes. Based on data from Denver, it is quite realistic for a sensor working a 14 hour shift to observe over 10,000 vehicles per weekday on an interchange ramp. Using the previous 7/4 ratio, this would imply that five days of measurements at such a site would yield data for 17,500 different vehicles. There are more than twenty such interchange ramps in the Chicago area. Two ramps which appear to have the necessary characteristics include I-88E to I-279E and I-290E to I-90N. If a mobile sensor visited twenty in 100 work days it would monitor 175,000 different vehicles.

Program Development

As the previously envisioned program outlined here develops, sensors could be added and relocated to ensure the optimum fleet coverage. The four scenarios above indicate in some detail where the first four sensors might be located. At the end of the first 100 days of monitoring (110 calendar days) we predict that at least 854,000 different vehicles would have been measured by these four sensors.

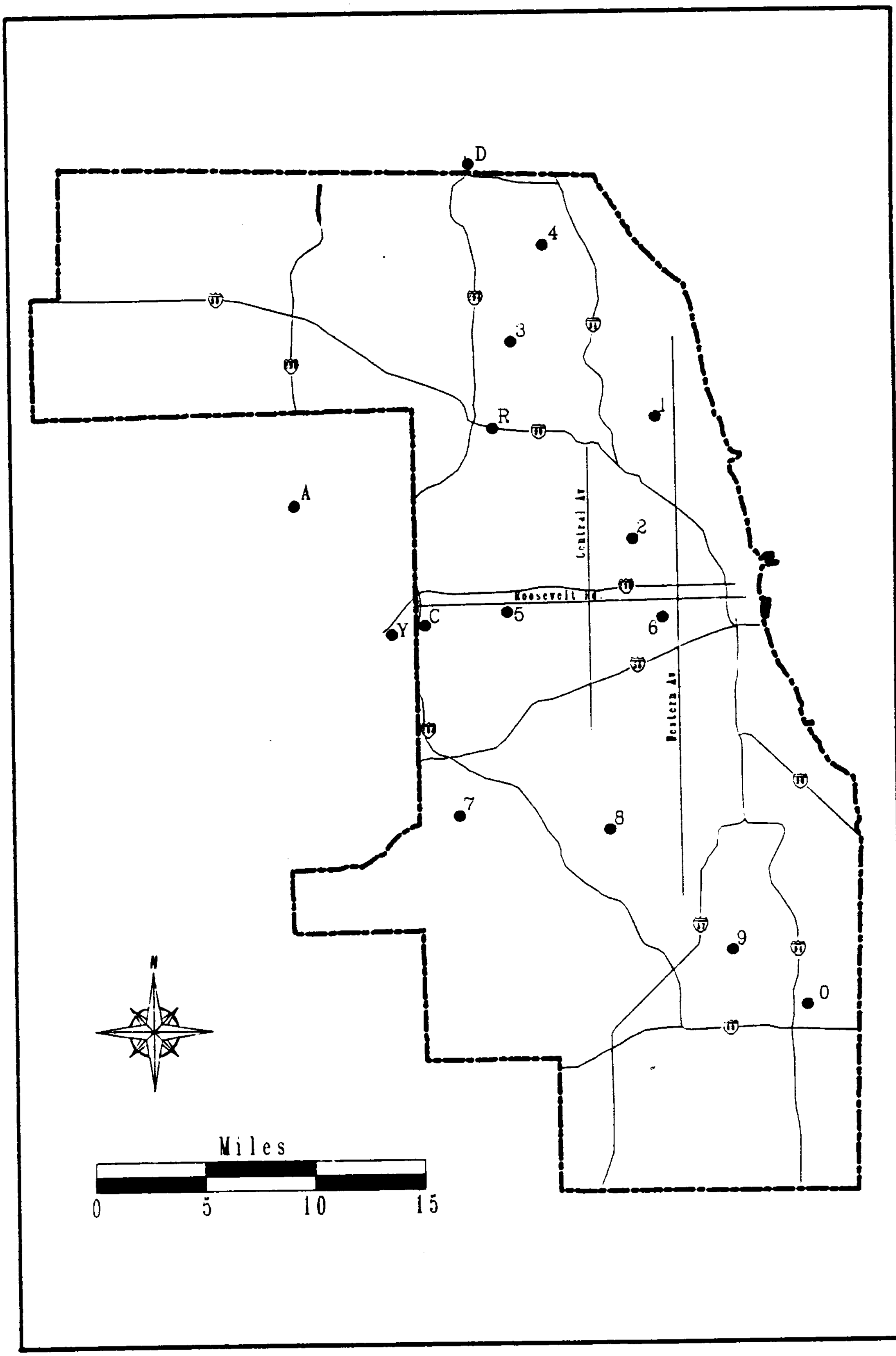
Toll Plazas	445,000
Surface Streets	94,000
Freeway On-off Ramps	140,000
Freeway Interchanges	175,000
TOTAL	854,000

Allowing for a generous margin for repeat measurements among the four types of site at least 800,000 unique vehicles would have been measured.

Relevant questions which could be asked as the placement process develops are for example: Where should the next monitor be located? Where is the optimum location to measure vehicles whose routes have not been specifically covered? Should a sensor be located close to O'Hare specifically to look for livery vehicles which are high mileage, and therefore most important? Should a sensor be placed in the Loop area for the same reason?. It will also be appropriate to determine which siting scenario best meets the goal of measuring a large number of vehicles which are important to air quality. For example it is possible that suburban toll roads carry a significantly newer fleet, and therefore a significantly less polluting fleet than the Chicago surface streets. That question could be answered directly from the remote sensing data. The resulting answer would need to be taken into account to achieve the goal of cleaner air with the minimum additional cost. Taking such air quality benefit determinations into account in a remote monitoring program is essentially identical to the notion that new vehicles should receive I/M tests less often because they fail those tests less frequently than older vehicles.

Traffic counts and patterns in the other counties of the VET enforcement area (DuPage, Kane, Lake and Will) need to be analyzed in a similar fashion. We estimate that Cook County can adequately be monitored by four rotating remote sensors. Short of a full scale analysis, we estimate that another sixteen sensors (four for each remaining county) would be needed, for a total of twenty. About 275 separate monitoring sites would be involved. Approximately 55 were estimated for Cook County. So, at most, 220 (55*4) would be needed for the other four counties. When added to the 55 Cook County sites the total sites required would number 275. About 100 would be permanent bunkers for the mobile modular sensors; the remainder would be utilized by the mobile units. Therefore, ten mobile and ten modular remote sensors rotating among about 275 sites (100 of which are fixed bunkers) could adequately monitor emissions from the Chicago area fleet.

Figure 4. Schematic diagram of Chicago area potential monitoring sites.



5. Data Transmission and Processing

Some of the aspects of data handling have been presented already in the description of each scenario for implementing remote sensing for vehicle emission monitoring. This section will discuss additional detailed considerations regarding data transmission and processing.

A. Vehicle Identification

Identification of the gross polluting vehicles measured on the road in the mobile and modular programs is one of the critical steps in controlling vehicle pollution. The data collected at the on-road sites must and will include emission concentrations and a video image of the back of the vehicle. That data must be analyzed to identify gross polluting vehicles. The following overall procedure is recommended.

1. Tapes, or other video media are transported from all monitoring sites to a central location about once a week.
2. Video pictures are processed through the Perceptics automatic scanning software to read license plates for all vehicles exceeding the minimum allowable emissions.
3. Most relevant license plates are read by Perceptics and the corresponding emissions data is encoded along with the corresponding plate number. Plates missed by Perceptics are processed manually.
4. The license plate list of gross polluters is sent to the Secretary of State for computerized registration information.
5. Registration information is incorporated into the central data base.
6. The central computer (CPU) processes registration and emission information according to programmed specifications to identify gross polluters with repeat measurements.
7. State enforcement procedures are implemented to notify vehicle owners and proceed with measures to obtain motorists' compliance with state environmental regulations.

Out-of-state (OOS) plate numbers and emission measurements could be coded and stored in a separate OOS file. Periodically (weekly or monthly), the OOS file would be reviewed for repeat offenders. Depending on state licensing regulations and other considerations, very high polluting repeat offenders and/or persistent or long-term repeat offenders could be tracked either in the field or through their (other) state registration.

Data processing for FEAT screening at centralized VET stations would be based on current procedures for centralized testing.

Electronic Scanning

The Illinois State Toll Highway Authority is currently testing an electronic scanning system which automatically identifies vehicles driving past a specific location. The Toll Authority is testing the system for its application to collecting tolls without vehicles having to stop every time they pass a toll booth location. This system could be applied directly to remote sensing of vehicle emissions.

The ultimate configuration of such a system and its method of application is beyond the scope of this report, but possibilities exist which should be borne in mind for future consideration. For example, if all vehicles in the enforcement area were equipped with a remote identification unit, the scanning system could be used in all FEAT screening formats. This would eliminate the both the need to read license plates, and the need for hard-copies of FEAT/VET results. Vehicle identification and current pass/fail emission status would be recorded automatically, and records transmitted weekly to the Department of Motor Vehicles for license plate renewal purposes. Any vehicle with a failing status could not be issued a license plate renewal. Renewal would be contingent on fulfilling emissions requirements and thereby obtaining a passing status.

If all vehicles are not equipped, a voluntary program could be implemented. For example, voluntarily equipped vehicles could be exempted from centralized testing. They would only be tested randomly by mobile or modular sensors. Or volunteering drivers could be required to drive by one of many specified locations at least once (or more) a year in place of centralized screening. It may be advisable to maintain contact with Toll Authority technical personnel to pursue the potential for joint developments and application.

B. Data Transmission and Communications

Specific data transmission and communication issues will be considered here. The following description provides an alternative to manual transport of tapes from mobile and modular sites by using automatic transfer of data over telephone lines.

The basic system organization and architecture of the FEAT on-road remote sensing system for measuring automobile emissions consists of three potential types of elements: centralized, mobile, and/or modular. The organization of the remote sensing system (RSS) and its connections to the central host computer is illustrated in Figure 5 (page 44).

The interrelationships of subsystems shown in Figure 5 is as follows: the host computer is a dedicated unit with communication network software capable of supporting multiple additional dedicated ports. These ports are modem interfaces for 9.6 kbaud telephone lines and an Electrical Industries Association (EIA) cable interface to a cellular radio or dedicated line modem subsystem. (2400 baud dial-up phone lines may suffice in place of the 9.6k.) The centralized site RSS is collocated with a VET fixed site and is connected to it via an EIA cable. The data from this centralized site RSS will share the existing dedicated telephone line and the currently used modem. If this timesharing of current VET resources cannot be done, then another separate dedicated link and modem will be required.

The mobile units will operate independently, with data tapes physically delivered to the central location approximately once a week. Each mobile unit will be equipped with a cellular phone or radio communication for trouble shooting.

The modular site RSS is shown connected via a dedicated telephone line using available utilities near the operating location or an interface to a dedicated cellular radio or line modem. The modem is shown connected to the modular site RSS via an EIA cable. It is assumed that this modular site RSS could transmit its data at 9.6 kbaud, but may not necessarily do so. Figure 5 also allows for the option that data will be collected at the time of weekly calibrations and returned by hand to the central processor as is the case for the mobile units.

Figure 6 (page 45) provides a more detailed description of the centralized and modular elements of the RSS. The centralized site RSS is shown consisting of a computer terminal, a CPU, and a modem. The modem is connected to the modem at the central facility. The FEAT subsystem is shown interfaced directly to the VET CPU with the appropriate conditioning equipment. The central system is represented as consisting of two CPUs and a terminal interface. Notice that one of the CPUs is employed as the residence of the database, while the other CPU performs the real-time data processing and communication processing.

The modular RSS is shown consisting of the same components as the fixed RSS, but since the interface can be to a cellular radio, the modem could be different. The cellular radio subsystem is shown as a single box which contains both the transmitting and receiving radio as well as the radio frequency medium. An error detection system will be required for all telephone and other transmission lines to make sure that line noise is not a problem and does not interfere with accurate data communication.

The communication protocol which supports this data communications process should have a Digital Network Architecture (DNA). The DNA structure is shown in Table 1 (page 46), and is compatible with the International Standards Organization (ISO) seven layer format. Due to the point-to-point form of the overall FEAT RSS, some of the layers are not implemented. The communications software resides at the central computer, compatible with DNA. Following are brief definitions of the various layers.

1. The user layer provides service that directly supports the user and application tasks such as resource sharing, file transfers, and remote file access.

2. The network management layer monitors network operations by logging events and collecting statistical and error information. Control of network parameters to include modems and interfaces are also handled by this layer.

3. The network application layer converts data for display on terminal screens and printers.

4. The session control layer manages the system-dependent aspects of a communication session. For example, when the end communications layer reliably delivers a message, the session control layer interprets that message for acceptance by the system software.

5. The end communications layer addresses the end machine without concern for routing and can perform end-to-end error recovery.

6. The routing layer relies on the error-free connections from the end communications layer to route messages to the various nodes in the network. The routing layer and higher layers are generally implemented in software.

7. The data link layer prepares messages for transmission according to a specified protocol, checks the integrity of the received messages, and manages access to the channel. This layer is usually implemented in both hardware and software.

8. The physical layer governs the electrical and mechanical transport of information between the systems. The media could be cables, fiber optic lines, microwave transmission, or telephone lines.

Figure 5. Communications and Data Transmission

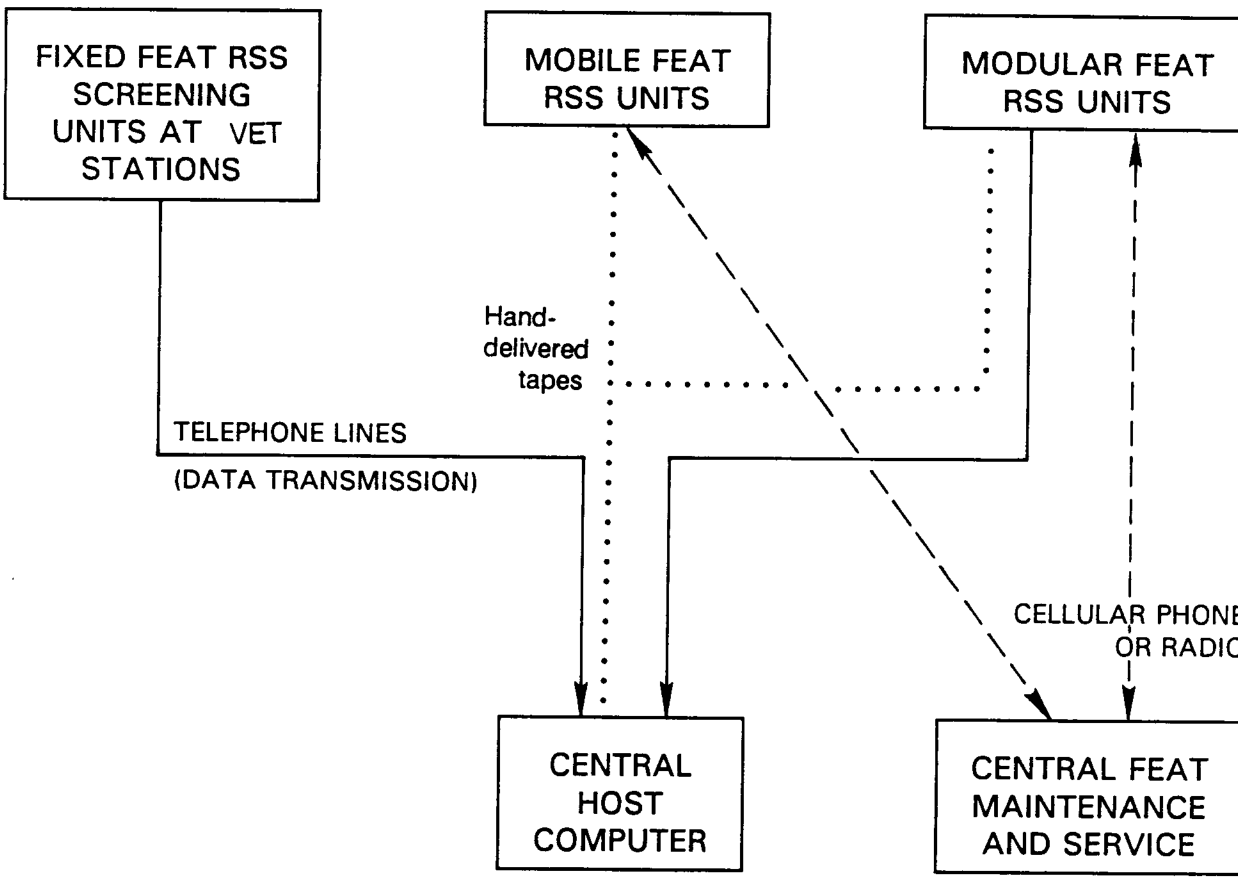
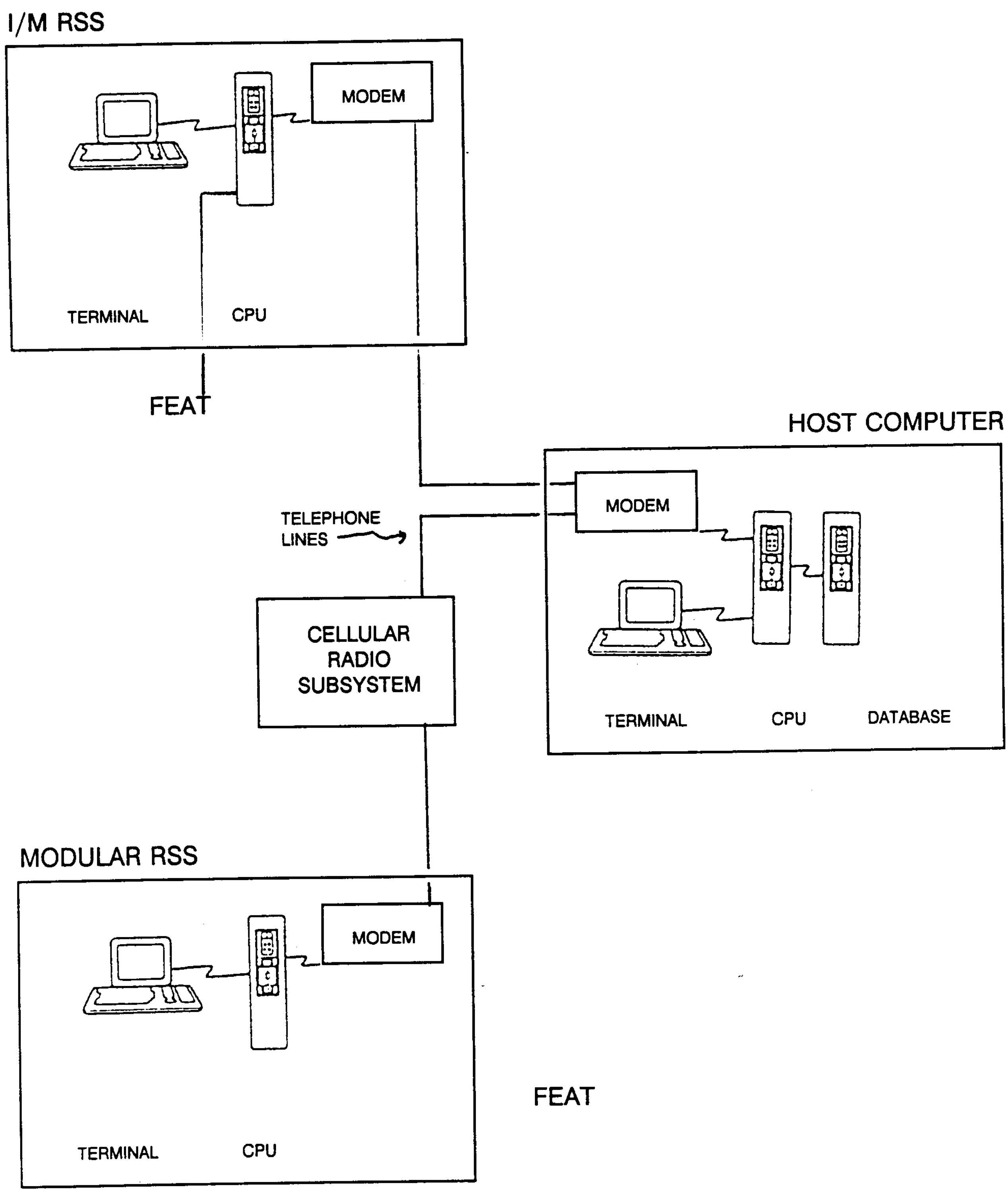


Figure 6. Detailed System Architecture



ISO Layers	DNA Layers	Functions
Application	User	• File Transfer • Down Line System Load • Remote Command File Submissions • Virtual Terminals
	Network Management	
Presentation	Network Application	
Session	Session Control	Task-to-Task
Transport	End Communications	
Network	Routing	Adaptive Routing
Data Link	Data Link	Point-to-Point
Physical	Physical Link	Multipoint

Table 1. Digital Network Architecture Structure

Alternative: Data can be collected on tape in the same way as for the mobile units. Tapes can then be picked up from modular sites once a week during maintenance and delivered to the central location for processing. Each modular site would still be equipped with a telephone connection for remote trouble shooting.

Security Considerations: Security precautions will have to be established to protect data transmission and the data bases themselves. Periodic quality control checks will be necessary to make sure that the communication and transmission systems are operating accurately. Provisions will have to be made to verify that data cannot be modified and that tampering is prevented. An enterprising computer hacker may be tempted to develop a cottage industry of "fixing" emission measurements for people whose cars are gross polluters. In the case of modular fixed remote sensing units, if they are connected with dedicated phone lines, such dial-up tampering would not be possible. However, other avenues of tampering should be considered and prevented.

C. Data Analysis

Computer analysis program routines will be established in all of the above approaches (centralized, mobile, modular fixed) to provide ongoing review, assessment, and evaluation of program operations and results. Analysis programs can include routines to produce site specific data summaries for each year, and year-to-year comparisons after the first year. Overall program statistics will be summarized annually, and year-to-year comparisons will be done after the first year. Additional statistics will be compiled according to desired parameters. For example, summaries of vehicle model years and vehicle makes for gross polluters will be compiled. These data will be compared with aggregate vehicle registration information to provide normalized analysis.

Management review of program evolution will be performed every six months. Specifically, changes in site and vehicle characteristics will be analyzed. Most importantly, a critical assessment of the achievement of goals, or lack thereof, will be completed.

It should be determined in advance, and evaluated as the program progresses, what level of emissions reduction should be observed based on predicted and actual gross polluter identification and repair. The remote sensing program described in this report would need to be integrally linked to the enforcement/vehicle repair program. If the linked programs work, average vehicle emissions will decline, and the decline will be measurable using the FEAT/VET data.

6. Fleet Coverage, Trip Distribution, and Other Issues

A. Fleet Coverage

The centralized FEAT/VET screening approach using FEAT remote sensing to speed up periodic testing of all vehicles maintains the same fleet coverage as the current VET program. Each complying vehicle is tested once a year (or as often as specified) regardless of mileage.

To achieve greater efficiency, on-road remote sensing based vehicle emission measurement is designed to identify high mileage gross polluting vehicles. The percentage of cars analyzed by FEAT on the road (mobile and fixed modular) out of all the cars registered in the test area is not directly relevant to the vehicle pollution emission problem. Of far greater importance is the percentage of total vehicle miles travelled (VMT) represented by vehicles captured by FEAT on-road measurements. On-road measurements (mobile and fixed modular) will provide a much better representation of VMT than a single annual test of all vehicles.

The impact of identifying high mileage gross polluting vehicles is demonstrated by an evaluation of the variation in emissions and mileage of a typical fleet. Table 2 (page 52) presents carbon monoxide emissions from a typical fleet in one day. A similar table regarding hydrocarbon (HC) emissions would show the same features. The variation in emissions is represented by the ten columns across. Each column represents ten percent of the fleet. The first seven columns, or seventy percent of the fleet, have low (5 grams/mile) CO emissions. The last three are higher; the last one defines the gross polluting category described in earlier studies. Given FEAT research findings to date, this distribution is typical of the emissions distribution of cars on the road. Half the pollution coming from less than 10 percent of the fleet has been the distribution observed at all locations yet tested. This statistic however does not account for the fact that some vehicles drive very few miles while a few drive long distances in the urban area in any given day.

The distribution in vehicle miles travelled is represented by the ten rows; each row again representing ten percent of the fleet. On a given day, about twenty percent of registered vehicles (the first 2 rows) are not driven at all. Each row beyond that has increasing amounts of miles driven. The last row, 250 miles per day, represents the high mileage vehicles, such as taxis and delivery vehicles. The numbers presented for emissions and mileage are based on conservative estimates of typical travel in Denver, Colorado. Actual numbers on any day in any location (such as the Chicago metropolitain area) will vary, but the overall pattern will be the same. As much as half the mileage may be driven by only ten percent of the fleet.

Thus, each box in the table represents the daily CO emissions from one percent of the fleet when we take in the fact that both the emissions and the mileage distributions are skewed. Note that the one percent of high mileage gross polluters (in the bottom right corner) account for approximately **thirty percent** of the entire fleet emissions. Two percent of the vehicles account for over 40% of the emissions; 3% of the vehicles--approximately 50% of the emissions, and the highest 10 percent approximately 75 percent of CO emissions. These are the vehicles which on-road remote sensors are best suited to locate, while leaving the 90% of the vehicles which contribute less than 30% of the pollution alone. A more conservative division would ignore the cleanest 50% of the fleet which contribute only 2% of the emissions! An alternative illustration of the same phenomenon is shown on Figure 7 on page 53. The high mileage gross polluters are the major contributors illustrated in the left rear corner.

The **actual** percentage of cars analyzed by the on-road systems out of all the cars registered in a given area can be determined by comprehensive data analysis of license plate numbers from random segments of all remote sensing data collected. The video records for a statistically significant selection of days from a variety of sites could be fully analyzed to develop the current profile of gross polluters compared to the total sample of cars measured in the selected records. This profile could then be extrapolated to the total area population with a known level of uncertainty. The result could be compared to the best available mobile source emissions inventory estimates. This analysis routine could be performed periodically at additional cost if desired for regulatory purposes.

A slightly less precise assessment of vehicle population coverage would be easily available through comparison of the distribution of gross polluters (number of different vehicles measured, number of repeat measurements), to the total number of vehicles measured. This extrapolation requires only that the heterogeneity of the observed gross polluters be similar to the heterogeneity of the observed fleet. Finally, within the overall level of accuracy of present VMT estimates, one could assess the relative representation of VMT captured by on-road remote measurements compared to that represented by centralized annual VET testing. The calculation method would be an application of the law of constant proportions.

On-road emission monitoring will never "catch" 100% of the cars registered in the enforcement area. Presuming that siting and analysis are responsibly carried out, the cars which are not "caught" by FEAT are mostly irrelevant to overall air pollution levels. Annual idle I/M tests miss a lot of polluting cars due to the large variability in results of that form of test (EPA 1988). Continuous on-road monitoring will identify a significantly higher percentage of actual pollution sources than could be found through single annual tests of all registered vehicles.

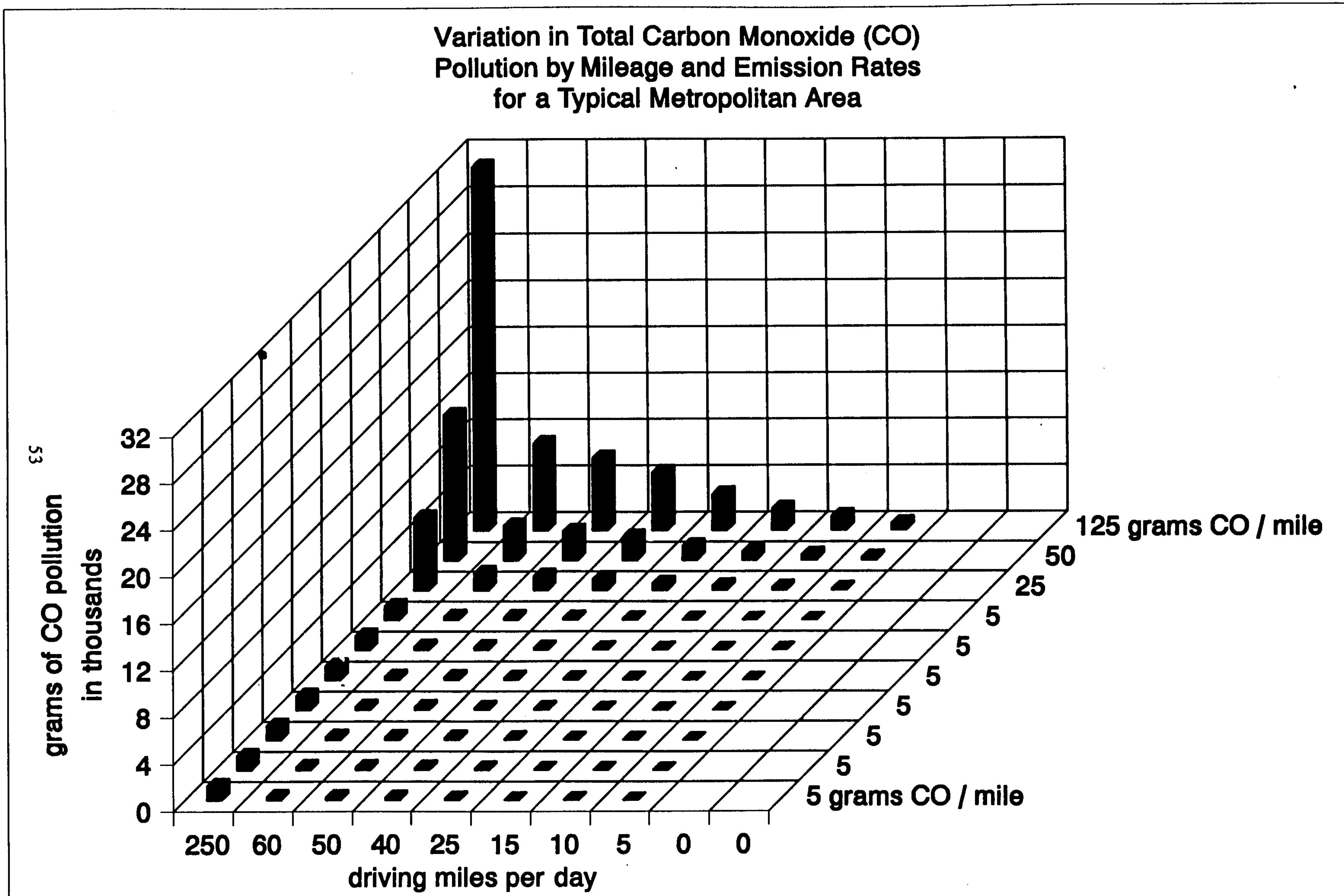
Table 2. Variation in Emissions and Mileage of a Fleet

Grams of CO Pollution From a Typical Fleet in One Day											
MILES PER DAY	Carbon Monoxide Emissions -- GRAMS PER MILE										
	5	5	5	5	5	5	5	25	50	125	TOTAL
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
5	25	25	25	25	25	25	25	125	250	625	1175
10	50	50	50	50	50	50	50	250	500	1250	2350
15	75	75	75	75	75	75	75	375	750	1875	3525
25	125	125	125	125	125	125	125	625	1250	* 3125	5875
40	200	200	200	200	200	200	200	1000	* 2000	* 5000	9400
50	250	250	250	250	250	250	250	1250	* 2500	** 6250	11750
60	300	300	300	300	300	300	300	1500	* 3000	** 7500	14100
250	1250	1250	1250	1250	1250	1250	1250	* 6250	** 12500	31250	58750
TOTAL	2275	2275	2275	2275	2275	2275	2275	11375	22750	56875	106925

Average grams per mile: 23.5
Average miles per day: 45
GRAND TOTAL grams: 106,925

Bold: 30% of daily emissions from 1% of the fleet.
Bold and **: 50% of daily emissions from 4% of the fleet.
Bold and ** and *: 78% of daily emissions from 10% of the fleet.

Figure 7. A three dimensional illustration of the data from Table 2.



B. Trip Distribution

Initial siting of on-road remote sensing locations can be done using local traffic maps and highway department help to determine characteristic travel patterns and assure representative coverage of local and regional trip distribution. Because of FEAT's capability to measure thousands of vehicles each day, comprehensive coverage of vehicle travel can be achieved with economy of effort.

Periodic (quarterly) review of gross polluter vehicle data will be incorporated into the siting strategy in order to continually improve coverage of trip distributions. Based on a realistic projection of measuring about two million different vehicles per year through mobile monitoring and approximately another 2 million vehicles per year through fixed modular units, the likelihood of a high mileage gross polluter not being measured repeatedly every year is negligible.

C. Pollution reduction goals

These proposed FEAT systems can provide a significant advance in identifying the small percentage of cars which cause a large percentage of mobile source emissions. A significant percent reduction in CO and HC emissions CAN be achieved if those gross polluters are then repaired. No pollution reduction is achieved if gross polluters are only identified. This report establishes the framework for implementing the identification program. It must be coupled with an effective program which obligates the owners of the identified gross polluters to tune, repair, or otherwise decrease their vehicle's emission level.

Some changes in regulatory procedures such as linking by law measured emissions to legal vehicle registration (as suggested above) will be required to implement an enforcement program based on identifying gross polluters by remote sensing. Pilot implementation of the remote sensing approach and a graduated implementation schedule overlapping with current centralized VET testing could be an effective and prudent mechanism to allow for orderly step-by-step changes to occur.

D. Quality Control and Quality Assurance

Rigorous quality control procedures are an integral part of these remote sensing programs, whether applied to centralized screening or on-road monitoring. Standard photometric and statistical procedures are used to verify calibrations, zeroes, spans, data calculations, and other technical monitoring and analytical processes. Certified traceable calibration gases are used for verifying all monitoring data.

A custom quality assurance program can be designed for each phase of any of the remote sensing programs described above. The purpose of a quality assurance program is to provide independent verification that the quality control program is functioning properly and that the QC program is suitable for its application. Since the above programs are totally new, a custom design for an appropriate quality assurance program is necessary.

7. Conclusions and Recommendations

A. Conclusions

The technology is available from the University of Denver to begin serious consideration of implementing remote sensing to identify gross polluting vehicles in the Chicago area. Remote sensing applied to vehicle emission measurements can be the basis for a flexible, efficient, cost-effective enforcement strategy which will not inconvenience the vast majority of drivers who are operating clean-running vehicles.

The initial implementation will require several detailed steps to locate sites, establish data processing procedures, train operators, and start up equipment. But the process can be carried out at a reasonable cost in a fairly short period of time.

It should be determined in advance, and evaluated as the program progresses, what level of emissions reduction is needed based on predicted and actual gross polluter identification and repair. The remote sensing programs described in this report must be integrally linked to effective enforcement procedures. The effectiveness of the linked programs should cause average vehicle emissions to decline. This decline can be measured using the remote sensing FEAT data.

B. Recommendations

Appendix A (pages 61 to 64) describes the steps recommended to complete a cost effectiveness evaluation of the programs described herein. Requirements for a communication program designed to help implement these programs successfully are presented. These two projects are the next steps towards application of remote-sensing for vehicle emission controls in the Chicago area.

Technical test work should continue to complete evaluation of HC monitoring and compare the characteristics of HC and CO emissions. Other types of on-road monitoring should be continued to expand the characterization of vehicle emissions and the FEAT monitoring system.

Remote sensing of mobile source emissions of nitrogen oxides and particles should be pursued.

Once a cost effectiveness analysis is completed, funds which will be saved due to more cost-effective FEAT monitoring can be reallocated to finance the development, testing and implementation of an effective program to repair gross polluters. This effort will probably overlap with the communication program development, since legislative as well as some socioeconomic and political modifications of the status quo will be necessary. As all the aspects of the proposed programs advance, failure analysis of designs and test programs should be completed, to develop and implement solutions as promptly as possible.

8. References

"An Analysis of On-Road Remote Sensing as a Tool for Automobile Emissions Control," D. H. Stedman and G. A. Bishop, Illinois Department of Energy and Natural Resources, ILENR/RE-AG-90/05, March 1990.

"IR Long-Path Photometry, A Remote Sensing Tool for Automobile Emissions," G. A. Bishop, J. R. Starkey, A. Ihlenfeldt, W. J. Williams, and D. H. Stedman. *Anal. Chem.*, **61**, 671A-677A, 1989.

"Oxygenated Fuels, A Remote Sensing Evaluation," G. A. Bishop and D. H. Stedman. Society for Automotive Engineers, Technical Paper Series, #891116, 1989.

"Automobile Carbon Monoxide Emissions," D. H. Stedman. *Env. Sci. & Tech.*, **23**, 147-149, 1989.

"Variability of I/M Test Scores Over Time," L. R. Smith, Southwest Research Institute, U. S. Environmental Protection Agency, Ann Arbor, MI. EPA 460/3-88-008, September 1988.

"Illinois State Implementation Plan for Air Pollution Control: The Illinois Inspection and Maintenance Program," Illinois Environmental Protection Agency. Supplement to the 1982 Plan Revision for Ozone and Carbon Monoxide, IEPA, Division of Air Pollution Control, Springfield, IL 62706, AQPSTR 86-1, February, 1986.

"Emissions from In-Use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program," D. R. Lawson, P. J. Groblicki, D. H. Stedman, G. A. Bishop, and P. L. Guenther. *J. Air Waste Mgmt. Assoc*, **40**, 1096-1105, 1990.

Appendix A

Preliminary Implementation Analysis for Remote-Sensing Enhanced Inspection / Maintenance Program in the Chicago Area

A. COST-EFFECTIVENESS EVALUATION

1. Costs and Effectiveness of Remote Sensing-Enhanced Automobile Emissions Control Program

A detailed cost-effectiveness analysis of selected remote sensing-enhanced emissions control programs will be completed, including the following elements.

a. Program Costs

- Hardware: lease/purchase; service and maintenance; replacement.
- Personnel training, software and supplies for startup.
- Operational costs--remote sensing equipment, supplies, data processing, enforcement, analysis, personnel.
- Program evaluation/review, research, program enhancement.
- Education program.
- Financing.
- Contingency.

b. Public and Individual Costs

- Individual participation costs and savings; social costs, inconvenience/ convenience; opportunity costs/ savings
- Government investments and operations.

c. Effectiveness

- Public and individual cost-savings.
- Potential annual pollution reduction.
- Cost per ton of pollutant reduced.

[Note: This report would not address health benefits or intangible economic benefits derived from environmental improvement.]

2. Cost/Effectiveness Comparison with Other Pollutant Reduction Programs

Available information on costs and effectiveness of other control strategies will be compiled and evaluated. Cost per ton comparisons will be tabulated. The study commissioned by the Arizona Department of Environmental Quality evaluating I/M and the studies underway at the Colorado State Auditor's office to evaluate oxygenated fuels and I/M will be consulted. Other control strategies to be considered include:

- Lower RVP gasolines.
- Oxygen-blended gasolines and other alternative fuel measures.

- Current Illinois I/M program.
- Traffic Control Measures (TCM): trip reduction programs, traffic light synchronization, bus/HOV lanes, new road construction to reduce congestion.
- Imposition of California Tailpipe Standards

3. Design of Stage 1 Implementation

A first-stage program will be designed using a model of the full-scale program, but requiring less than 25% of the total investment. The staged approach is recommended to work out inevitable bugs, screen for internal inconsistancy and verify all premises.

4. Final Report

A draft final report summarizing the work of each section above with detailed appendices will be prepared for review and comment by the IDENR Research Section. The DU project leader will meet with IDENR staff to respond to comments. A final report will then be prepared based on the draft and recommended changes.

B. COMMUNICATION PROGRAM: DESIGN FOR PUBLIC ACCEPTANCE

Successful implementation of a revised vehicle emission control program in Illinois will require effective education and information dissemination to those individuals and groups who will be affected by the program. Having a good idea and having it accepted by the public are entirely different matters. People are often reluctant to accept new ideas or products.

The purpose of this communication program development is to design a communication strategy to insure program support and acceptance. Such a program is necessarily front-end-loaded; the strategy must be ready to implement before the State goes public. The proposed steps for designing the communication program are:

1. Identify parallel cases.

Conduct a literature review to identify examples where specific communication strategies have led to broad public acceptance of new products or ideas. Search results will provide examples of strategies that worked, those that did not work, and the reasons for success or failure. The search will be broad, involving several commercial data bases, and will be conducted with the assistance of a search specialist. Hard copy documents will be obtained for each of the citations falling within our search parameters. Analysis of these documents will identify:

- cases of successful public acceptance of new ideas,
- cases of public rejection of new ideas,
- the communication strategies employed in both successful and unsuccessful cases,

- how agencies successfully managed conflict,
- key individuals who managed successful communication programs who might be contacted for further information.

2. Identify and analyze audiences.

Identifying all the audiences that will be affected by the revised emission control program is a necessary first step in communication design. Some audiences, such as the Illinois EPA, lawmakers, the mass media, and auto mechanics may be obvious. But obscure audiences must not be neglected. For example, organizations representing poor citizens might conclude that this emissions program unfairly targets poor people since they are thought to own the oldest automobiles and might bear the greatest repair expenses. Key audiences will emerge and they will be included in the communication design process. Fleet owners and operators, new and used car dealers, emission testing operators, car clubs, and environmental and health advocacy groups will be included.

Audience analysis is directed toward developing the best means for translating the program to the larger audience and eventual successful implementation. Although it may be concluded, based on solid scientific evidence and cost-benefit analysis, that the remote sensing program will benefit the public, the public remains to be convinced. Individuals and groups hold different values, attitudes, and beliefs and they are differently motivated. Not understanding these differences often results in communication failure. For example, if auto mechanics already believe that the proposed program will result in a loss of revenue, this counter-argument must be addressed to enable mechanics to hear the message. Similarly, if this work discloses that the audience will decide subjectively whether to accept or reject this program, it would be unproductive to design a communication program containing complex objective data that the audience does not understand.

The primary objective is to design a communication program so that the audience understands the message within a framework that is highly ethical. This will assure that the public not only accepts the message in the short term, but will be happy with that decision in the future. The framework for designing the communication program is a communication tool known as the Elaboration Likelihood Model. Its premise is that the best means of obtaining long term changes in values, attitudes, beliefs, and, ultimately, behaviors, is through the use of logical, thoughtful processing of information. Some models employ thoughtless processing techniques that may temporarily change values, beliefs, attitudes, or behaviors, but may lead to long-term dissatisfaction with the decision as well as the source of the communication. Our interest is in obtaining thoughtful processing and long term decision-satisfaction that will maintain and enhance program credibility.

Determining how to translate the program requires an understanding of the values, beliefs, and attitudes of the audiences identified. The best way to find out what these are is to ask the people who belong to these groups. Individual interviews will disclose the primary concerns, beliefs and attitudes these audiences hold. Based on initial interviews, simple belief and attitude scales will be developed and administered to other audience members. This effort will show the latitudes or ranges of acceptance and rejection people feel toward the program. In other words, people will tell us how to design our message, both in terms of content and context, so as to address the issues that are important to them, in a way they will understand. The scales should also provide some indication of how much change in the emissions program the audience will tolerate. Focus groups will be formed to obtain greater insight for groups deemed particularly critical to program acceptance.

3. Convene advisory panel.

A panel of advisors will be convened to review the results from Step 2 and to recommend the best strategy for implementing the communication program. The work conducted in Steps 1 and 2 will disclose key people we would want on the advisory panel, including:

- Reflective practitioners who are familiar with the communications field (those rare individuals who have had a wealth of experience as well as the time to reflect on it in a larger social context),
- Media people who are familiar with marketing, advertising, and public opinion. These people should be from Illinois, familiar with local problems and public attitudes, and be available for consultation during the implementation phase of the remote sensing program,
- IDENR, IEPA, and other state representatives.

Prepared information packages, consisting of a program description, a statement of institutional objectives, and audience profile data (collected in #1 and #2) will be the basis for discussion. The panel will recommend the best strategies for implementing the communications program.

4. Synthesize and integrate strategies.

Prepare a summary of the work conducted, synthesizing and integrating the results of Steps 1 through 3. The summary will including recommended strategies for pilot testing and final implementation. As many as five strategies may be pursued in the pilot testing stage.

5. Pilot test of selected strategies.

Conduct pilot tests, summarize results, modify communication approach as necessary, and prepare final implementation plan. The implementation plan will be designed to:

- Specify the nature and general content of communications.
- Specify the time frames for particular activities.
- Identify the audiences to be targeted.
- Identify the key individuals involved in the communications program.
- Identify other relevant issues not addressed.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.
4. Title and Subtitle Remote Sensing Enhanced Motor Vehicle Emissions Control for Pollution Reduction in The Chicago Metropolitan Area: Siting and Issue Analysis			5. Report Date October 1991
			6.
7. Author(s) Carol E. Lyons and Donald H. Stedman			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of Denver, Atmospheric Science Center, University Park, Denver, CO 80208-0179			10. Project/Task/Work Unit No. 90/009
			11. Contract(C) or Grant(G) No. (C) AQ 30 (G)
12. Sponsoring Organization Name and Address Department of Energy and Natural Resources, Office of Research and Planning, 325 West Adams, Room 300, Springfield, IL 62704-1892			13. Type of Report & Period Covered
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words) This report describes three specific scenarios for implementation of remote sensing to enhance inspection and maintenance programs for controlling motor vehicle emissions. Screening at centralized stations, mobile sensors, and modular fixed sensors scenarios describe the range of potential applications of a Fuel Efficiency Automobile Test (FEAT) remote sensor to motor vehicles emissions control. A combination of two or all three scenarios would be most effective in identifying high mileage gross polluting vehicles. The preliminary implementation framework of each scenario is described for the purpose of this work is to contribute to the development of acceptable plans for the further reduction of emissions from vehicles in the Chicago metropolitan area. Remote sensing of vehicle emissions to identify the small percentage of vehicles responsible for most of the motor vehicle pollution can contribute to an efficient and effective air pollution control strategy that can be implemented.

17. Document Analysis a. Descriptors

Air pollution, Air pollution detection, Infrared detection, Pollution control, Air pollution control, Automobile exhaust, Exhaust gases, Mobile sources

b. Identifiers/Open-Ended Terms

Auto-emissions - Chicago, Illinois

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution. Available at IL Depository Libraries or from National Technical Information Service, Springfield, VA 22161	Unclassified	74
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce