Final Technical Report

for

ITS for Voluntary Emission Reduction:

An ITS Operational Test

Using Real-Time Vehicle Emissions Detection

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DISCLAIMER

The statements and conclusions in this report are those of the authors and may not necessarily those of the sponsoring agencies.

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EXECUTIVE SUMMARY

The Smart Sign project has successfully demonstrated the merging of two separate technological disciplines of highway messaging and on-road vehicle emissions sensing into an advanced ITS public information system. This operational test has demonstrated that it is possible for an unattended emissions information system to be designed and operated successfully. During the period of May 16, 1996 to May 15, 1997 the system delivered more than 3 million readings to more than 250,000 individuals. We estimate that more than 4000 repairs were made during the year at an operating cost of $30,000. The ability to operate the system without constant human supervision has created a cost effective messaging system capable of delivering real-time vehicle emissions information for a long term cost of only $0.02 per test.

Using input from the public, a new type of variable message sign was designed to interactively display vehicle emissions information. The difficulties in designing a sign with easily recognizable and understandable information were many, especially due to the short viewing time (about 1.5 seconds) which the drivers would have to digest the information. Relying on multiple elements of words, colors and graphics the resulting design that Skyline Products constructed has been positively received. The follow-up focus groups illustrated the high level of recognition that the public could quickly gain from the sign (see Appendix A). These groups highlighted the fact that everyone does not always respond to all of the various elements. But that by using the combination of words, colors and graphics we were able to connect with a larger audience. Owners with "GOOD" readings whose vehicles malfunctioned and obtained "FAIR" or "POOR" readings were particularly motivated to obtain prompt repair.

The Smart Sign system has been shown to be a viable technical concept which can be operated dependably even in high traffic areas (in excess of 1000 vehicles per hour). The system was subjected to a wide range of operating conditions including weather extremes (-20" to 100°F, heavy rain, hail, snow) and local construction problems. All of these conditions presented challenging trials for the systems hardware and software to deal with and these learning experiences have helped to create a more robust messaging system than we initially started with, resulting in a final design which could be replicated nationwide.

Highlights of the operational test:

1) The design and construction of an advanced variable message sign for real-time public information delivery.

2) Successful integration of a remote vehicle emissions monitor with a variable message sign and installation of the system at a high volume interstate location.

3) Successful unattended operation of the advanced messaging system in all types of weather with more than 3 million measurements completed during the operational test year.

4) System operation was not found to hamper traffic flow at the interchange and no reported crashes were attributed to the Smart Sign system.

5) The system was not subject to any vandalism during the entire operational test.

6) Public response to the concept and implementation was positive.

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ACRONYMS AND ABBREVIATIONS

CAAA	Clean Air Act Amendments of 1990
CDPHE	Colorado Department of Public Health and Environment
CDOT	Colorado Department of Transportation
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSU	Colorado State University
DU	University of Denver
EPA	US Environmental Protection Agency
HC	Hydrocarbons
I/M	Inspection and Maintenance Program
ITS	Intelligent Transportation Systems
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
IR	Infra-red
LPR	License Plate Reader
NDIR	Non-Dispersive infra-red absorption spectroscopy
NO_2	Oxides of nitrogen
RSD	Remote sensing device
RSTi	Remote Sensing Technologies, Inc.
USDOT	US Department of Transportation

INTRODUCTION

Urban air quality does not meet the federal standards in many cities. Violations of the ozone standard arise from photochemical transformation of oxides of nitrogen (NO_x) and hydrocarbons (HC). Carbon monoxide (CO) standards are primarily violated as a result of direct emission of the gas. Although there are differences between compounds, and between different urban areas, mobile sources are a major factor in all urban emissions inventories for carbon monoxide, hydrocarbons, and oxides of nitrogen. In addition mobile sources in the U.S. are a significant cause of the greenhouse gas carbon dioxide (CO,) emissions, and the major cause of increasing CO, emissions.

Air pollution control measures taken to mitigate mobile source emissions in non-attainment areas include inspection and maintenance (l/M) programs, oxygenated fuels mandates, and transportation control measures. Nonetheless, many areas of non-attainment remained after the 1987 deadline for attainment of clean air standards, and some areas are projected to remain in non-attainment for several more years despite the measures currently undertaken. One shortcoming of several of these approaches is that the information provided to motorists is infrequent, i.e. l/M programs are at most annual and in many cases they are bi-annual. This provides the opportunity for many vehicles to experience equipment failures or malfunctions which can go undetected for extended periods of time, and cause significant amounts of pollution. It is certainly apparent that new ideas are needed in combating poor air quality in urban areas.

The Intelligent Transportation System (ITS) program has as one of its goals to contribute toward improved air quality and increased energy efficiency. The difficulty in obtaining these goals is that most programs do not directly address the source of the problem. Many State and local entities are still in the initial phases of developing guidelines to meet the local and national program standards. If air quality is to improve it must involve the cooperation of the various governmental organizations working closely with their respective transportation agencies to overcome the institutional barriers of policies, assessment, and enforcement to meet standards (USDOT and EPA, 1993).

The U.S. DOT in a report to the United States Congress has adopted one goal in regards to reducing energy and environmental impacts (USDOT, 1992):

National ITS Goal: To reduce the environmental and energy impacts of surface transportation.

Objectives:

1. To reduce harmful vehicle emissions.

2. To reduce fuel wasted by congestion and navigational inefficiencies.

3. To reduce surface transportation energy consumption per vehicle-mile and per passenger-mile traveled.

The potential for a cost-effective approach to meeting objectives 1 and 3 motivated the operational test of The Smart Sign.

Project Goals and Objectives

Previous vehicle emissions research has demonstrated that less than 10% of the vehicles on the road in the United States emit 50% of the emissions (Bishop and Stedman, 1996). These gross polluting vehicles have been shown to be broken vehicles in need of emission repairs (Lawson et.al., 1990 and Bishop et. al., 1993). Finding and fixing these gross polluters is the most cost-effective tool available to reducing urban air pollution. Previous emissions research has shown that through the use of a remote sensing device (RSD) gross polluting vehicles emitting excessive levels of CO could be successfully identified and repaired resulting in large reductions in all pollutants and improving fuel economy (McAlinden et. al., 1994).

Since excess vehicle emission levels are directly tied to vehicle maintenance, any new way which this link can be brought to a drivers attention has the potential to provide air quality benefits and improved fuel economy. Both the Clean Air Act Amendments and the ISTEA Legislation have mandated improvements to overall transportation efficiency without creating adverse effects on air quality and other aspects of the environment. The aim of this project is to support both of these important pieces of legislation as well as the National ITS program by utilizing existing technology to inform the driver of his/her vehicle emissions levels, and if excessive the need for maintenance.

This operational test directly addresses the potential of ITS to support cleaner air, reduce fuel consumption, and promote general environmental awareness to the public. The overall goals and objectives for the project are outlined as follows:

Project GOAL: Reduce mobile source pollutants at a location in a metropolitan non-attainment area (Denver, Colorado).

Objectives:

1. To merge existing and commercially available technologies into a new travel demand management/Emissions reduction tool which will provide real-time vehicle emissions information to the driving public.

2. Educate the public that a well tuned vehicle is the most cost-effective means to obtain and maintain clean air. That fixing broken vehicles (gross polluters) will pay for itself in fuel cost savings alone.

3. Encourage the public to voluntarily have their vehicles tested often and quickly act on the information to catch maintenance problems early.

4. Demonstrate the usefulness and public acceptance of this approach for reducing harmful emissions, improving fuel economy and its applicability to the national IVHS program for use in other locations.

Smart Sign Operational Test Team

The operational test team consisted of the Colorado Department of Transportation, which served as the local sponsoring/oversight agency. The University of Denver whose expertise in remote vehicle exhaust measurements was responsible for the day to day installation and operation of the Smart Sign. Remote Sensing Technologies provided the remote sensing device. Skyline Products Inc. helped develop, design and construct the variable message Smart Sign, and Conoco Oil Company help design the art work and distribute the brochures.

Smart Sign ITS Operational Test Chronology

The development of this project has a long history, including the collaboration of a number of private, public and non-profit sector organizations. Such public education programs require a good deal of communication with, and feedback from a variety of potential stakeholders. The following chronology shows the attention paid to this aspect of the project.

1986-87

DU remote sensor originally designed with support from the Colorado Office of Energy Conservation. The basis for support is the potential for fuel economy improvement with voluntary repair of measured high CO emitters. High on-road Carbon Monoxide readings are a good indicator of poor fuel economy which can be improved by means of proper repair.

Summer 1992

CDOT approaches DU for potential IVHS collaboration,

Fall 1992

Collaborative proposal submitted to USDOT including significant public/private collaboration.

Spring 1993

Strong positive reviews but failed to meet program criteria.

Fall 1993

USDOT writes new program criteria (Fed. Register V58, #172:p47,312, Wed. Sept. 8, 1993, "Travel demand management: emissions detection") for 1994 solicitation including in the statement of work verbatim quotations from the CDOT 1993 proposal.

January 1994

New CDOT/DU/CSU/Conoco/Skyline/RSTi collaborative proposal with strong public/private partnership submitted to USDOT.

Summer 1994

Proposal accepted; USDOT over $300,000 commitment received. Program publicly announced by CDOT.

Spring 1995

CDOT contracts written and signed off with D.U. and C.S.U. Equipment purchased and acquired as per proposal, focus groups organized and carried out, sign designed, roadway plans acquired, software rewritten, periscopes built, etc. DU cost share provided by a gift from the Bosack and Kruger Foundation for this program.

June 1995

Project suspended by Colorado Department of Transportation.

October 1995

Colorado Department of Health joins operational test team and project resumes.

March 1996

Remote exhaust sensor and license plate reader become operational.

May 16, 1996

Smart Sign is dedicated and system becomes fully operational for public use.

May 16, 1997

One year anniversary of the Smart Sign system. During the first year more than 3 million measurements were made.

SMART SIGN OPERATIONAL TEST AND COMPONENTS

Location

The Smart Sign operational test is located in Denver Colorado at Interstate 25 exit number 112A. This is a single-lane uphill (4% grade) off-ramp which connects to southbound Speer

Blvd. This ramp is located in the central Platte valley near downtown Denver, and Speer Blvd. is a major arterial feed for downtown traffic. This central location experiences some of the heaviest traffic in all of the Rocky Mountain region.

This site was chosen for several important reasons. It has one of the longest monitoring histories for remote sensing measurements dating back to 1989 (Bishop and Stedman, 1990). In addition the experience at this location ensures a near ideal location for conducting tailpipe emission measurements with an RSD as the successful measurement rate at this location consistently exceeds 98% for ideal conditions. Two final pluses are the close proximity to the University of Denver's campus and the fact that electrical power has already been installed on both sides of the on-ramp. Both of these aspects help to maximize the data collected and minimize the costs associated with performing the demonstration. In addition the Denver area weather includes all major types which will need to be evaluated for determining the test's suitability for other national locations.

The Remote Sensing Device

With support from the Colorado Office of Energy Conservation in 1987, the University of Denver developed an infra-red (IR) remote monitoring system for vehicular CO exhaust emissions (Bishop et al, 1989 and Bishop and Stedman, 1996). Significant fuel economy improvements result if rich-burning (high CO and HC emissions) or misfiring (high HC emissions) vehicles are tuned to a more stoichiometric and more efficient air/fuel (A/F) ratio. The basic instrument measures the carbon monoxide to carbon dioxide ratio (CO/CO_2) and the hydrocarbon to carbon dioxide ratio (HC/CO_2) in the exhaust of any vehicle passing through an IR light beam which is transmitted across a single lane of roadway. Figure 1 shows a schematic diagram of the instrument setup.

The RSD was designed to emulate the results from a conventional non-dispersive infra-red (NDIR) exhaust gas analyzer. Thus, it is also based on NDIR principles. An IR source sends a horizontal beam of radiation across a single traffic lane, approximately 10 inches above the road surface. This beam is directed into the detector on the opposite side and divided between four individual detectors; CO, CO_2, HC, and reference. An optical filter that transmits IR light of a wavelength known to be uniquely absorbed by the molecule of interest is placed in front of each detector, determining its specificity. Reduction in the signal caused by absorption of light by the molecules of interest are translated into tailpipe concentrations.

An RSD 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 within a few feet of the ground. The instrument is not limited to ground based sources and can be elevated to sense exhaust emissions which exit from the tops of vehicles like heavy-duty diesels and has been demonstrated to give good agreement with other methods (Bishop et al, 1994). The CO/CO_2 and HC/CO_2 ratios can be determined independent of wind, temperature, and turbulence in 0.9 seconds per passing car. It is effective at measuring vehicles traveling between 2.5 and 150 mph. They have been shown to give correct readings for CO and HC by means of double-blind studies of vehicles both on the road and on dynamometers (Lawson et al. 1990;

CO and HC Remote Sensing

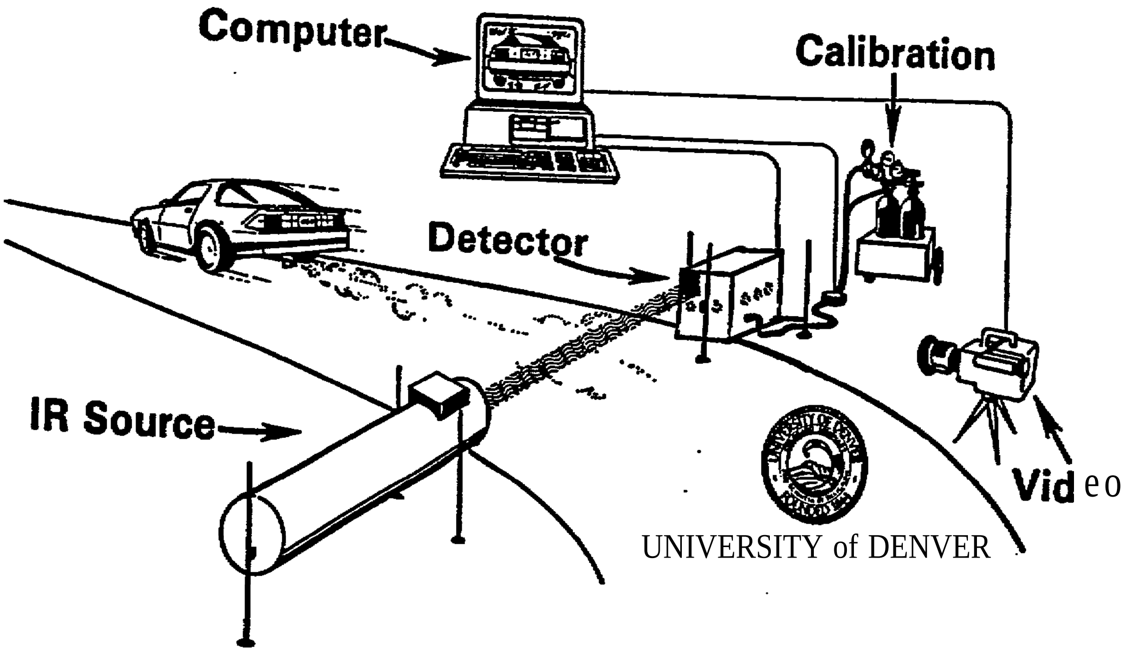

Figure 1. A schematic diagram of the University of Denver on-road emissions monitor. It is capable of monitoring emissions at vehicle speeds between 2.5 and 150 mph in under one second per vehicle.

Stedman and Bishop, 1991 and Ashbaugh et al, 1992).

Variable Message Sign

The operational test combines a remote sensor to determine vehicle exhaust emissions with a custom variable message sign to display emission levels to the driver.

The variable message sign was designed and constructed in cooperation with Skyline Products Inc of Colorado Springs, CO. It incorporated many of the advanced highway sign technologies which are currently being used around the country and took advantage one new product. Research suggested that three emission categories were needed to fully cover the current vehicle fleet. Three emission categories necessitated a three color system that would be visible in bright sunshine. The multi-colored sign is organized with red (> 4.5% CO, a gross polluting vehicle), amber (1.3 - 4.5% CO, a marginal emitter) and green (< 1.3% CO, the low emitting vehicle). Amber and red LED's have been available for some time in high intensity versions suitable for daytime applications. The Smart Sign is one of the first uses of a new high intensity green LED technology.

License Plate Reader

It was necessary for this project to conduct some type of evaluation to fully determine the public's reaction to the Smart Sign. Sampling designs dictated that we would need to directly contact drivers who frequented this exit ramp. The most appropriate way to obtain this type of information was through vehicle license plate information. With a vehicle's license number it would be possible to obtain a name and address from the state motor vehicle records. This information could then be used to locate a phone number of the owner of the vehicle and provide a way to survey the opinions of vehicle owners.

An automatic license plate reader (LPR) was purchased from Perceptics, Inc. of Knoxville, TN. The LPR was mounted on a light pole at the entrance to the ramp in special environmental housings to protect it from the weather. This system is a strobe based system and uses a xenon strobe to illuminate the plate and then through image processing techniques it converts the picture of the license into its respective alphanumeric representation. The system is not capable of reading the license of every vehicle which uses the ramp due to a very limited field of view. In operation the system proved capable of reading between 10% and 15% of the vehicles that used the ramp during daylight hours. This enabled the collection of between 1,000 and 1,500 vehicle plates per day.

The LPR is not expected to be a necessary component in future uses of the Smart Sign as its design is to provide the public free emissions information. The use of any LPR system in future work will offset the "public benefit" message as it hints at a loss of privacy.

Smart Sign

Focus Groups. The partners conducted three focus groups in an effort to design and implement the plans for a the variable message sign and the overall design of the operational test (Bohren and Williams, 1997). We sought input on key issues such the type of information to convey, the number of signs to use, their size, their motivational and attention getting properties and their information processing and learning components.

The first group was composed of a group of experts from various fields including the business, communications, graphic design, marketing/advertising, transportation and academia. This group was assembled to help narrow the field of topics to be discussed in our general public focus groups. The discussion that followed centered on three categories the group felt important, external factors affecting the effectiveness of the sign, methods and communications.

External factors that the group felt were important included the potential for a driver being shown the wrong emissions reading due to variance in the ramp speed of the vehicles. Drivers not having enough time to read and process the information from the sign. The natural emissions variability and thus inconsistent readings of some vehicles. The language problems of some population segments and the potential for inconsistent messages between the sign and other vehicle inspection programs. Many of these concerns were viewed as largely uncontrollable from the standpoint of the operational test but important to consider in advance to assure the credibility of the information.

Concerns about the methods and design of the study involved the question of generalizability of the data. Would the public perceive the license plate reader as an invasion of privacy? How would we involve the media? A concern was expressed that we needed to downplay the government role.

All of these participants felt that the communications aspects of the program and the design of the sign to be the most important. They felt the sign should use color for attention getting purposes and to assist in conveying information. That some type of scale with pictures were preferred over words and numbers. The scale used needed to have an understandable rating system and we needed to keep the sign simple and humorous.

This information was collected and used to refine the questions and issues which were next submitted to two focus groups from the general public. In February of 1995 two groups (one men and one women) of randomly selected drivers were assembled for a two hour discussion of general air quality concerns and their perceptions about the Smart Sign. Graphic designs of potential sign concepts prepared by Conoco, were viewed by each group and comments were taken. Figure 2 shows a graphic which included all of the various test elements that we examined in the groups.

Conclusions of the groups were that the idea of a variable message sign offered as a public service was viewed very favorably. This favorable view grew out of the groups interest in improving Denver air quality and the idea that current access to vehicle emissions information

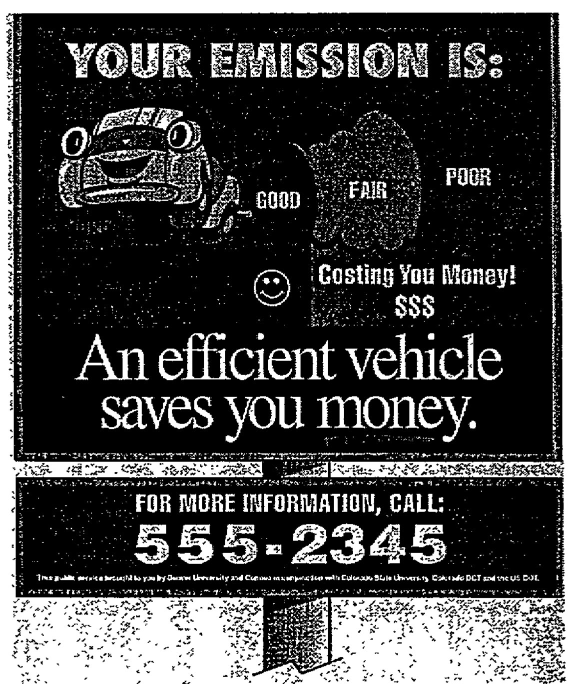

Figure 2. A composite drawing showing many of the design elements tested by the focus groups.

was too infrequent. They encouraged us to make the sign fun emphasizing a lighter side encouragement as opposed to a “big brother” type of big stick approach. The groups also wanted the sign to stay away from numbers in favor of Good/Fair/Poor and to use monetary incentives as opposed to environmental concerns. The women were especially emphatic about money being a stronger motivational message.

Key Features. The Smart Sign design that emerged from the focus groups was one which involved a multi-colored variable message sign which would could provide emissions information to drivers on several different levels. It was widely acknowledged that all of the information on the sign would be difficult to comprehend in a single exposure and our exposure experiments show that different people were drawn to different elements in the sign. The sign design team took all of these suggestions to mean that we needed to denote the emissions information in a variety of ways.

The basic design elements would include a declarative statement to describe the type of information being provided like “Your Emission Is:” or “Your Cars Health” at the top of the sign. In the middle would be our cartoon car whose facial expression would change with changing emission levels. This would be supplemented with a “GOOD/FAIR/POOR” description of the vehicles emissions and each of these emission levels would be color coded. At the bottom of the sign would be motivational message of “Saving You Money” for “GOOD” readings and “Costing You Money” for “FAIR/POOR” readings.

Implementation. Consultation with Skyline Products Inc. personal eliminated several layouts. For example the groups had felt positively toward the idea of the emissions plume behind the vehicle being color coded. This would require a large number of LED’s which would put the construction price beyond the limits of this project. The design team settled on using a painted on emissions plume into which the “GOOD/FAIR/POOR” colored coded messages would be displayed. Cost constraints also dictated that the motivational messages would need to be a single color. We chose to use green and its natural link with both money and the environment.

An 11 ft. by 8 ft. sign was constructed with an all aluminum cabinet and sign face (approxiamate weight of 800 lbs.). For service the front face of the sign could be raised and lowered via a screw drive located on the bottom edge of the cabinet. To improve the nighttime viewing the declarative statement and the cartoon car would be back lit using standard fluorescent bulbs. This was accomplished by machining the outline of the characters and the car into the aluminum face plate. All of the lettering used 8 in. characters. To improve the nighttime viewing of. the remaining sign features, diamond grade Scotchbrite reflective sheeting was used for the white plume outline and the blue background. All of the LED segments were masked against a black background except for the radiator area of the cartoon car. This area was masked in a grayish white to give it a more car-like appearance. Finally the entire face was covered with a single sheet of polycarbonate sheeting to prevent damage to the sign facing from vandalism. The final product is shown in Figure 3.

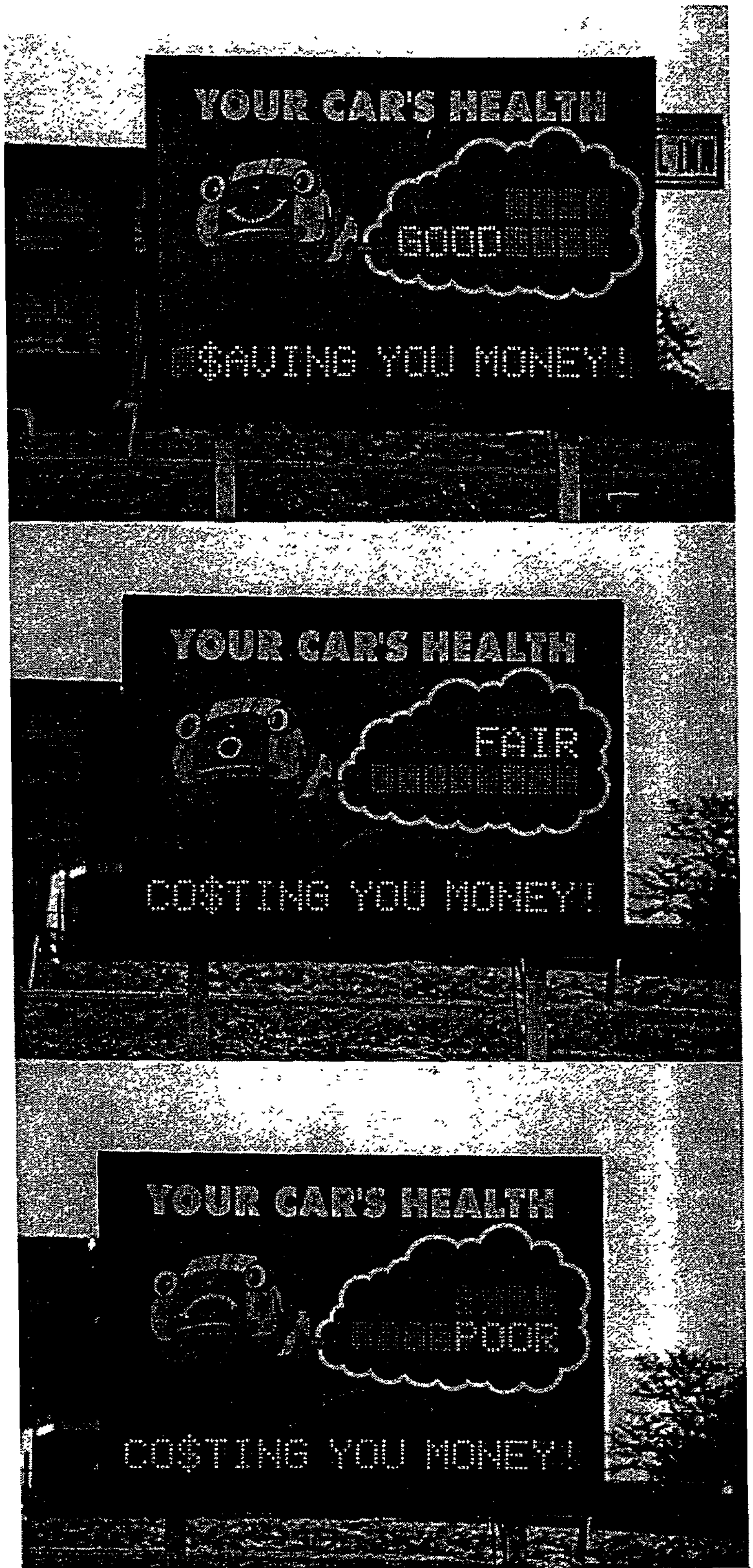

Figure 3., Photographs of the Smart Sign as deployed. The top photo displays the GOOD message, the middle photo the FAIR message and the bottom photo the POOR message.

Site Construction

The site selected is located in the southwest quadrant of the interchange between southbound Interstate 25 and eastbound Speer Blvd (see Figure 4). The site had previously installed electrical hook-ups on both sides of the off-ramp. Site surveys were conducted by Merrick Engineers & Architects and utility permits were obtained from the Colorado Department of Transportation.

Additional site preparation was needed to route the electricity to the five equipment locations on the outer edge of the ramp and to a single installation on the inside edge of the ramp. A phone line needed to be installed. Underground manholes for the detector and the source needed to be constructed and concrete footings were needed for the VMS sign mounts.

Site preparation began in October 1995 and continued through February 1996. The two companies utilized for site preparation included Utilix and W. L. Contractors, both of Denver. Conduit was installed from the nearest telephone pedestal located about 300 ft. west of the site. Installation of this conduit was accomplished via a directional bore. Additional trenching and conduit were laid from the location for the control cabinet to the signs location, to the remote sensor manhole, to the utility pole which would hold the license plate reader and the location of the optical sign triggering device. All conduit was installed to meet the installation requirements of the Colorado Department of Transportation. Electrical wiring and signal cables were installed in separate conduit.

Approximately 250 ft. up the off-ramp two concrete manholes were prepared below ground level to house the detector and source units. The detector manhole was constructed using two pre-cast concrete pipes (2.5 ft long, 3 ft ID) fitted with a 3 1.5 inch diameter aluminum manhole ring and lid. The manhole ring was cemented to the top of the two precast pipes. The source manhole, located on the inside portion of the off-ramp, was fabricated at the site from concrete. This manhole is a 24 inch diameter cylinder approximately 5 feet deep with a square aluminum hatch and mounting ring. The bottom of each manhole was lined with approximately 3 inches of coarse gravel for drainage purposes. Both of the lids were painted black to obscure the fact that they were aluminum.

The Safetran model 336 aluminum control cabinet was located on the outside shoulder of the off-ramp. Since the cabinet was located safely outside of the crash zone a concrete pad was poured for its permanent installation. All of the electrical, signal and phone cabling located on the outside portion of the off-ramp terminated at this cabinet.

Merrick Engineers & Architects designed and certified the footings and steel mount for the sign. Two foot diameter reinforced footings were poured for the sign and a breakaway steel mounts were constructed by J & S Contractors to hold the Smart Sign.

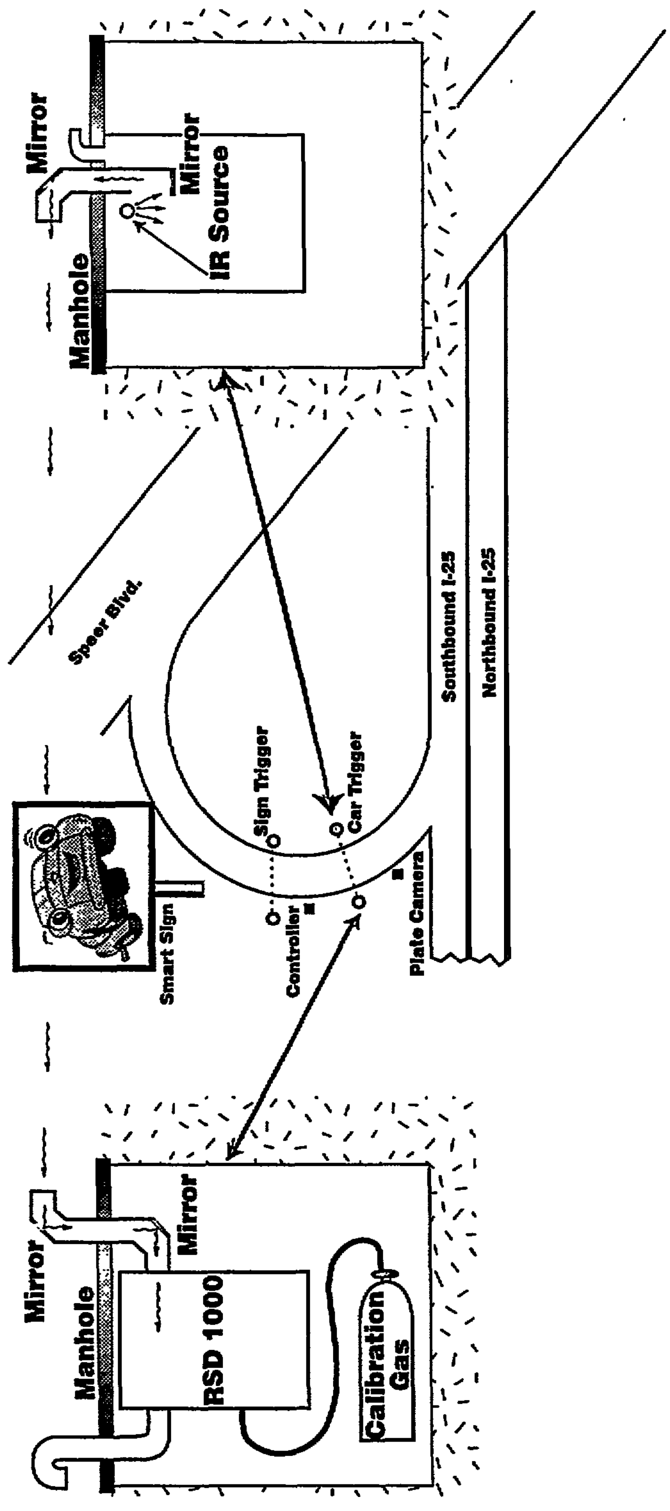

Figure 4. Artist rendering of the site layout at Speer Blvd. and Interstate 25. The enlarged views give a schematic representation of the detector and source manholes with the optical periscopes.

Sign Operation

The Smart Sign began operations on the afternoon of Thursday May 16, 1996. Through May 15, 1997 more the 3 million measurements had been completed. The system has been operated in all types of weather conditions and extreme temperature ranges of -15°F to 101 "F. High traffic volumes at the site have been experienced at the site despite a major construction project at the intersection during the Fall of 1996.

Detailed Hardware and Software Descriptions. The Smart Sign system was composed of 5 major sub-systems (see Figure 4). 1) The remote automobile exhaust sensor, 2) the master computer system, 3) the license plate reading/recognition system, 4) vehicle position sensing and sign control system and 5) the Smart Sign.

The remote automobile exhaust sensor was an RSDlOOO unit supplied to the project by RSTi. This unit was capable of monitoring CO, CO, and hydrocarbons. This unit was mounted vertically (see Figure 4) by an aluminum I-beam underneath a 31.5" diameter aluminum manhole cover. Light entered the front of the unit through a custom made periscope assembly. The periscope consisted of two square 6" x 6" front surface aluminized mirrors fitted into a 4" diameter PVC pipe assembly. Lightweight PVC pipe was chosen to minimize the cost and weight of the periscope with the expectation that at some point in the project it would be destroyed by a passing vehicle and need to be replaced. Flow through ventilation was provided via the RSD1000' s internal fan and a filtered inverted air duct. Since the unit was installed below ground no additional environmental controls were provided. The RSDlOOO unit communicates with the master computer system via a 115 kbaud serial link.

A traffic signal control cabinet (model 336, Safetran Traffic Systems, Inc., Colorado Springs, CO.) houses the master computer system, the image processor for the LPR and the vehicle position sensing and sign computer system. The master computer system is a rack mount IBM compatible 25 Mhz 386 with 2 megabytes of memory, a 40 megabyte hard disk and a math coprocessor. The system included a 14.4 kbaud modem, 4 high speed serial ports, monochrome EGA graphics and ran MS-DOS 6.22.

Probably the single most important component in the day-to-day operation of the Smart Sign was the use of a remote control software package (Close-Up v6.0, Norton-Lambert Corp., Santa Barbara, CA.). Early in the project it was decided that a dedicated phone line to the site would be used as the primary means for monitoring the Smart Sign system. Through the use of this software package we were able to communicate with the Smart Sign's master computer system via standard phone iines from anywhere in the world at anytime. This allowed us the luxury of conducting the vast majority of system maintenance, data downloads, software/hardware testing and monitoring without having to visit the site.

The license plate reading/recognition system (model LPR-SL9000) was purchased from Perceptics Corp., Knoxville TN. The system consists of a high resolution monochrome camera (model 2100 RS-170, Cohu Inc., San Diego, CA.), a high-pressure xenon flash strobe assembly and the IP940LT image processor. The camera and strobe are mounted in their own weather proof enclosures and were mounted 15 ft. above the roadway on light pole approximately 60 ft. distance from the remote automobile sensor. The image processor is located inside the traffic control cabinet and communicates with the master computer system via a 9600 baud serial communication link.

The vehicle position sensing and sign control system consists of a dedicated microprocessor control unit and two vehicle position sensors. The dedicated microprocessor is a cigarette pack sized unit (Micro-440, Blue Earth Research, Mankota, MN.) which uses a BASIC program to monitor two retroreflective vehicle position sensors (model MAXI-BEAM RSBLV, Banner Engineering Corp., Minneapolis, MN.), communicate with the master computer system and activate the Smart Sign's GOOD/FAIR/POOR message.

Operational Parameters. This section will detail many of the operating criteria which have been developed over the course of this operational test. Many of these parameters have been chosen for operator convenience, while others were chosen to protect public safety. Many of these criteria have been used to evaluate the operating conditions and performance of the system and decide when service might be needed.

The original remote vehicle exhaust system was designed to have an operator present during operation, to be operated in a single lane environment and only during dry weather conditions. So one of the first tasks was to develop a list of weather conditions and instrument problems which would need to be detected and the actions which could be taken to best mitigate the situation. Table I provides a list of situations currently handled by the Smart Sign control program.

Operation of the sign was guided by the desire that the data reported to the public have a high confidence level. So that when rain or snow start to degrade the instrument's successful measurement rate we stop displaying the results on the Smart Sign. The choice of 80% as the determining point was a matter of convenience. The instrument normally operates in the mid 90's. During a rain or snowstorm this rate has been observed to range below 30% success rate. This means that there are periods of operation when the system is functional but the Smart Sign does not display any results because of external conditions or equipment problems.

It was decided to only operate the LPR during daylight hours out of safety concerns for the driving public. As previously described, the LPR system uses a xenon arc strobe system to illuminate the license plates of passing vehicles. This provides the opportunity for the system to function as well at night as it does during the day. Even though the strobe is pointed downward at the rear of the vehicles we were concerned that the flash might be a major distraction after sunset. Therefore, an operational decision was made to only operate the LPR system during daylight hours.

Dav-to-Dav Operations. The operation of the Smart Sign relied heavily upon the use of a modem to modem remote control program. The software system allowed nearly complete control of the system. Researchers usually checked on the system in the morning and evening

Table 1. Smart Sign Operational Situations and Corrective Actions

Weather Conditions Problems	How Detected	System Response
Rain/Snow/Sand	When the valid measurement rate for the last 100 vehicles drops below 80%.	Smart Sign turned off until measurement rate recovers. System issues an error message.
Loss of IR Signal	Loss of IR signal should only occur when vehicles block the beam. A timer detects when a loss of signal is too prolonged.	A self-test is performed on the detector unit. If a problem found then a system reset is issued. If ok the system pauses then tries to monitor cars again. If this failure mode is repeated more than 10 times the system shuts itself down and issues an error message.
Data Transmission Errors from manhole to main computer	Data are serially transmitted in blocks with check sum error checking. Repeated check sum violations are used to detect this condition.	A self-test is performed on the detector unit. If a problem found then a system reset is issued If ok the system pauses then tries to monitor cars again. If this failure mode is repeated more than 10 times the system shuts itself down and issues an error message.
Temperature Changes	Detector voltages violate preset upper or lower limits.	The system automatically resets the detector gain settings.
Sunrise/Sunset	Time of Day.	The LPR system was restricted to daylight hours only as a safety precautions due to its use of a strobe to illuminate the plates.
Hard Disk Full File System Failure	Detected by DOS system storage errors.	The system reports the error and disables automatic logging of data. The Smart Sign continues to operate.
Power Failure	No phone response.	System is setup to automatically reboot and run the Smart Sign after a power outage. During the outage remote control of the system via the phone is impossible.
Position Sensor Failure	Detected by a persistence low voltage signal from the detector.	Smart Sign turned off. System issues an error message.

of each day. More frequent checks would be conducted if changes in weather conditions occurred or if the system had been experiencing any operational problems. A log of conditions, vehicle activity, system operating parameters, system upgrades or changes, and any problems encountered was maintained.

Physical visits to the site were only conducted if a problem could not be resolved over the phone. Typical service items, their manpower needs and time required to complete are listed in Table II. Service visits average 2 to 3 visits per month with the activities changing with the seasons. For example, cleaning the source detector optics was required more in the warmer months, especially after rain storms. While in the winter, snow removal from in front of the vehicle position sensors was a more common activity. The decrease in cleaning the instrument optics was due to the colder temperature. At the higher summer temperatures clean optics were a necessity for optimum signal-to-noise considerations. Colder temperatures improved the RSD's detector signal-to-noise enough that dirtier optics could be tolerated for longer periods.

Table II. Smart Sign routine maintenance items.

Routine Service Items	Manpower	Time to Complete	Service Frequency
Clean vehicle position sensors	1	15 minutes	Every 2 weeks or after a rain/snow
Clean source optics	1	15 minutes	Summer:monthly Winter:Every 2 months
Clean detector optics	2	45 minutes to 1 hour	Summer:monthly Winter:Every 2 months
Backup data	1	1 hour	Monthly (does not require a site visit)
Clean/change air filters	1	15 minutes	Monthly

Most maintenance items were simple to conduct. Often during a site visit we would routinely clean the above ground optics on the source, detector and vehicle position sensors. This would require a small amount of water and several optical grade tissues. Each optical surface would be washed and dried. This normally required ten to fifteen minutes. For a more thorough cleaning or other maintenance action the source and/or detector would need to be removed from its manhole. The source could be extracted by one person and serviced while it rested on the ground. The detector unit, due to its larger size and weight required two people for safe extraction. After disconnecting the power to the detector unit, extracting the system required the manhole lid to be unlocked and a lifting pin installed into the top of the lid. Using a crowbar one would alternatively lift each side of the cover and install a large C-clamp on opposite sides of the lid. It was now possible for two people to safely lift the lid and detector unit straight up (this combination weighed approximately 100 lbs). Once the detector unit clears the top of the manhole two 2x4's could be positioned across the top to provide a shelf which the detector and lid combination could be safely rested on. Access is now possible to all parts of the detector unit without disconnecting any of the signal/power cables.

After reinstalling either the source or the detector unit realignment of the sensor beam would have to be undertaken. Of all the service items this is the most difficult and time consuming. Alignment tools include a visible laser beam which follows the path of the sensor detection optics, an audible beeper which changes frequency with changing signal levels and a graphical alignment computer display. All of these help the alignment process, but there is no substitute for practice. Alignment of the source is less critical and our experience has been that after the initial installation only minor adjustments are needed to return the source to its original position. Alignment of the detector unit requires more time and usually a more thought out approach. Extraction, cleaning and realignment of the source and detector requires 45 minutes to 1 hour to complete. Our experience has been that this is a once a month item in the summer and once every other month in the winter.

The Smart Sign's main computer system has enough disk capacity to store about a months worth of emissions data. At the end of each month these data were removed and archived either via a modem download or in conjunction with a site service visit. Data from this program have been archived to QIC-80 tapes on a month by month basis.

<u>Operational Testing</u>. The Smart Sign system was covertly tested for accuracy by the contractor which performed the operational evaluation and the results of those measurements have been reported by Bohren and Williams (1997) . The system was also tested for accuracy by the University of Denver. These tests involved the use of an instrumented vehicle which is capable of varying its CO emissions throughout the Smart Signs measurement region and simultaneously measuring its own tailpipe emissions. Typically the driver instructs the vehicles engine computer to adjust the air/fuel ratio to a specified value. The vehicle is then driven in as close to a steady-state mode as possible past the remote sensing device while all of the vehicle emissions information is recorded by a computer. We attempt to drive the vehicle in a steady-state mode because it is not possible for use to know the exact second of emissions that are measured by the RSD as the vehicle passes. By using a steady-state driving mode we are able to post-process several seconds of data and assign them as the true reading.

There are always inherent variabilities when attempting a comparison of this type. Because the instrumented vehicle is forced to operate in regular traffic it is not always possible for the driver to maintain a steady-state driving mode which can cause rapid changes in tailpipe emissions. Any emissions variability introduced by changes in driving mode will show up as increased noise since the comparison with the remote sensing readings have not been expertly time aligned. Figure 5 gives the results of a drive-by test performed at the Smart Sign site on April 30, 1996 with a 1:1 line drawn for comparison. The figure plots the ratio of CO/CO, for the instrumented vehicle versus the reading measured by the remote sensor. The ratios are plotted to eliminate the need to correct the instrumented vehicle measurements for excess air. The remote sensor makes measurements assuming no excess air in the exhaust and since excess air in exhaust produces diluted and therefore lower absolute percentages we have chosen to plot the ratios to avoid this correction. For guidance a CO/CO, ratio of 1 is approximately 8.8% CO and a CO/CO, of 0.25 is approximately 3.2% CO.

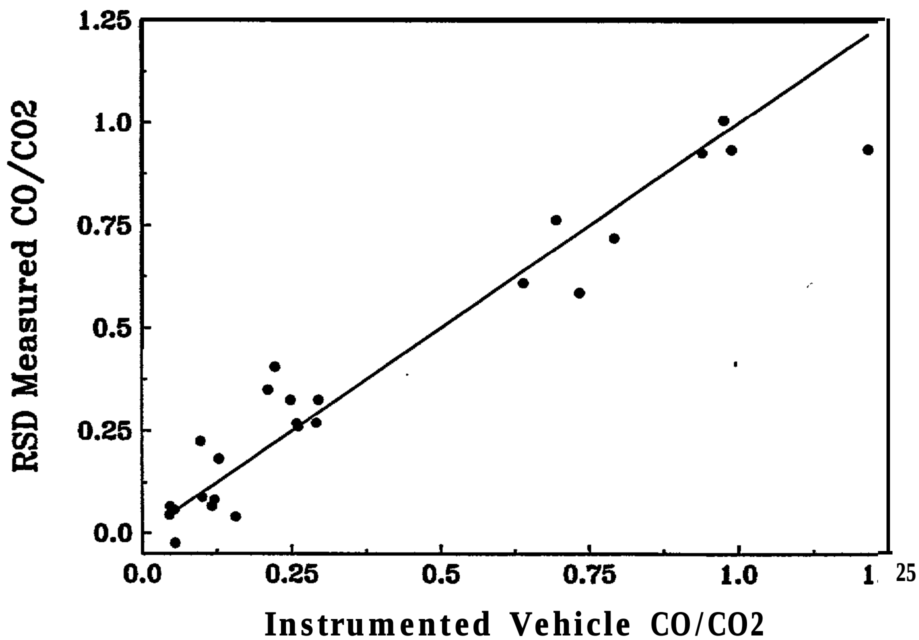

Figure 5. Comparison of emission measurements made at the Smart Sign site between the remote sensor and an instrumented vehicle of variable emissions.

Twenty five passes were made with the Taurus with CO/CO, ratios varying from 0.05 (- 0.6% CO) to 1 (- 8.8% CO). This more than covered the operational range of the Smart Sign from GOOD (< 1.3% CO), FAIR (1.3% - 4.5% CO) and POOR (> 4.5% CO). There is only one reading (the highest reading given by the instrumented vehicle) which appears to be dissimilar from the 1:l line. This measurement does have a higher degree of uncertainty attached to it due to the fact that a vehicle was following the instrumented vehicle very closely. There is some uncertainty as to which vehicle the remote sensor measured. However, even with this data point included the system more than passes an adequate accuracy standard for operation of the sign.

Ouerational Conditions. The Smart Sign system was operated 24 hrs a day seven days a week beginning in March of 1996 through May of 1997. The effects of changing environmental and weather conditions were viewed as a major test of the hardware and the technique. Being situated in the middle of a major freeway interchange one of the more difficult environmental problems is dust and spray when wet. There is always a constant source of fine rubber particles from tire wear and this is compounded in the winter with the presence of road salt and sand. All of the computer and housing systems were equipped with changeable or washable filters. These were changed regularly and we found these to be of some help. However, it was impossible to prevent a build up of dust and grime in most of the electronic systems which did not impair their operation.

Weather conditions in Denver can change very rapidly and cover the entire spectrum of conditions found throughout the US. Heavy rains, hail, hot dry weather, blizzard conditions, sub-zero temperatures, snow and freezing rain were all encountered during the operational test. The system did not always operate during these periods as there were times when the rain or snow was so heavy that the detector could not adequately sense enough heat from the source to continue. At these times the system would suspend operation until a later time when it could continue. In the early months of the program this usually required the system to be restarted via the phone. As software modifications were made during the test, many of these decisions were incorporated into the master computer and could be made automatically.

The system operated between temperature extremes of -20” and 100°F. The extreme cold weather in January persisted for two weeks with the system logging a large number of hours below zero with no obvious problems. As discussed later we did discover that subzero weather presents difficulties which prevent making tailpipe measurements. A number of snow storms (1” to 14”) subjected the components not only to the cold and snow but salt, sand and plowing which invariably accompanies the snow. While Denver is generally a very dry place we do have violent thunderstorms which drop large quantities of water in a short period of time. One such afternoon storm in August 1996 dropped 1.5” of rain and hail in less than 30 minutes. The system shut itself off during this storm and was later restarted by phone.

Operational Problems. Problems encountered during the test were varied. Soon after the Smart Sign was activated Denver received a large amount (for Denver) of rain. Since it had been dry during most of the construction, this new moisture resulted in a large amount of settling to several of the sensor sites. This caused several operation outages during May and required the sensor systems to be realigned after each rain. In October a vehicle knocked over the light pole on which the LPR system was mounted. The accident only caused minor damage to the environmental housings for the strobe and camera but destroyed the wiring and electrical conduit attached to the pole. New conduit and wiring had to be installed. The LPR system was out of service while these repairs were being made.

Occasionally vehicles were given incorrect readings by the Smart Sign. This always occurred during or after truck traffic on the ramp. The most likely cause was related to the decision to mount the two vehicle position sensors near ground level. This complicated precise counting of high clearance vehicles which are trucks predominately. What would happen is that a high clearance vehicle (which most often was not even measured by the emissions monitor due to a high level exhaust) would be located near the outside of the curve at the bottom of the ramp and the middle of the curve at the top of the ramp. Due to the fact that the slant of the roadway is larger at the first position sensor (at the bottom of the ramp) than at the second, and that the position sensor beam is angled upward from outside to inside combined to cause the first position sensor beam to pass underneath some trucks as opposed to passing through the middle of the trucks body. This most often resulted in a large count (blocks/unblocks) on the first position sensor and a lower count on the second which would automatically disable the Smart Sign's and no reading would be displayed until the system could reset itself. However, occasionally the lower sensor would under count on a large truck (most often a low exhaust cube type truck) resulting in a trailing vehicle receiving the reading which was intended for the truck.

Numerous power problems were encountered during year. However, the majority of them were beyond our control. Construction of a pedestrian walk-way by the city and installation of a new sprinkler system at the interchange by the State resulted in power interruptions on at least 3 occasions. Crews cut the main power line to the interchange on each of these occasions. Our equipment was shutdown on two occasions when condensation built up in a ground fault protected outlet and the circuit breaker was tripped. This had to be manually reset.

During the winter of 1996/97 the system has operated during several snow storms and experienced sub-zero temperatures on several occasions. What we have learned is that below zero degrees (F) the conditions are such that the system cannot maintain a high percentage of valid measurements. The combination of road sanding and vehicle exhaust condensation plumes sufficiently interferes with the beam to limit the Smart Sign operation. Above zero degrees, and with a dry roadway, the system operates normally. Usually the Smart Sign display is affected during and after a snow or rain storm until the roadway adequately dries. After the instrument recovers a valid completion rate of measurements (80% valid or above) the Smart Sign display is turned back on.

To date we have experienced only one known instance of vandalism. The remnants of a white paint ball were visible for a short time during the summer on one of the lower edges of the sign's polycarbonate shield. No one has defaced any of the above ground equipment with graffiti despite our being located within 0.5 mile of Federal Blvd. which has Denver's highest incidence of graffiti. We are aware of no traffic control problems associated with the Smart Sign's use but were made aware by two construction workers that the public's interest in the Smart Sign's had made their job's more difficult. During October and November a sidewalk was replaced and installed over I-25 on Speer Blvd. This required the traffic to be stopped on the exit ramp to allow trucks to enter and leave the site. The flag people were required to be more animated and visible to attract the attention of drivers on the ramp because of their interest in the Smart Sign. The sign itself has been maintenance free.

Operational Improvements. Several operational improvements were made during the operational test. The most important was the discovery of a teflon sheeting which is used as a mold release by the fiberglass industry. This sheeting was found to be nearly transparent in the infrared regions which are monitored by the RSD. This sheeting was used to cover the outside opening of the detector periscope, effectively sealing the optics from the outside environment. This prevented almost all rain/snow/dirt buildup which normally collected on the detectors periscope optics and therefore greatly reduced the need to remove the detector from its manhole. This sheeting was not discovered until very late in the operational test but after using it for the last several months of the test we estimate that the need to clean the detector optics can be reduced to once or twice a year. This helps eliminate one of the more time consuming regular maintenance operations.

The position sensors were adjusted as best possible to compensate for the differences in the slant of the roadway at the two sensing locations. One change made at the lower sensor was to raise the height of the reflector on the inside of the curve. This reduced the number of trucks which the beam passed underneath. It is recommended for future installations that the position sensor mounts be raised 3 feet above ground level. This would allow the beams to parallel the roadway and eliminate one of the difficulties encountered with the current installation.

Software for the RSD for this type of project did not exist prior to the operational test and was specifically developed to meet the special needs of the Smart Sign. Therefore periodically we changed or refined our approach to dealing with operational situations. The operational software was updated several times during the test and included refinements in how rain/snow interruptions were detected and waited out. How proper detection of hardware problems with the RSD detector was made by the master computer and how it could automatically reset the detectors unit computer. Additional cosmetic changes were made to several of the interfaces to improve our ability to remotely contact and control the system. All of the software improvements allowed us to increase the periods of unattended and uninterrupted operation.

DISCUSSION

Site Statistics

For the one year of the Smart Sign’s operational test (May 16, 1996 to May 15, 1997) more than 3 million vehicles passed through the system. This location is a very busy interchange and is one of the major gateway’s into downtown Denver. A major university, amusement park, major league baseball park, many state government offices in addition to many of the downtown businesses are accessible via this interchange. Table III lists average Smart Sign statistics by day of week and Table IV gives the monthly data including all days that the system was operational. The mean model year calculated in Table III is from a much smaller sample than the mean %CO values due to the nature of the plate reader. Figure 6 shows similar data graphed against hour of the day. One factor which affects these values is the amount of time the LPR system was used. Initially with the LPR functioning, daily vehicle counts were depressed approximately 15% due to the additional computer time needed to process the plates. Figure 7, which shows the number of vehicles processed each day, clearly shows this reduction for the first four months of the operational test. Software changes later in the operational test allow us to speed up this processing time and greatly reduce its impact on the systems throughput (compare daily counts for April 1997 - May 1997 with May 1996 - August 1996 when the LPR ran full time).

Table III. Average Weekly Statistics

Day of Week	Mean Vehicle Volume	Mean %CO	Mean Model Year
Sunday	7211	0.57	89.6
Monday	9445	0.63	89.4
Tuesday	9953	0.62	89.4
Wednesday	10495	0.62	89.5
Thursday	10031	0.62	89.5
Friday	10126	0.63	89.5
Saturday	9161	0.58	89.6

Table V lists the operational hours on a month by month basis. The percent of up time improved each month that the Smart Sign was operated. The one exception to this is for the month of December. A contractor installing a sidewalk and sprinkler system at the Speer Blvd./I-25 interchange cut the main power cable to the site on the 23rd. This power outage was not repaired until December 31. This long loss of power accounts for 95% of the downtime in December.

For the full operational test year the system was operational for more than 91% of its operational hours. This value increases by 3% to 94% if we allow for the operational hours lost to power outages caused in October and December which were beyond our control. It should also be mentioned that operational as reported in Table III means that the emissions detection system and the sign were operational. Actual sign operation will be less than the total operational hours due to weather conditions. For example during snow/rain storms the system is operational but may not be available to the motorist due to the road conditions. During winter snow storms this may mean sign activity will be curtailed for extended periods of time.

During the operational year the emissions monitoring system was capable of successfully measuring more than 94% of the vehicles which passed through it. This figure includes attempted measurements on vehicles which have elevated exhaust and are not capable of being measured by the system and all of the periods of inclement weather. This value is an

Table IV. Monthly Smart Sign Statistics.

Month/Year	Vehicle Volume	Mean %CO
May / 96[a]	218169	0.72
June /96	263933	0.65
July / 96	253539	0.63
August / 96	262044	0.62
September / 96[b]	99363	0.65
October / 96	300370	0.62
November / 96	292729	0.6
December / 96	188420	0.55
January / 97	282077	0.59
February / 97	259806	0.58
March / 97	318381	0.6
April / 97	283886	0.62
May / 97[c]	166564	0.56
Totals	3,189,281	0.61

a Includes data from May 16 to the end of the month.
b Lost data.
c Includes data from May 1 - May 15.

operational upper limit since there were periods when the sign was not operated due to weather and/or congestion.

Average CO emissions are plotted in Figures 8 - 9. Emissions variability as seen in these plots is produced by several factors. The largest of these influences is fleet age. Figure 10 shows the average CO emissions by model year. This correlation between emissions and age is well known. Therefore since CO emissions are directly linked to the average age of the fleet. Any changes in the average age, caused by sampling changes, will lead to changes in the mean CO. For example Table III shows that the weekends have lower average emissions and in general a newer fleet than during the weekdays. Additional sources of variability are days with reduced data collection due to weather or problems with the system and fuel changes. The sampling changes of collecting data during only a portion of the day can produce changes since the fleet age is not homogenous during the day.

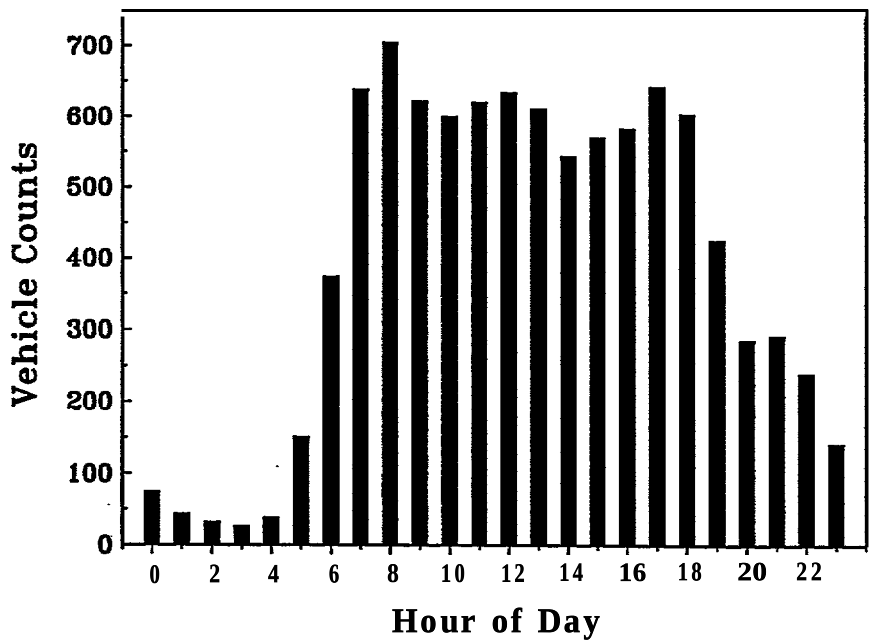

Figure 6. Average vehicle volume by hour of the day for days the Smart Sign system was operational even for only a portion of the day.

Figure 9 shows the weekly averages collected by the Smart Sign system. Notice that with the longer averaging time the variability introduced by smaller sample size has been reduced. Denver and the metro area use oxygenated fuels between October and February each winter which lowers on-road CO emissions. This has been demonstrated by a number of researchers and can be better seen in the monthly averages given in Table IV.

Estimates of Unique Vehicles

Analysis of the plate reader data suggests that more than 160,000 unique vehicles have been past the sign and at least 90,000 more arrive with each passing year and all have obtained SMART SIGN readings. The analysis is given in detail below.

The plate reader provides, together with the alphanumeric reading, a measure of the certainty of that reading. We have observed that certainty readings of 8 or 9 (on a scale of l-9) are likely to be correct. This data set is the one used for most analyses given below. The plate reader was only turned on during daylight hours, thus longer hours in summer, shorter in winter.

During the first year of sign operation (May 1996 to May 1997) the plate reader was used intensively for the first 100 days and then sporadically thereafter. The plates read as of August 1996 were submitted to the Colorado Department of Motor Vehicles who provided

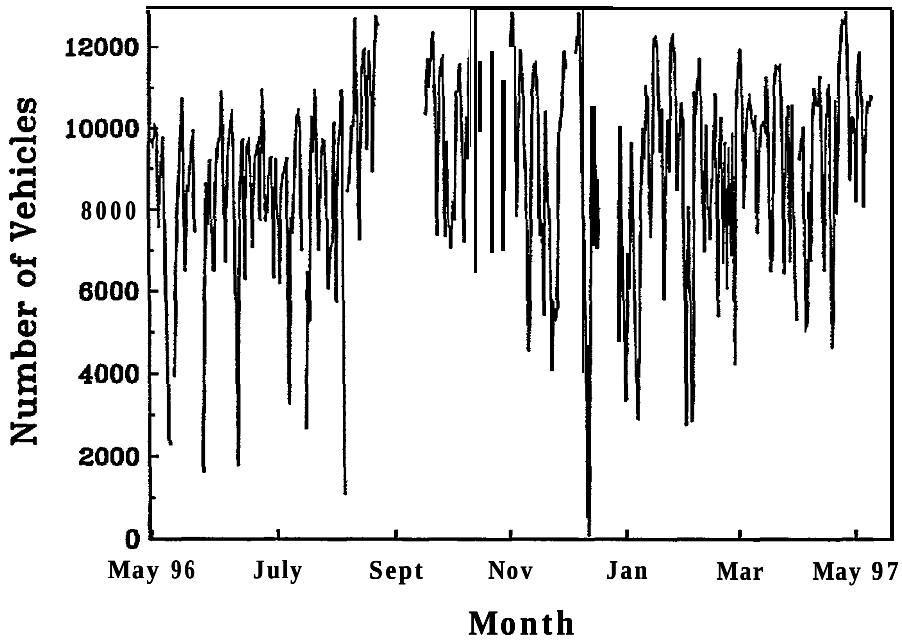

Figure 7. Daily number of vehicle counts processed by the Smart Sign system. The LPR system reduced throughput in the beginning. This restriction was later mitigated by software changes.

make and model year information, as well as owner name for the owners contacted by the CSU survey team. From the make and model year information, the average age of the measured fleet was determined to be seven years. This compares to two previous published studies at Speer and I-25 for which the average age of the fleet was determined to be 7 years old in 1989 and again 7 years old in 1994 (Bishop and Stedman, 1990 and Zhang et al, 1996). We had expected the plate reader to be biased toward new/clean plates most likely found on newer vehicles, however, compared to the fleet ages found by previous studies at this site that does not seem to be the case.

Figure 11 shows the success rate with which plates read by the plate reader at various levels of certainty are matched at DMV. Plates with 8 and 9 are not far below the ability of a human reader who routinely achieves 92% success at DMV matching. One reason for the higher success rate of a human reader is the human reader screens out-of-state plates, the automatic reader does not.

One vehicle had its plate read as many as 69 times, while most were measured only once. On average, plates were read 1.3 times. The distribution, and the predominance of plates measured only once is shown in Figure 12 which shows as an insert the same graph but with the x- and y- axes expanded to show the smaller numbers of repeated readings for the multiple repeats. One application for this data base which has never been investigated is to

Table V. Smart Sign operational activity by month.

Month/Year	Monthly Hours (Operational Hours) Percent	Comments
May/96	384 hours (270) 70%	Start up problems. Alignment changes due to settling.
June/96	720 hours (687) 95%	
July/96	744 hours (662) 89%	Electrical problems causing detector failures.
August/96	744 hours (648) 87%	Detector failures increase.
September/96	720 hours (667) 93%	Software upgrade to detect and restart after detector failure.
October/96	720 hours (653) 88%	57 hrs of operation lost due to power interruption.
November/96	720 hours (681) 95%	
December/96	744 hours (503) 68%	181 hrs of operation lost due to power interruption.
January/97	744 hours (708) 96%	
February/97	672 hours (672) 100%	
March/97	744 hours (744) 100%	
April/97	744 hours (706) 95%	Heavy rains tripped GFI in control cabinet.
May/97	360 hours (360) 100%	
May/96-May/97	8760 hours (7961) 91%	If power outages are removed system operated 94% of the time.

study the predictability of subsequent Colorado IM240 (Air Care) readings depending on how many times the individual car had been measured by the SMART SIGN in a low/high

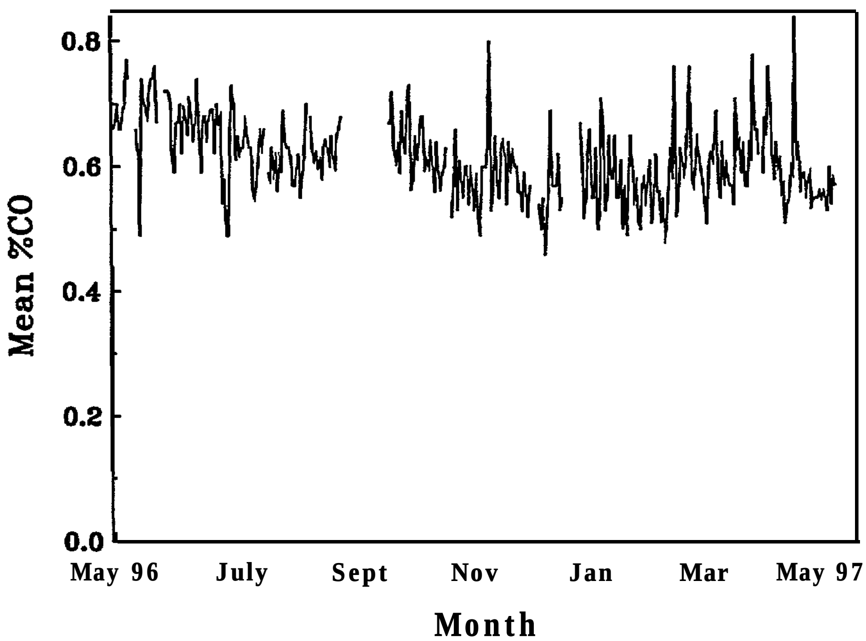

Figure 8. Daily mean %CO values are plotted for the time period of May 1, 1996 to May 16, 1997.

emitting state (a clean screen/dirty screen analysis).

The basic model for unique vehicle counts starts with a simplification of the data on daily vehicle counts shown in Figure 7. These data show that typical vehicle counts were 9,000 to 12,000 per day with low excursions for bad weather and weekends. This was approximated to 10000 counts per day, constant.

The next approximation concerned the plate reader and its ability to report plates with certainty above 7. Figure 13 shows the whole year of plate data. The line shows the total plate counts by day and the points are the number of plates which were uniquely new at the time they were measured. Notice that on the first few days, as expected, almost all plates read are unique. The plate count per day varies from 100 to 1500. The model assumes a constant plate reading count of 720 per day (the measured average). The winter days have Iower plate counts because of the shorter daylight hours. That does not effect this analysis because the winter samples are only used to estimate how fast the fraction of unique plates recovers after the intensive plate reading campaign.

A lower limit on the number of unique vehicles which passed the site is the number of unique plates which the plate reader reports. The cumulative counts are shown in Figure 14. The steeply increasing line shows that over three million readings were obtained in the first year, even excluding the 22 days of lost data in September and 10 days lost in December 1996.

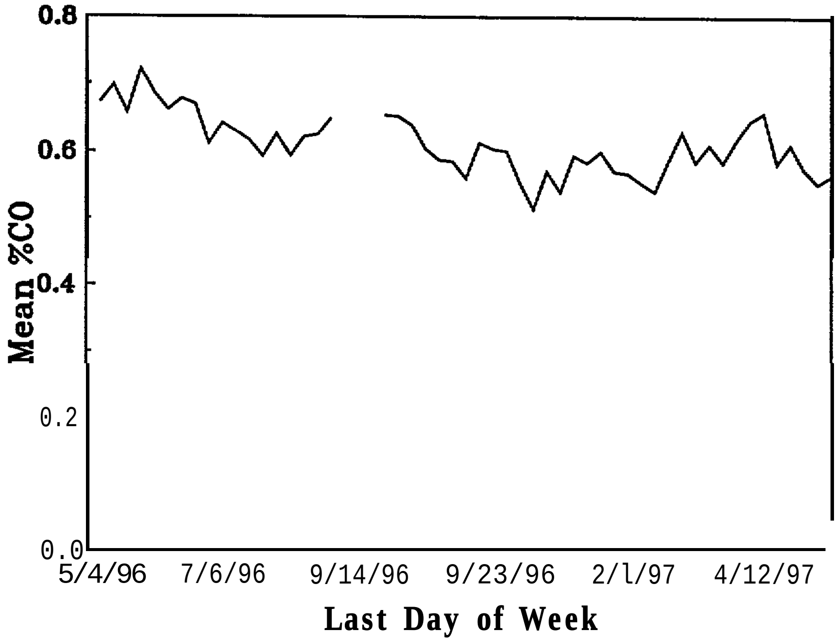

Figure 9. Average weekly CO measurements plotted against the ending day of the week for the period May 16, 1996 through May 15, 1997.

From the three million readings about 145,523 plates were reported (line with crosses) and about 99,916 of those were unique (lowest fine). The purpose of the model is to estimate how low the lower limit of 99,916 is compared to the actual number. This purpose is achieved by means of a model which attempts to match the observed fraction of unique to total plates as a function of time.

Figure 15 shows the results of two differing models as a solid line and a dashed line compared to the fraction of week day new plates shown as "●" data points for the first 250 days of the program. The data points are scattered, however much of the scatter results from weekend days (shown as "O" data points) which always have a lower vehicle count and a higher fraction of unique vehicles, as would be expected for a commuting site where a different fleet of vehicles/drivers appears on weekends to attend downtown sporting or entertainment events.

The data basically show a quick drop off from 100% unique on the first day, then a slower drop off after about 20 days. When the plate reader was turned off in August, the fraction of unique vehicles recovered for each succeeding brief plate reading campaign.

<u>The model construction and its uncertainty.</u> As stated above, the model assumes a constant 10,000 cars/day and a constant 720 valid plates read per day. The model is based upon the concept of two potentially observable fleets, a static fleet with various arrival frequencies at

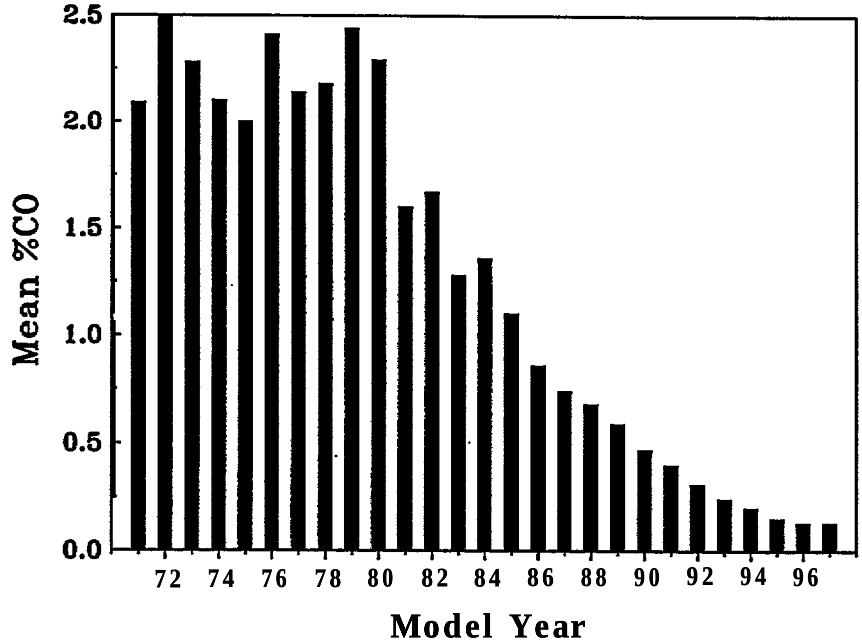

Figure 10. Mean CO emissions by model year. The data have been truncated at model year 1971 for lack of significant numbers of older vehicles.

the site and a replacement fleet which replaces vehicles in the static fleet proportionately with newcomers in order to achieve the observed recovery in plate fraction after the reader was turned off. The recovery is modelled as a 300 day exponential replacement time (which amounts to about 33 new vehicles each day) based upon the observations. The static fleet is modelled with various numbers in four possible arrival frequencies, “daily”, “weekly”, “monthly” and “yearly”. (D,W,M,Y). Actually the model uses 1,5,20 and 200 day frequencies respectively.

Two extreme but not impossible model runs for the weekdays only are shown in Figure 15. The solid line uses 2500 vehicles in the daily (commute) category, 3000 weekly, 10,000 monthly and 200,000 which only appear on average once per year. The steep decay in the first few days is dominated by the daily fleet, whereas the slow decay from 75 to 100 days is dominated by the size of the yearly weekday fleet. The shape of the bulge in between is responsive to the weekly and monthly fleet volumes. The total vehicles which use this site during weekdays in one year according to this model is 537,000. The dashed line shows a similar model comparison to the data in which the unique weekday fleet size is reduced to 160,000. In view of the fact that we believe the line should fall through the lowest data points, we prefer the 537,000 unique vehicle model, however the sensitivity is such that we can not conclusively rule out total fleet unique vehicle counts as low as 150,000 or as large as about 700,000. These numbers nevertheless exceed considerably the lower limit of 99,916 and are comparable to the estimate of 240,000 given in Bohren and Williams (1997) based

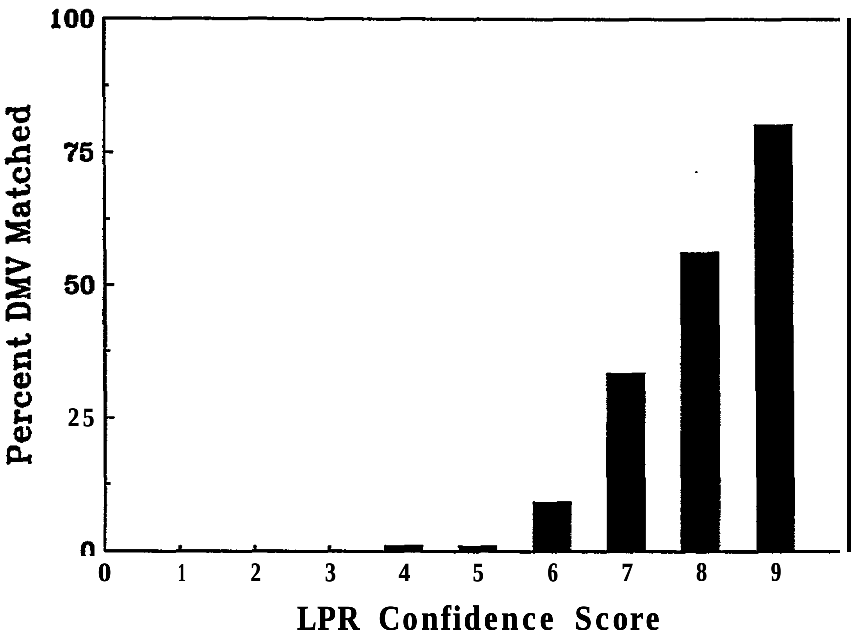

Figure 11. Data collected during the first 100 days of operation of the Smart Sign showing the correlation between the LPR systems confidence score and a successful match against Colorado DMV records.

upon limited survey data.

Both of these claims remain lower limits because the plate reader data specifically exclude vehicles which pass during the hours of darkness and twilight. In summer, these only amount to 18% of the vehicle counts. If these vehicles have the same demographics as the diurnal vehicles then one could claim 18% more than the above numbers suggest, however they may be a more static and habitual fleet, thus contributing 18% of the readings but, for instance, only 9% more unique vehicles. We have also not included the unique vehicles which are accumulating on the weekends. The open circles in Figure 14 which denote the fraction of unique vehicles on weekends is building up at only 2/7's of the speed of the week day totals. This would further increase the total number of unique vehicles perhaps by as much as 50% because of the fact that the weekend fleet is not dominated by commuters as during the week. Thus, a safe claim would be more than 240,000 participating vehicles and more than 4,500 participants potentially claiming to have repaired their vehicles based upon the sign data.

The turnover data show that for every year of continued operation at least 90,000 more vehicles would enter the fleet measured at this site. Both the 4500 repairs and the 90,000 new vehicles argue for the benefits of maintaining sign operation for more than the one-year pilot program.

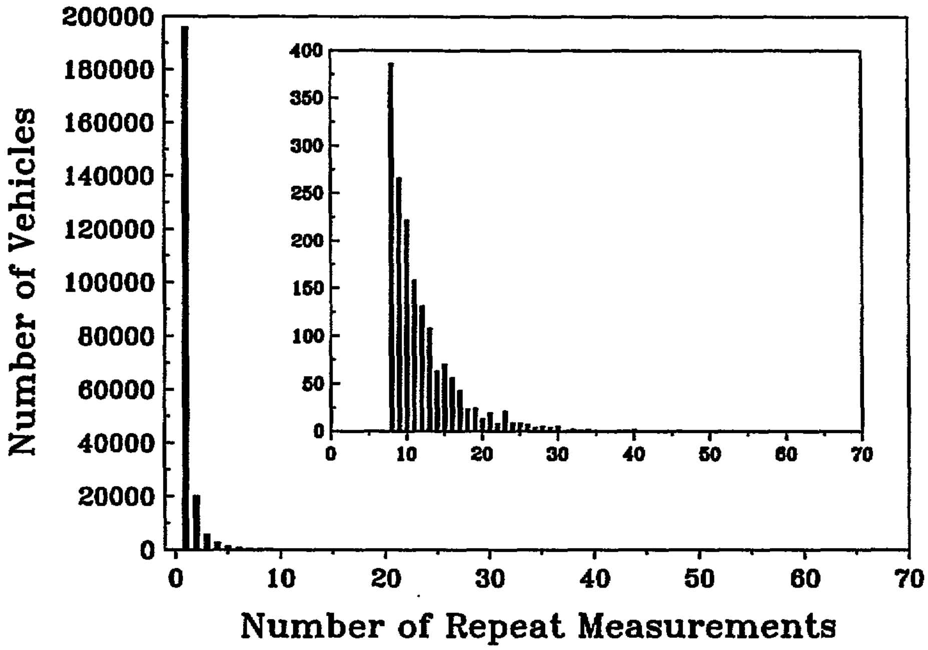

Figure 12. Vehicle counts as a function of the number of repeat measurements. The inset graph is a continuation of the larger graph with an adjusted y-axis to provide more detail.

Basically, the unique vehicle estimation model consists of five exponential terms, one fixed in quantity but adjustable in time to match the observed recovery and four fixed in time but adjustable in quantity to match the first hundred days. Because there are five adjustable parameters to match only one data set, the precision with which any particular term can be determined is very limited. In mathematical terms, the fraction of unique plates model is:

$$Fr = D(1-e^{(-\frac{L}{t})}) + W(1-e^{(-\frac{L}{5t})}) + M(1-e^{(-\frac{L}{20t})}) + Y(1-e^{(-\frac{L}{200t})}) + recovery\ term(1-e^{(-\frac{Tr}{t})})$$

Where D,W,M,Y are the assumed fraction of the static fleet in the daily...etc. category, Tr is the exponential recovery time (fit by 300 days), t is the number of days of measurement and L is the fraction of plates read (P = 720 each day) compared to vehicles passed each day (C = 10,000). L = P/C.

FT, the total static fleet number, is derived from:

$$FT = \frac{C}{D + \frac{W}{5} + \frac{M}{20} + \frac{Y}{200}}$$

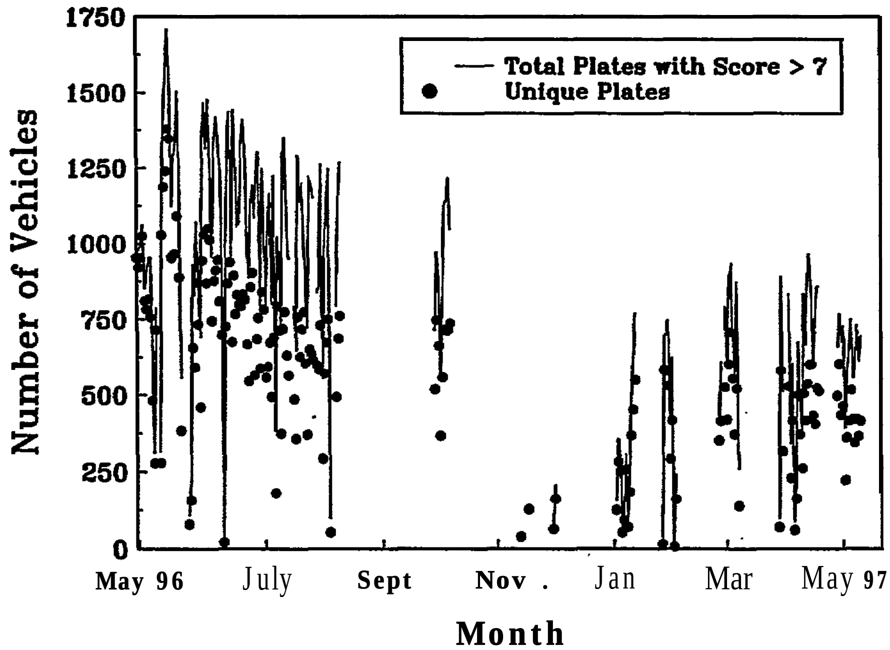

Figure 13. The number of vehicles measured on a daily basis with LPR confidence score's greater than 7 (line) and the number of unique plates (●).

The dynamic (replacement addition to that static fleet at the end of the year is) $FT^*\frac{365}{Tr}$

Thus the total number of unique vehicles have been past the sign in this model is the sum of the two, namely $FT(1 + \frac{365}{Tr})$.

The problem with the accuracy of this model is that the "Y" term has a very large leverage on the derived total number of vehicles in the fleet, but .a relatively small effect on the shape of the curve of plates measured each day.

Emissions Distributions

Remote sensing emission records at the Speer Blvd. location date back to 1989 with studies having been conducted in 1989, 1992-93, 1994 and 1995 (Bishop and Stedman, 1991; PRC Environmental, 1993 and Zhang et. al. 1996). We have performed additional studies in Denver at 6th Avenue and I-25 which is a few miles south of the Smart Sign and they are included for additional comparisons (Stedman et. al., 1997). During this period, the average CO emissions have decreased as new emissions control technologies have been introduced into the light-duty fleet. Table VI lists the results from the Denver studies and compares it to the data collected by the Smart Sign system. Denver uses two distinctly different fuel blends.

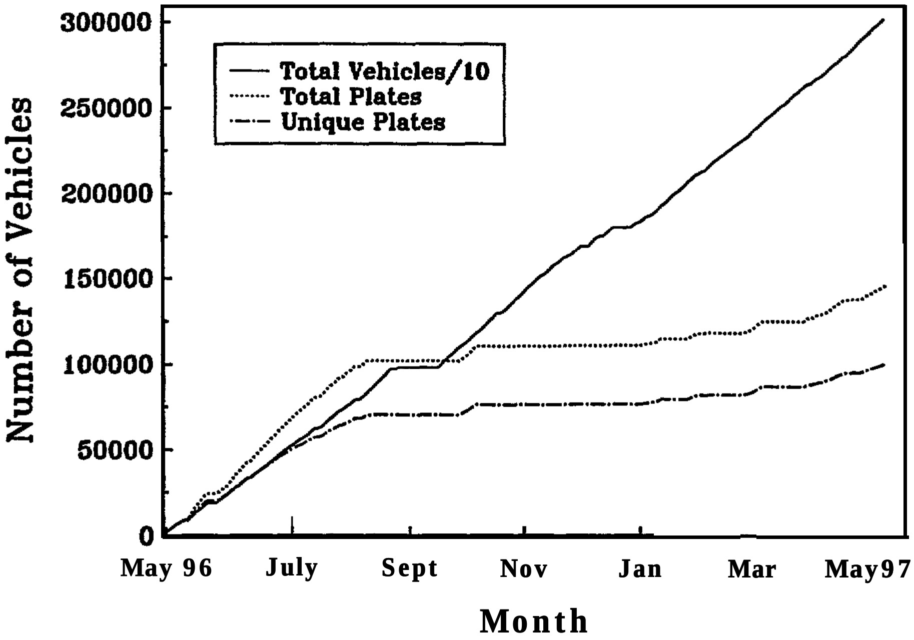

Figure 14. Cumulative vehicle counts for the Smart Sign's operational test. Total vehicle counts are divided by 10 for display purposes. Only plates with LPR confidence scores greater than 7 were used to calculate total unique plates.

Wintertime fuel has much higher oxygen content than the fuel used during the other times of the year and for this reason the data are segregated accordingly.

Figure 16 displays in graph form the time dependence of the mean CO readings listed in Table VI. As shown previously in Figure 10 the age dependence of fleet emissions is one of the most important factors. And fleet turnover is the largest single factor which accounts for the large drop in CO emissions observed over time at these two locations. However, the average age of the fleet at these two locations has changed little over the years studied and so the large drop in CO emissions with time has also been influenced by one other very important factor. The deterioration of vehicle emissions has also been reduced during this time period as well. The exponential curve that one can see in Figure 10 is additional evidence to this effect that 1994 model year vehicles for example stay lower emitting longer than did 1987 models. If all model years emissions deteriorated at the same rate one would expect Figure 10 to have an approximately linear increase in emissions with increasing age.

The fleet emissions are dominated by emissions of the FAIR and POOR vehicles at the site. For the entire operational test the breakdown in the percentage of Smart Sign readings by category was 86.7% GOOD, 9.9% FAIR and 3.4% POOR. The breakdown in total CO emissions were that the GOOD group contributed 23.8%, the FAIR group contributed 42.3%

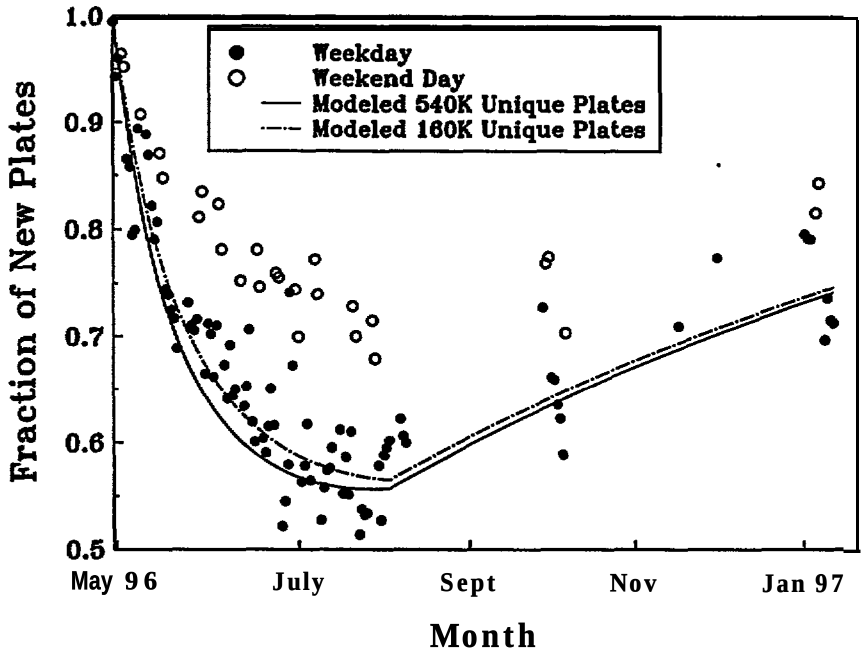

Figure 15. Fraction of new plates as a function of time for week days (●) and weekend days (0). The solid line is modeled for a fleet of 540,000 week day vehicles. The dotted line is modeled for a fleet of 160,000 week day vehicles.

and the POOR group was responsible for 33.4%. The percentage of POOR readings decreased, as did the mean CO emissions, during the test. Figure 17 provides three different views how the emissions from those vehicles for which we have model year information contribute at the Smart Sign location.

The fleet for this analysis is composed of 88,029 measurements from vehicles for which we have Colorado DMV information. The emissions distribution of this subfleet is very similar to the total fleet with 86% receiving GOOD readings, 10.7% receiving FAIR and 3.3% receiving POOR. The top figure shows how the GOOD/FAIR/POOR readings are distributed for each model year. Since emissions are known to increase with age it is reasonable to expect that FAIR and POOR readings will also increase with age. The graph shows that there are very few poor readings in the newest four or five model years. This fraction slowly increases until it reaches a steady state around model year 1980. This plot by itself however, gives an incomplete picture since their is no information to indicate the size of the fleet found in each model year category.

The middle plot provides this information as well as repeating the information found in the top graph. This plot highlights the fact that 12 year old and newer vehicles are the most common vehicles measured by the Smart Sign system. The bottom plot is a product of the average emissions by model year and the number of vehicles per model year with the fraction

Table VI. Summary of Study Results from two Denver Locations.

Location/Date	Vehicles	Mean $\%CO_{oxy}$	Mean $\%CO_{nonoxy}$	%Measurernents Responsible for 50% of Emissions	Mean Age
Speer / January 89	2,011	1.04		8.7	6.8
Speer / May 89	962		1.21	8.8	6.9
Speer Nov. 91 & Feb. 92	19,933	0.60		6.1	6.8
Speer Oct. 91 & April 92	20,086		0.80	7.3	6.9
Speer / January 94	2787	0.55		6.2	7.3
Speer / July 95	3176		0.51	6.9	6.6
Speer Nov. 96 - Feb. 97	1,023,032	0.54		5.2	7.4
Speer May 96 - Oct. 96 & March 97 - May 97	2,166,249		0.61	5.8	7.5
6th Ave / Jan 96	30,675	0.53		6.4	7.1
6th Ave / Jan 97	46,348	0.51		5.6	7.0
6th Ave / April 97	39,3 19		0.65	6.3	7.2

of emissions contributed by the Smart Sign categories indicated. It might be surprising to some that the majority of CO emissions are contributed by vehicles (1983 and newer) which all were originally equipped with the most advanced emissions control equipment. This is in large part due to the large number of these vehicles which are on the road.

Technically, the poor emissions readings seen from these Colorado registered newer model year vehicles should not exist. As mentioned previously all of the vehicles originally were equipped with modem emissions control equipment and all of these vehicles are subject to the Colorado Air Care inspection and maintenance program. The Smart Sign was designed to specifically to address just these types of vehicles.

We estimate that this sign, if operated for ten years would achieve a total overall operating cost, including capital, of two cents/test ($60,000/yr).

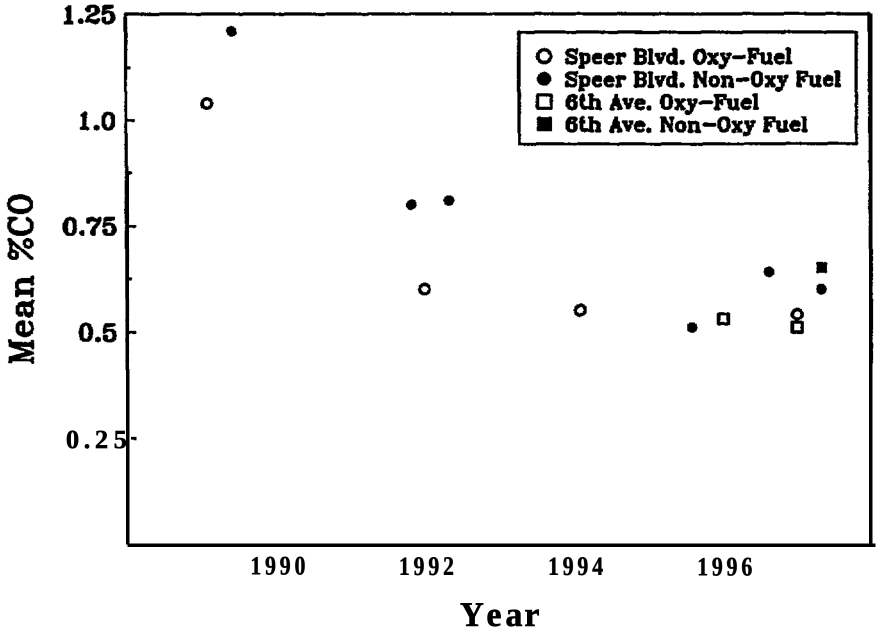

Figure 16. Time dependence of mean CO measurements from the two Denver locations of Speer Blvd. & I-25 and 6th Ave. & I-25. Oxygenated fuel is used between November and February in Denver.

Driver Response Focus Group

Toward the end of the operational test it was suggested that additional information might be gleaned from the drivers that had been exposed to the Smart Sign through some additional focus groups. One area that we were especially interested in gaining more insights were with the drivers who had received POOR readings from the Smart Sign. There was concern that the POOR group had been underrepresented in the telephone survey due to a higher than average refusal rate. To help corroborate the findings of the telephone survey we assembled three groups of drivers who had passed the sign at least once. Two groups were drawn from the category of drivers that had received a poor rating, one of females and one of males. The third group was made up of males and females who had received either a GOOD or a FAIR reading (see Appendix A).

Each group was led through an initial discussion of air pollution and control issues ending with each group providing reactions to the Smart Sign and any suggestions which they might have. The participants were not informed as to how they had been selected and they were unaware that we had selected them based on the readings they had received from the SmartSign. We hoped that by using this selection criteria new insights into the groups comments could be made.

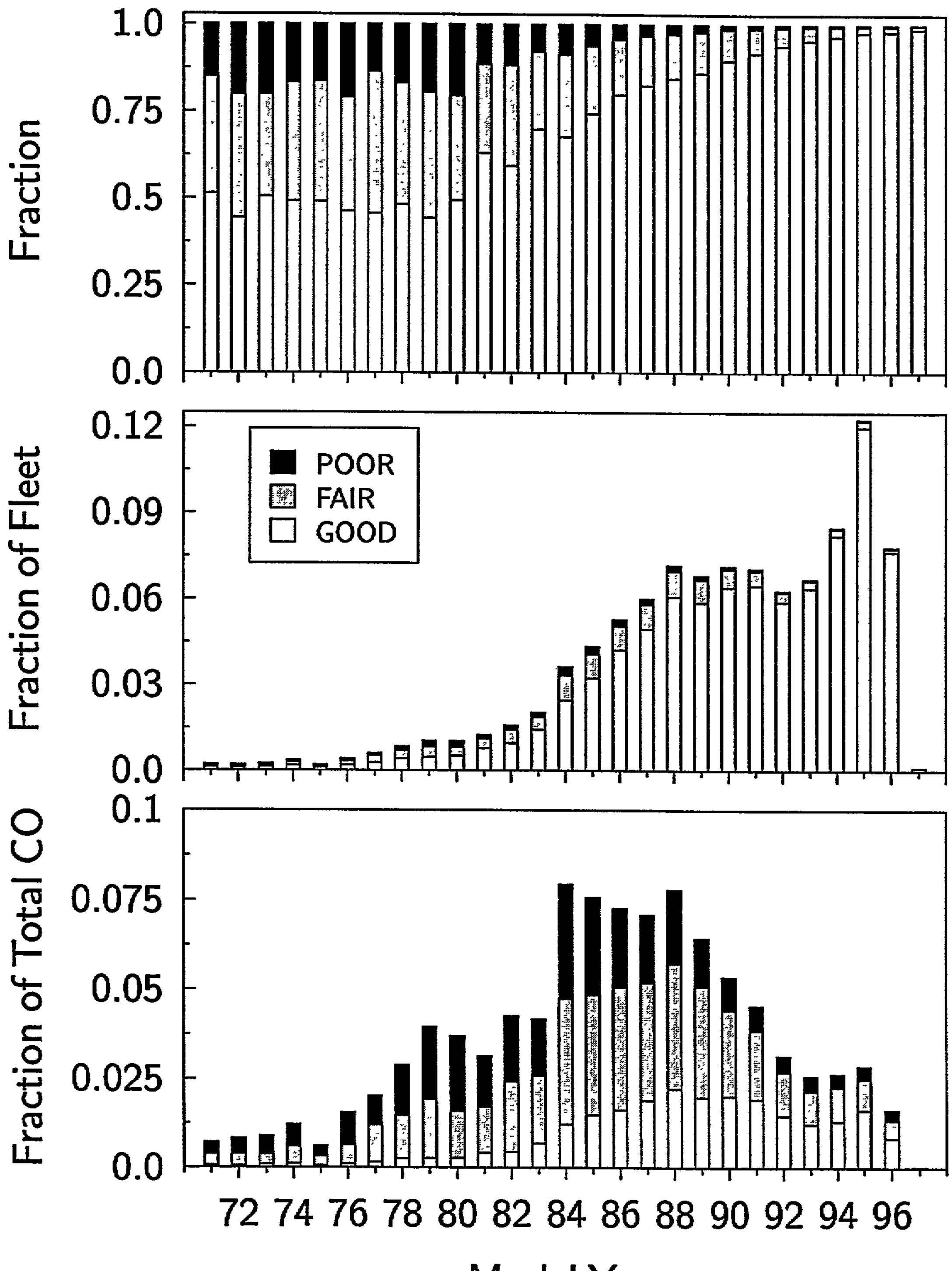

Figure 17. Fraction plots for 88,029 vehicles by model year. The top plot details the distribution of GOOD/FAIR/POOR readings. The middle plot shows the fleet distribution and the final plot shows the fleet weighted CO contribution.

Initial questions about the Smart Sign and if each participant recalled driving by the sign produced different responses between the POOR and GOOD/FAIR groups. The majority of the participants in the GOOD/FAIR group recalled driving by the sign and many remembered the reading they had received. The POOR groups on the contrary did not initially admit to seeing the Smart Sign. Only one of the men admitted to having received a POOR reading from the sign, though he did not completely believe that it was accurate even though his vehicle failed a subsequent emissions test. With time both POOR groups “remembered” the Smart Sign and that they had received various readings including POOR.

The major criticisms of the program included the lack of any useful connection between the sign and its supporting information, namely the brochure and the hotline. While the brochure was viewed very positively the fact that most of the group participants had never seen it before the groups highlighted this lack of connection. In addition the groups felt that the sign title of “Your Car’s Health” was vague and misleading and needed to be changed to “get to the point”. It was also felt that if the sponsorship of the sign was made known it would lend credibility to the entire program. The use of the license plate reader was not seen as a negative to the program.

Overall reactions to the program were very positive. The information was seen as useful, particularly as a “signal” or a pretest before going ***to*** central emissions. The voluntary component was especially well received. The differences in the initial responses tells a lot about the two groups and the approaches necessary to translate the Smart Sign information into some type of action. All of the groups agreed that additional access to information to answer questions raised by the Smart Sign were needed. One group suggested the use of a local radio transmitter as one approach they might be explored in future uses. All of the groups express an interest in using additional incentives to reinforce the smart sign message.

The major conclusions of the telephone survey were reinforced, namely the education, awareness and action items were all successful. In particular owners of vehicles which obtained routine “GOOD“ readings were very much influenced to repair their vehicles upon receiving a FAIR or POOR reading. Although we did not solicit these comments, several routine users of he sign who used that status change to elicit immediate repairs did contact us. A few even stronger messages were received from owners who took no action after a GOOD to FAIR/POOR status change and later paid for their failure to take immediate action. Some of these anecdotal reports are in the “wrap-up” PR material attached as Appendix B.

RECOMMENDATIONS

Future uses of this technology combination should be able to benefit from our first experience with the Smart Sign. The recommendations are to help others who follow to improve upon our design and implementation.

1) The title line of the Smart Sign “Your Car’s Health” should be changed to include the word emissions or pollution. Perhaps "Your Car’s Emissions”. All of the preliminary focus groups and the final focus groups recommended against the word health as being too vague

and not to the point. Our use of the word health was a political compromise with a participating group which did not want the word emissions used for fear it would feed upon the public's dislike for some local emission programs.

2) The most difficult aspect to successfully complete was to provide motorist additional information to answer questions raised by the Smart Sign. While the follow-up focus groups gave high marks to the sign and brochure, they gave low marks to the hotline and a basic inability to get a brochure. While the brochure was available at local CONOCO stations there was no way for motorist to know this. Perhaps others will have additional insights into how to link the support information to the Sign. One idea that was raised in the follow-up focus groups was the idea of a low power radio transmitter to provide brochure like information from a known location.

3) Permanent installations like this operational test have higher startup costs and are thus more cost effective with longer operation times (a 10 year estimate for this site has costs of only $0.02/test). The expected downsides of a permanent installation appears to be offset by the fact that long term users of the system have a higher level of trust in the readings and act quickly at the first signs of problems with their vehicles.

4) Due to the limited number of high volume sites, like Speer Blvd. and I-25, we recommend exploring the option of making the Smart Sign portable. A portable system would allow a number of different uses for instance local employers could use the system for their employee commuting fleet.

5) We recommend implementation of this technology for any area which is contemplating using on-road emissions measurements as a local enforcement tool prior to the start of the enforcement program. Public access to emissions information is an important step to build support for any new program. Installation prior to any enforcement action can also be used to provide a warning to the public an allow many problems to be rectified without additional government action.

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APPENDIX A: Smart Sign Follow-up Focus Groups

DRIVERS RESPONSE
TO THE
VARIABLE MESSAGE SIGN PROGRAM

FOCUS GROUP REPORT

IVHS for Voluntary
Emissions Reduction
Operational Tests

April 1997

INTRODUCTION

The IVHS Operational Test focuses on the use of remote sensing technology to provide real time feedback to drivers regarding their vehicle's emissions. The twofold purpose' of the project was to: (1) demonstrate the feasibility of combining remote sensing technology with a variable message sign (VMS) to educate and motivate the driving public to maintain an effectively running vehicle and (2) determine the efficiency, accuracy, and effectiveness of the system. Complementing the VMS were other reinforcing communication vehicles, including a brochure and telephone hotline.

FOCUS GROUP PURPOSE

The current field test of remote sensing technology using a VMS as the delivering device to motorists in real time is the first of its kind. The design and evaluation of the program utilized a multi-trait/multi-method methodology. A series of focus groups with experts in the field of communications and with Denver metro area drivers provided information for the design of the sign and brochure. Drivers' responses to the sign were measured in a telephone survey of drivers who had passed the sign during the test year. Additionally, technical analyses were conducted to determine the accuracy and dependability of the equipment.

The primary purpose of the focus groups described in this report was to gain more of an in-depth understanding of driver perceptions of the sign and its motivational properties. Of particular interest were drivers who received "poor" ratings from the sign and those who received more than one rating (i.e. "flippers"). In the survey sampling, those who received "poor" ratings were underrepresented due to a higher than average refusal rate. Because their response to the sign was positive, even in terms of reported behavior to fix their cars, it was felt to be important to gain convergent validity with regard to attitudes and behavior resulting from exposure to the sign. Content issues of importance besides sign information were focused on the brochure and hotline. Survey responses indicated few drivers had accessed or been exposed to either. Finally, physical issues such as sign placement and readability were of interest as factors that enhanced or detracted from the sign's effectiveness.

METHOD AND SAMPLE

Three focus groups were recruited from a random sample of drivers who had passed by the sign at least once. The samples were drawn from the list of license plates recorded by the plate reader used to provide the sampling frame for the survey sample.

Two of the groups were drawn from the category of drivers that received a poor rating. One group was comprised of males ‘and one of females. The third group consisted of males and females who had received either good or fair readings. Each group consisted of 12 participants ranging in age from 18 to 65. In the group consisting of drivers who had received good -or fair readings, there were 7 men and 5 women. They were evenly split between good and fair readings. Most had, in fact, received both ratings at one time or another.

Group participants were recruited by telephone. Those who worked in research or advertising fields or for a related government agency were screened out.

Discussion in each group covered the following topic areas:

- Aii pollution perceptions
- Emissions testing
- Maintenance behavior
- VMS sign
- Brochure
- Incentives
- Recommendations

In order to provide context for the participants, each group was shown a video that replicated the drive-by experience. The three taped segments showed the sign giving one of the three readings - good, fair, poor. The brochure was also provided to recipients for review. Each reading was also provided on an overhead in order to control exposure. The protocol for the discussion is contained in Appendix A.

SUMMARY OF RESULTS

Results of the conversations with all three groups will be discussed in the approximate order in which the conversations took place. Differences between male and female groups and between the poor and good/fair groups will be highlighted when appropriate.

Air Pollution Perceptions

In general, all three groups felt that air pollution is a serious problem.

"Big problem, getting worse."

Most of the discussion focused on visibility issues. Including the brown cloud and visible exhaust. Health effects were also noted, particularly respiratory problems among the elderly.

The central problem for Denver continues to be the effects of growth. Participants were able to make a direct connection between growth and pollution. They attributed the lack of planning, sprawl, deterioration of highways and congestion to growth.

". . . .(Denver area) growing like a beast."

"There is always just one person in a car."

The groups were also in agreement on the primary direct cause of the pollution problem - automobiles. While they were aware that other sources of pollution have gotten better (i.e., industry, wood burning), driving was perceived to be the biggest culprit, in terms of the number of vehicles on the road, congestion, and driving vehicles that pollute because they are not well maintained. The problem was also seen as a political issue because of the lack of regional government cooperation and the power of lobbyists for development.

"The American West was invented by the automobile."

"I drive 20,000 miles a year going nowhere."

Even though all of the participants felt air pollution was a problem, perceptions regarding the scale of the problem varied as did views on potential solutions. A few thought the problems were overstated and "gives Denver a black eye." Many felt that if growth were controlled, much of the pollution problems would be alleviated. Other solutions offered were better transit, flexible work hours, and better street sweeping.

Emissions Testing and Maintenance

Most of the participants reported they had their cars tested and/or maintained within the last year. With a few exceptions, all of the participants had gone to an

Envirotest facility. Reviews of the experiences were mixed, but clearly an improvement over past experiences. Interestingly, females were more positive than males, although they felt the whole system was somewhat of a "rip-off" since one contractor did all of the testing.

Males questioned the specifics of the program, such as what was tested. They did recognize that service was generally better and waiting time reduced. Males in the “poor” reading group felt strongly that there should be some leniency in getting cars fixed when driver’s don’t have the money to pay.

“They didn’t test the things that cause pollution - PM1 0.”

All three groups were knowledgeable about the emissions testing system and the controversies. Several knew about remote sensing technology. Many felt the current system was a ‘political deal” and the real solutions to air pollution were not with centralized testing. Solutions offered included:

- Better public transportation
- Reducing overall miles driven
- Raise gas prices
- Rideshare

Most drivers in all three groups report getting their vehicles checked at times other than the two year centralized emissions requirement. However, maintenance was typically not done on a regularly scheduled basis. Behavior is typically triggered when a problem is observed (e.g., visible emissions like smoke). This type of behavior provides an opportunity for a VMS to play an important role in reducing pollution between centralized test periods. The sign niessage can act as a signal just like visible smoke does. It alerts motorists to a potential problem. This is particularly important for certain types of emissions like carbon monoxide which is invisible.

The SMART Sign (VMS)

When asked if they recalled driving by the sign, a majority of participants in the “poor” reading group said they did not remember seeing it. Almost all of the participants in the “good/fair” reading groups did recall driving by.

For those that did remember driving by the sign, the issue of credibility was foremost in their impressions.

"I'm not sure it's accurate."
"It's a game for me. It's different all the time."

These feelings were voiced primarily by participants in the "poor" category and by some in the "good/fair" group who experienced a great deal of flipping between readings. Because of the lack of information explaining why they might get different readings, they used the variances to discredit the information. They did say they would pay more attention to it if the readings were more consistent.

Awareness. In order to provide participants with reminders of what the sign looked like, each group viewed a video of the sign taken from a passing car. Each of the three readings - good, fair, poor- were viewed separately on the tape. After they viewed the tape, they were asked their perceptions and what features caught their eye.

Two types of discussion tended to dominate the conversations of all three groups. First was the specific reading *a* participant received. Interestingly, "poors" did not admit to this reading initially. Either they said they couldn't recall or that they had received a fair or even a good reading. Later in the conversations, both males and females indicated they had indeed received a poor reading. Only one male originally admitted he had received a poor reading. He took the vehicle to Envirotest and it failed.

The second issue discussed was the sign location. Several felt that it was set in a hazardous location where traffic was merging, construction was in progress, and that it was located on the wrong side of the road. Others felt that the heavy traffic made it both hard to concentrate on the sign as well as not being sure that the reading they observed was actually their car.

Knowledge of sign components The economic message of the sign was viewed positively.

"Money is so important."

You might just take it in to get it checked."

"We want the cars (in our family) to last as long as they car?'
(Response from a woman who has four children in college)

Participants understood that the term "costing you money" referred to their car not running efficiently. It did catch their eye. Some felt that the message would be stronger if it connected directly to air pollution.

The sign's top line, Your Car's Health, was not viewed positively. Almost half of the participants did not recall the line. Amazingly, there was consensus across all three groups that the world "health" was the wrong word to use. It was seen as vague, not directly related to pollution. The attempted connection between personal health and car health was understood once it was explained, but participants felt it was too abstract for people to make the connection from a drive-by sign.

"What's missing here is pollution."

The car itself and the facial expressions (except for the fair expression) were seen as very positive and attention getting. Interestingly, males and females split on the appropriate tone of the pictures and messages. Males felt that using humor and staying away from "'Big Brother" like messages would go over better. Females felt that guilt and the dangers of pollution would get more response. Both felt that making the message as personal as possible was important.

"You have to put it on a personal level."
"I like the choking car idea."

The good-fair-poor readings generated a great deal of discussion. Several felt that the designations weren't informative enough.

"It doesn't say they are polluting."
"I don't know if "good" is the best I can do or not."

Generally, however, most participants knew that "good" was related to one's vehicle running well. Some felt that it meant you couldn't pass the central emissions test. "Fair" on the other hand was seen as the most vague.

". . kinda like kissing your sister."

Although it was generally understood that a "poor" or "fair" reading was a signal that there may be a problem, particularly if it registers after a series of "goods", some of the males felt it simply meant "You try to get away with it a little longer." "Poor" was seen as a definite attention getter, again if it followed a series of better readings. For some, however, it meant "take a different route." It would also take some other kind of validating information, such as smoke, to confirm a real problem. This general lack of understanding regarding the fundamental messages the sign is conveying highlights the importance of educational materials to accompany or proceed exposure to the sign. Even without such information, however, the sign Was perceived to be attention-getting, useful, and a signal to seek further information.

Several suggestions were made regarding information that would be useful in enhancing the sign's effectiveness:

- Explanation of technology. There is no information explaining how it works or how to assess its accuracy.

"How does that sign know?"

- Explanation of purpose. There is no information explaining why the sign is there, that it provides free information to be acted upon in a voluntary manner.

"I didn't know what its purpose was."

- What it measures. There is no information explaining that what is being measured is car emissions, carbon monoxide, and air pollution.

"What are they measuring, what's good?'

- Who is responsible. There is no information that describes the responsible parties.

"Who put it there?'

In fact, each of these issues is discussed in the brochure or on the hotline, but few had the opportunity to access information from either. In the discussion among participants regarding why this information would be useful, it became clear that the information has two purposes. First, it gives credibility *to the* sign and the information. For example, having the sign sponsored by a university or government agency is perceived as more credible than by a private sector firm, who might be involved just to make money. However, the government's credibility depends on the purpose. Some participants speculated the sign could be some type of "sting" operation. Knowing that it was a free service encouraging voluntary action allayed such fears.

The second important purpose was to be more educational and straight forward. Earlier conversations had established the importance of air pollution. The sign would be more effective in drawing attention and motivating action if air pollution, or at least emissions, were clearly linked to the sign.

The second sign. Following the SMART sign on the off-ramp was a smaller fixed message sign that provided the phone number to access the hotline. In the three groups only two participants remembered seeing the sign, and no one remembered the number.

"A real itty bitty tiny phone number."

When queried regarding the value of the phone number, everyone agreed it would be useful if the hotline answered some of the questions they had raised earlier. Getting a "poor" reading was seen as a motivator to make such a call. The participants did point out some difficult logistical issues. One was the sign placement. Having the sign so close to the merging traffic was given as a primary reason for not noticing it. Drivers are too busy negotiating traffic. Also, it is too small. Several thought the numbers were hard to remember and suggested using some type of acronym.

"I'm not going to take the time to write it down."

A fmal key point was that drivers are still trying to process the information from the SMART sign when they pass the hotline number. The result is they fail to notice it. Of course, this problem is partially alleviated by repeat exposures.

SMART SIGN BROCHURE

Participants in each group were given a copy of the brochure to review (Appendix B). All three groups agreed that the information contained in the brochure was very helpful in answering the questions they had raised earlier.

"It gives you more information about what you're going to see."

Several suggestions were given regarding ways to improve its effectiveness. While the cover was viewed as attractive, several felt they would not be motivated to pick it up. They suggested putting the sign on the front and providing a call-to-action message or asking a question.

"Have you seen the SMART sign?"

All three groups felt the brochure should not look commercial. For example, having Conoco on the cover raised suspicions. Some felt that Conoco's motive would be ***to*** get people to use their products or services.

"First thing I see is Conoco."

When participants saw who the other sponsors were, they believed the program to then be credible in terms of motives to help the public. Conoco being a part of the list was not seen as a problem. Their recommendation was not to single out Conoco. By making Conoco part of the larger list, it would enhance both the program's credibility and Conoco's.

Several recommendations were also made regarding the kind of information that should be in the brochure. In general, participants in all three groups wanted more specific information and stronger ties to the air pollution problem. Of the different comments, the Questions and Answers section was viewed most positively. The sponsor list was also a plus. Recommendations for enhancing the information include:

- Be more direct regarding how the public and the individual will benefit. Don't gloss over the air pollution issue.
- Make it personal. Either tie personal health and the car's health together directly with facts or get rid of the "health" concept.
- Give ***more*** specifics regarding saving and costing money when a car pollutes. Provide actual dollars.
- Clarify why older cars may not get "good" readings, and why readings may vary.
- Provide additional information on what people can do to make their cars more efficient (e.g., properly inflated tires).
- Provide facts regarding the extent of the air pollution problem, the contribution of automobiles, and the personal contribution of an individual driver. Make the problem significant and real. Do the same for benefits.

Overall, participants were positive toward the brochure. Most felt it would better prepare them for seeing the sign, and interpreting its meaning.

INCENTIVES

Participants believed that all three sources of information - SMART sign, hotline, brochure - contain some motivational properties. But, all three groups agreed that the program would benefit from some form of direct incentives. Monetary incentives were the most often mentioned. Males tended toward positive incentives, rewarding good behavior. Females, consistent with previous discussions, were also in favor of positive incentives, but felt punishing poor behavior was also appropriate.

> "How about a nbte in their mail box that says, 'I know who you are.. .'"

The impetus for monetary incentives was driven by a concern for those who do not have the money to pay for repairs and/or getting the repairs would cause them to miss work. Recommendations included:

- Free diagnostic service
- Focusing on the really bad cars, (e.g., buying back "clunkers")
- Diagnostic costs applied to repair costs
- Tax credit

> "Huge gaps between the awareness stage and the action stage."

RECOMMENDATIONS

Throughout the conversations, participants provided a variety of recommendations regarding how to improve the program. It is important to realize that their overall reaction to the program was very positive, especially once they understood it and became aware of the different components. The information was seen as useful, particularly as a "signal" or a pretest before going to central emissions. The voluntary component was very positively received. The positive results from the "poor" group found in the telephone survey evaluation were supported. "Poors" do care and report' a willingness to take action.

But, participants viewed their mission in the groups as providing a critical analysis that might lead to program improvements. As such, they provided a number of thoughtful recommendations:

- Logistics
  - 0 Location of sign should be in a less congested area. Allows for more concentration and greater assurance the reading is connected to the right car.
  - 0 Location of sign on the curve is too far forward toward merging traffic.
  - 0 Hotline phone number is a problem because it is even closer to merging traffic.
  - 0 There needs to be some kind of message before the SMART sign preparing people to read it.

- Style
  - 0 Messages should be personalized.
  - 0 Mixed recommendations on the value of positive vs. negative tone and incentives. One recommendation by the female group was to "publish the polluters." Everyone agrees positive is good. No consensus on the value of negative.

- Credibility
  - 0 Viewed as the single most important characteristic of the program.
  - 0 Trust is vital to message acceptance and action.
  - 0 Government and university sponsors are credible. Private sector sponsors can also be credible, but in combination with others.
  - 0 Message consistency increases credibility.

- Information
  - 0 Clarify what good, fair, and poor means and what is measured. Maybe the introduction of a scale to show relativity of reading.
  - 0 Educate with regard to who, why, and what the program is about.
  - 0 Clarify purpose. "Health" should be dropped and replaced with "emissions".
  - 0 More specific and direct messages, including numbers.
  - 0 Radio was perceived to be a potentially useful way to provide additional information.

- Incentives
  - 0 Development of a grants program for low income drivers.
  - 0 Coupons provided by private sector.
  - 0 Voluntary action is tied directly to the dollar investment, so cost reduction incentives are most valuable.

0 Connect incentives to Envirotest program. (i.g., provide access to diagnostic facilities between mandatory test periods.)

In summary, the SMART sign was viewed positively, and capable of playing an important role within the overall fight to reduce pollution. If anything, it spurs the desire for more information, and information that is directly related to the issue - air pollution and the contribution of exhaust emissions.

"Let's get to the point."

APPENDIX A

FOCUS GROUP PROTOCOL

PROTOCOL
IVHS OPERATIONAL TEST
FOLLOW-UP FOCUS GROUPS

I. INTRODUCTION

A. Purpose of Meeting
1. Focus on air pollution
2. Information that will help you maintain your car

B. Focus group explanation
1. Conversation
2. Between people with common experiences
3. Results reflect many others opinions

c. why you?
1. You drive
2. Breathe Denver air
3. Represent others
4. May have driven by the SMART SIGN

D. Ground rules
1. Honest - won't hurt anyone's feelings
2. No right/wrong answers
3. Tape recorded/mirror
4. One at a time talk
5. 1 1/2 - 2 hours with a break

II. AIR POLLUTION PERCEPTIONS

A. Is air pollution in Denver a serious problem or not?
PROBE: Why or why not: health, visual, economics, e.g., personal fuel costs, emissions, testing, etc.

B. What causes air pollution in Denver?
PROBE: Automobile exhaust
Wood burning
Utilities
Geography
Growth and sprawl

a. Technology
b. Centralized emissions testing
c. Alternative fuels
d. Driving less
e. Better care of our cars

III. INFORMATION AND AIR POLLUTION

A. Most studies have shown that automobile exhaust. is a major cause of air pollution. I'd like to talk about this a little more.

I. How many have had your car's emissions tested recently?
   a. Envirotest?
   b. Other?
2. What was the result? Pass vs. Fail?
   PROBE: If failed, what happened then?
3. What was your experience
   a. Convenient vs. inconvenient
   b. Friendly vs. not
   c. Simple vs. confusing
   d. Expensive vs. not
4. Attitude toward the testing system
   a. Positive - More stringent
      Reduces pollution
      Fair
   b. Negative - Not reliable
      Not convenient
      cost

B. Before you went in, did you have a sense about whether you car would pass or fail?

PROBE: For those who said "yes" probe how they knew or what information they had?

C. How often do you get your car checked or maintained?

D. What causes you to take it in?

1. Scheduled maintenance
2. When I see or hear something wrong
3. Before the emissions test

IV. THE SMART SIGN

How many of you remember driving by a sign that told you about your car's emissions?

(Aided recall: I-25 and Speer)

A. What do you remember about the sign?
   1. Car graphic
   2. Plume
   3. Face smiled or frowned
   4. Reading - Good, Fair, Poor
   5. Information - saving/costing you money
   6. Your car's health
B. Do you remember what reading you got - Good, Fair, or Poor?
C. I'd like to show you the sign and get your reactions to it. [show tape]
   1. Show all three versions at once
      a. What features stick out?
      b. What features changed?
         - reading
         - face type
         - message
   2. Repeat all three versions
      a. Anything stand out this time that you didn't notice the first time through?
      b. Do you remember how easy, or hard, it was to read the sign as you were driving by?

      PROBE: Why it might have been hard
      c. Describe your experience when you drove by:
         - a lot of cars
         - sun glare
         - sign was turned off
         - too busy to really notice it
      d. How many of you drove past the sign more than once?
         - if only once - why?
         - if more than once, describe how your perceptions changed with increasing exposure
         - did you always get the same reading?
      e. Attitude toward the sign
         - favorable vs. unfavorable PROBE: Why?

D. Knowledge of sign components

   Now I would like to look at each of the different sign messages in a little more detail

   [Show an overhead of each message]

1. What does the message ________________________ mean to you?
   a. Good: <u>PROBE</u>: Running well
      Saving money
      Good gas mileage
      Not polluting
   b. Fair: <u>PROBE</u>: O.K., but watch it
      Polluting more than it should
      On the verge
   c. Poor: <u>PROBE</u>: Needs maintenance
      High polluter
      Poor gas mileage
      Losing money
2. What is your reaction to the lead in - "Your Car's Health"
   a. Clear or confusing
   b. Connection to personal health
   c. Attention getting
3. What is your reaction to the "Saving/Costing You Money" tag lines?
4. What other reactions to you have to the sign and its various featutes?
   a. How easy is it to read?
   b. Understand?
5. Is there other information that you would like to see on the sign that might be more useful to you?
6. Overall attitude
   a. Favorable - Why?
   b. Unfavorable - Why?

E. Taking action
1. Do you think this sign could be helpful to motorists?
2. How?
   a. Signal to get repairs
   b. Pre-test before going to Envirotest
3. What actions might people take if they get a. . . . . .
   - Good
   - Fair
   - Poor
4. What would it mean if the reading changed back and forth?
   - Fair ->Poor
   - Poor ->Fair
   - Good ->Fair
5. What other information would you like to have before you decide to take action?
6. How many of you have taken some action? What? Why Not?

F. The second sign
1. For those of you who drove by the sign, do you recall seeing a second sign? <u>PROBE</u>: Phone #

2. What do you think it was for?
3. Did anyone call it?
4. If "yes", what happened?

V. THE BROCHURE

A. Did anyone receive a brochure - SMART SIGN?

1. Where did you get it?
2. Did you read it?
3. What did it say?
4. What part was most useful?

B. Evaluating the brochure [PASS OUT BROCHURE]

1. Read brochure
2. Reactions .
3. Review
   a. Front Page
   b. Sign Picture
   c. Q&A
   d. Map
   e. Explanation
4. How could we improve it to make it more useful for you?
5. Suggestions for getting it into your hands?

VI. INCENTIVES

A. What else could be done to encourage you to get your car.. . .

1. diagnosed
2. repaired

<u>PROBE:</u> Free diagnosis
Monetary incentive → How much is reasonable?
Tax credit
Other?

VII. RECOMMENDATIONS

A. How to make the sign more useful?
B. How to encourage you to maintain your car?

APPENDIX B

SMART SIGN BROCHURE

What is The Smart Sign?

A tool to raise public awareness about the importance of a well-maintained car. Motorists can waste hundreds of dollars in fuel costs and contribute to the city's air pollution problems by not keeping their cars well maintained. Vehicles pass through an invisible beam that instantaneously measures carbon monoxide emissions. In less than a second, the Smart Sign flashes a reading of "GOOD," "FAIR" or "POOR" to help motorists assess their vehicle's fuel efficiency and overall condition.

the Smart Sign

Sponsored by
Conoco and the University of Denver
with assistance from
Colorado State University
RSTi Tucson,
Skyline Products,
Federal Highway Administration,
Colorado Department of Public
Health & Environment
and
Colorado Department of Transportation

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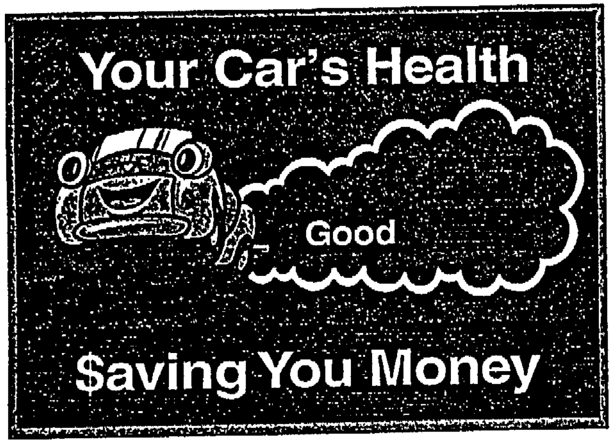
Chemistry Dept.
University of Denver
Denver, CO 80208

the Smart Sign

A Quick Way To Measure Your Car's Health



The Smart Sign can help you...
maintain your car, get better gas mileage and support Denver's drive for better air.

conoco

Questions & Answers

the Smart Sign

Q. What does a "GOOD" reading tell me about my car?

A. **"GOOD" means your car or truck is generally well maintained and emits very low levels of carbon monoxide into the air. Nine out of ten cars manufactured after 1982 should receive a "GOOD" rating.**

Q. What about "FAIR" or "POOR" reading?

A. It **may be time for an engine checkup. Healthy older vehicles manufactured before 1975 may get "FAIR" readings; however, a "POOR" reading always means that your vehicle is in need of repair.**

Q. What does it mean if my Smart Sign readings vary from day to day?

A. As a vehicle grows older, parts begin to wear out, causing variable carbon monoxide emissions. The Smart Sign simply measures and reports that variability. Most well-maintained vehicles have "GOOD" readings every time.

Q If I get my car tuned, will its Smart Sign readings improve?

A. **In most cases of excessive emissions, YES! Basic** repairs **should solve the problem.-Studies have shown that such repairs often pay for themselves in just a few months with better gas mileage and overall performance improvements.**

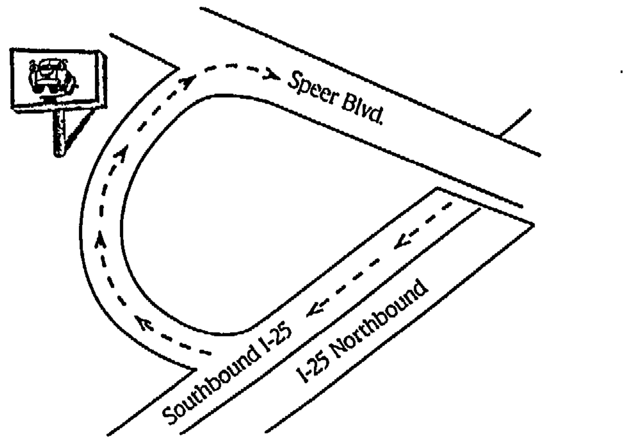
Q. What happens if a car gets a "POOR" readii and the motorist chooses to do nothing about it?

A. The Smart Sign program is for information only. It's there to help motorists check on their cars, keep them running and save money. Any action is left up to the motorist.

Q How does the public benefit from such a program?

A. Benefits include fuel conservation and cleaner air. A "GOOD" reading usually indicates a healthy car maintained by a concerned motorist. "FAIR" or "POOR" readings suggest that there might be engine problems. Check your manufacturer's recommendations about how to keep your car healthy and our air clean.

The Smart Sign at Speer Blvd and I-25



To obtain a reading on your car, just drive through from Southbound I-25 to Southbound Speer Blvd.

APPENDIX B: Close Out Press Release Packet

UNIVERSITY of DENVER

Office of Communications

NEWS RELEASE

Contact: Donald Stedman, 87 l-2580

IS YOUR CAR COSTING'YOU MONEY? THE SMARTSIGN KNOWS!

AUG. 5, 1997 — Smart Sign technology can help fight air pollution and save motorists money, two University of Denver scientists explained during today's release of data from a year-long research program.

The Smart Sign unmanned emissions monitor made more than 3 million readings of an estimated 232,000 different vehicles between May 1996 and May 1997 at its test site in Denver. An infrared beam measures carbon monoxide in the exhaust of cars exiting from southbound I-25 to inbound Speer Blvd. Within one second, a computer sends the results to an electronic sign at the top of the ramp, telling the driver if the car's emissions are "GOOD," "FAIR," or "POOR."

An independent survey conducted by Colorado State University indicates that more than 4,000 motorists made voluntary repairs to their vehicles in response to a "'POOR" emissions reading. An additional 4,000 motorists plan to make repairs because of information they received from the Smart Sign, according to the survey. The sign has made more than 4 million readings to date.

According to DU chemistry professor Donald Stedman, co-inventor of the Smart Sign with DU research engineer/analyst Gary Bishop, the technology has both an economic and environmental impact, and has applications well beyond Denver.

"Poorly running vehicles not only generate more emissions, but also waste gasoline and their driver's money. The Smart Sign technology is vehicle-friendly, and may be especially useful in nations where cost and access to testing equipment are major issues," he said.

Other findings showed:

- The Smart Sign costs l-10 cents per reading to operate.
- The Smart Sign technology performed well, reporting appropriate readings to the appropriate motorists. Only 1 percent of the respondents from a sample of 474 felt they weren't getting the right information.
- Motorists surveyed believed that Smart Sign technology could enhance existing emissions programs and that the Smart Sign was a good way to periodically check their cars' performance.

-more-

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- Seventy percent of those interviewed believed that the Smart Sign could stimulate action among the driving public.
- Anecdotal evidence suggests that many drivers who ignored poor readings regretted it when they were forced to pay high repair bills later.

The Smart Sign research was sponsored by the Federal Highway Administration, the University of Denver, Conoco, Colorado Department of Transportation (CDOT) and the Colorado Department of Public Health and the Environment (CDPHE), with assistance from RSTi Tucson and Skyline Products.

The Colorado Department of Public Health and Environment currently is conducting studies of the effectiveness of remote sensing. The results of the department's remote sensing pilot project in Greeley will be announced this fall.

In a report to the Colorado General Assembly, the Colorado Air Quality Control Commission said: "Clean Screening vehicles on the basis of their remote sensing measurements appears to be an effective way to reduce the costs and inconvenience of an inspection and maintenance (I/M) program. If clean screening's potential is validated through an established program, there could be the possibility of implementation into the rest of the I/M program area."

Due to the encouraging results of the Smart Sign study, the University of Denver is exploring several options:

1. Seeking funding to keep the Smart Sign and remote sensor operating at the current site for another winter season

2. Putting the sign on a trailer to make it portable, allowing the university to conduct an emissions education/awareness campaign in other parts of Colorado and the United States

3. Moving the sign to another site that has a high-emissions history to collect additional data and raise awareness for a different set of drivers.

"The cost/benefit analysis in our study shows that an automated site can save thousands of dollars over other approaches," Stedman said. He predicted that the Smart Sign technology may one day become an alternative to existing emissions monitoring stations.

The University of Denver, the oldest independent university in the Rocky Mountain West, enrolls more than 8,700 students in its undergraduate, graduate, professional and certificate programs. The University was founded in 1864 by John Evans while he was governor of the Colorado territory. Earlier he had established Northwestern University in Evanston, 111.

-30-

UNIVERSITY of DENVER

Office of Communications

MEDIA ADVISORY

Contact: Donald Stedman, 871-2580
Su Ryden or Jerome Ryden, 832-4600

SMART SIGN AIDS IN FIGHT FOR CLEANER AIR

AUG. 4, 1997

WHAT: NEWS CONFERENCE to announce the results of the Smart Sign auto emissions monitoring research project. Since May 1996, the Smart Sign in the cloverleaf exit at I-25 and Speer Blvd. has been telling motorists if their auto emissions are GOOD, FAIR or POOR. University of Denver scientists Donald Stedman and Gary Bishop will release study results showing how the Smart Sign performed during the test period.

WHEN: 1 p.m. Tuesday, Aug. 5, 1997

WHERE Cloverleaf at I-25 & Exit 212 (Southbound I-25 to Southbound Speer Blvd.)

NEWS HOOK: Drivers can save money and help clean the air by monitoring their engine performance between inspections. In addition, Smart Sign technology may one day become an alternative to the existing emissions monitoring stations.

VISUAL HOOK: The Smart Sign is an electronic billboard featuring a cartoon car that smiles or frowns as drivers pass, depending on the level of carbon monoxide in their exhaust. The sign also tells motorists if their car's performance is saving or costing them money.

The Smart Sign will be operational during the news conference.

WHO:

- Donald Stedman, professor of chemistry and biochemistry, University of Denver (co-inventor of the Smart Sign)
- Gary Bishop, research engineer/analyst, University of Denver (co-inventor of the Smart Sign)
- Neil Lacey, research implementation specialist, Colorado Department of Transportation
- John Bennitt, Director of Public Relations, Western Division of Conoco

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Office of Communications

ANECDOTES

Contact: Donald Stedman, 871-2580

DRIVERS RELATE THEIR SMART SIGN EXPERIENCES

AUG. 5, 1997

Sarah Brown, 441-3090
Brown went so far as to write a letter to the Rocky Mountain News, describing how her car went from "Good" to "Fair" to "Poor." She went in for immediate maintenance, and the mechanic found several disconnected hoses. She probably saved herself a $1,000 catalyst replacement.

Karen Shatten, 770/254-0283
Shatten was driving a I986 Ford Taurus, which obtained consistently "Good" readings until July 1996, when it started getting "Fair" and "Poor" readings from the Smart Sign. She took no notice until the vehicle died going up Wolf Creek Summit. Repairs and a $300 towing bill restored the "Good" readings and made her wish she had acted sooner.

Jeff Romeo, 654-3380
Romeo owns a 1989 Ford Taurus which always receives a GOOD reading. His 1993 Mazda RX-7 started obtaining POOR readings in 1996 but he waited until 1997 before it needed to go to its scheduled I/M test. It failed miserably and did not pass again until a new catalyst was installed at a cost of $ 1,000! The $1,000 repairs would have been under warranty if he had taken his car in when the failure first was observed by the Smart Sign.

Dorothy Moran, 666-3896
Moran started getting high readings from the Smart Sign on her 1992 Saturn. She took it to the CDPHE test center who told her the oxygen sensor needed replacement. She has been trying to persuade her Saturn dealer that is really the problem ever since.

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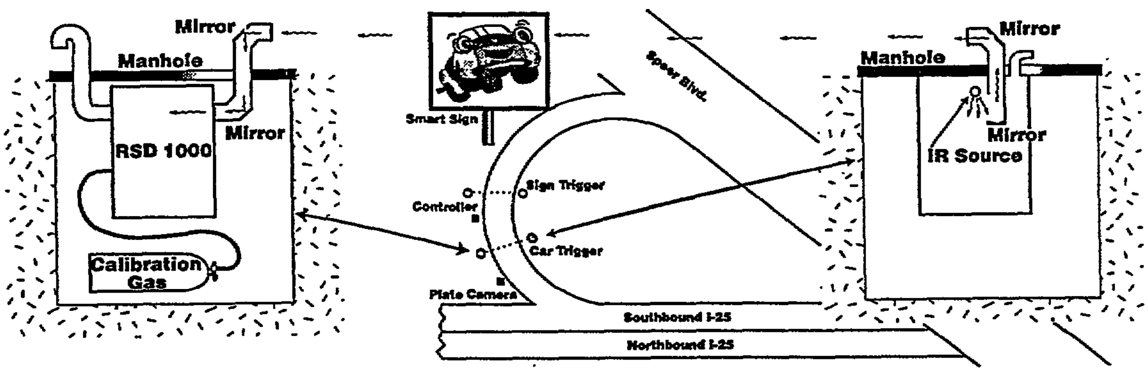
BACKGROUNDER

Contact: Donald Stedman, 87 l-2580

THE SMART SIGN TECHNOLOGY

AUG. 5, 1997



The Smart Sign, produced by Skyline Products, is located at the cloverleaf curve on Exit 212 off I-25 at Speer Blvd. It flashes GOOD, FAIR, or POOR as cars drive past. The sign is triggered by the car blocking an optical beam just as the driver is facing the sign. The Smart Sign readings are based on each vehicle's carbon monoxide emissions measured two seconds previously by means of a remote sensing system. During the test, 86 percent of the cars have received a GOOD rating (less than 1.3 percent carbon monoxide emissions); 10 percent have received a FAIR (less than 4.5 percent carbon monoxide), and 4 percent have received a POOR (more than 4.5 percent carbon monoxide).

The remote sensing system consists of two devices. On the inside of the curve, under a square manhole, is the infrared (heat ray) source. On the outside of the curve, under the round manhole, is an RSD 1000 unit provided by the Remote Sensing Technologies division of Envirotest. The infrared light beam and the first car trigger beam pass across the right-of-way about a foot above the roadway.

A computer in the aluminum controller box analyzes the data and controls the system. Further down the hill, on a utility pole, is the license plate reader. It provides license plate information for Colorado State University scientists to use in their surveys of human factors related to the sign. Colorado State surveyed about 1,000 participants. The license plate reader can read more than 500 plates each day, so the reader was turned on only occasionally after the first week.

-30-

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PROJECT SUMMARY

ITS Operational Test Project: ITS For Voluntary Emissions Reduction

Background

This Project was conceived to assess the potential of ITS to support cleaner air by providing real-time vehicle tailpipe emissions information (carbon monoxide levels) to the driving public. It made an appeal to the driving public to accept responsibility for maintaining their vehicles, to increase gas mileage and minimize harmful tailpipe emissions.

The ITS Operational Test project combined a unique variable message sign (SMART SIGN) with a remote sensing device (RSD). The merging of these technologies into a remote sensing information system (RSIS) made possible, for the first time, provision to the public of real-time tailpipe emissions information from the vehicle they are driving. The purpose of this project was to test the accuracy of the combined system and to evaluate the motorists' perceptions and responses to such a system. This is a unique project because it combined new technologies, provided the potential for dramatically increasing awareness, made an appeal to the minority of gross polluting vehicle motorists to accept responsibility for their dirty cars, and alerted owners of normally low emitting vehicles if an emission system failure had occurred.

How the System Works

An infrared beam crosses the highway right at tailpipe level. When a passing car breaks the beam, the computer knows it's time to take a carbon dioxide reading, it does this by a process known as spectrum absorption. The readings are virtually instantaneous (2 seconds) and the results are flashed on the sign ahead of you. If your CO_2 levels are good - 86% of cars get good ratings - you'll see a "smiley face" on the car graphic on the sign. Cars with fair ratings get an "uh-oh" face; poor rating merit a frown. The latter two also get a text message warning at the bottom of the sign that their cars' performance is costing them money.

Evaluation Objectives - Phase I

1. To determine the efficiency and effectiveness of the integration, implementation, and operation of the various equipment components of the RSIS.
2. To determine if the RSIS delivered accurate tailpipe emissions information to the driving public,
3. To access how the information was received, processed, and responded to by the driving public.
4. To access the extent to which the driving public became educated regarding the need for regular vehicle maintenance.

Evaluation Approach

The evaluation used a hierarchy of response Framework to measure the technical ability of the RSIS in disseminating emissions information and to assess the behavioral response of the driving public to the RSLS.

PROJECT COMPONENTS:

COMPONENT 1: TECHNICAL - Verifying the accuracy of the technical system by addressing:

1) Did the RSIS work (the combination of RSD and VMS technology)?;
2) Were the motorist's emissions being accurately measured and reported?; and
3) Was the correct information displayed to the appropriate motorist? Component I addressed Evaluation Objectives 1 & 2.

COMPONENT 2: BEHAVIORAL - Evaluating the effectiveness of the information sources on motorists' response levels by attempting to answer;

1) Did it influence awareness of emissions levels?
2) Did it influence knowledge of the relationship between emissions, maintenance/repair and fuel economy?
3) Did it influence intentions to respond to the emissions information such as repairing the vehicle? and
4) Did it influence the motorist to actually do anything (action) in response to the sign? Component II addressed Evaluation Objectives 3 & 4.

Evaluation Results - Phase I

A sample of motorists driving by the RSIS at I-25 and Speer Blvd. were interviewed by telephone for the ITS Evaluation Project. The sample analysis was weighted to reflect the actual population passing the sign. The findings indicated that the respondents considered growth followed by air pollution to be the major environmental problems in Denver. The majority of the respondents believed that cars (especially when coupled with growth) were the number one contributor to the air pollution problem. Approximately one-third of these respondents stated that Denver's air quality was improving.

Most of the respondents thought central emissions testing, increased awareness of pollution and better cars were the most frequent reasons for the improvement in Denver's air quality, They thought that the technology of the SMART sign could enhance the existing emissions programs and the SMART sign was a good way to periodically check their cars' performance. If the car's performance reading was not good, they would take their car in for repairs. Over one-half of the motorists interviewed thought it was a valuable tool for motivating people to repair broken cars. Almost two percent (1.6%) of motorists had actually done something in response to the sign (more men than women) and 8% plan to do something in response to the sign. Most respondents had favorable impressions of the sign. They seem to understand the relationship between well maintained cars, good emissions and fuel economy. Almost all agreed that “a well maintained car can reduce air pollution” and that “a well maintained vehicle actually saves money).

A smaller sub-sample of the population was interviewed using in-depth case study techniques to better understand the reasoning behind the responses to the questionnaire. The case study participants expressed an understanding of the link between well-maintained vehicles, air pollution and fuel economy. They were very favorable toward the sign and thought people would use it regularly to check the performance of their cars. Most of the case study participants thought the sign would encourage action to reduce air pollution in Denver.

The case study participants were also asked how much they were tilling to pay to repair their car so that it would fall into the good category. Three-fourths of the case study sample said they would pay $100 dollars or more. The case study sample was also asked for possible solutions to the air pollution problem. The need for mass transit was the overwhelming response, however, the use of the RSIS in combination with the Central Emissions Testing, if improved, was seen as the best way to control air pollution from automobiles.

Seventy percent of the case studies (14) felt that the Smart Sign could stimulate action among the driving public. Over half of those in the poor category found the sign interesting-and were in favor of it. Two of these thought at it might be a good replacement for the central emissions test while one thought it might serve as an appropriate prelude to the emissions test. Others thought that the sign might encourage some people to fix their cars. Of those with good emissions readings, most said they would fix their car if they received a reading other than good. They also felt that the sign would encourage some people to take action. One person thought that there should be more signs to make people aware of their car’s condition and remarked how simple the device is in comparison to going to the “emissions testing place”. . Another person was disappointed to hear that the sign would be taken down. All of the people who received both a good and fair reading made favorable comments regarding the sign. Both of the people who had both a good and poor reading believed that the sign would create action. The interviewee who had received all three readings was skeptical of the technology and did not do anything as a result of the sign. He thought it might be effective for some people. In general, the sign was found to be very favorable by both the telephone sample and the case study sample,

Accomplishment of Objectives:

Component I addressed the questions:

1. Did the RSIS work (the combination of the RDS and the VMS technology)? The data recorded by the data logger from the OTC analyzer showed do indications that the combination of the RSIS technology did not work other than under conditions such as ram or snow, accidents, equipment failure or unforeseen events.

2. Were the motorists' emission being accurately measured and reported? The data from the OTC analyzer suggests no malfunctions in the sign's ability to report the correct category of vehicle CO emissions: GOOD, FAIR, or POOR. Fluctuations of plus or minus 3% should be expected.

3. Was the correct information displayed to the appropriate motorist7 The RSIS was capable of displaying the appropriate readings to the appropriate motorist. Only 1% of the respondents from a sample of 474 felt they weren't getting the right information. The software is written in such a way that a vehicle close behind you invalidates your signal which is not displayed, instead displaying for the rear vehicle. When trucks and trailers lead a pack of vehicles, it is possible for the sign time to become confused. The confusion is reset with the next 8 second gap. We estimate that this causes incorrect readings for less than 0.7% of the vehicles.

Component II addressed the questions:

1. "Did the sign influence awareness of emissions levels?" The data indicates that the sample stratum with good emissions readings has a greater awareness of their emissions levels as indicated by the high percentage of recall of the last reading reported by the sign. In general, the motorists in the good stratum had driven past the past sign more times and recalled their readings better than those in either the poor or fair stratum. We did not reach our target population, the poor stratum, as well as we would have liked. However, approximately 2/3 of the weighted population thought the sign was informative.

2. "Did the sign influence knowledge of the relationship between emissions, maintenance/repair and fuel economy?" The data indicated that most of the motorists understand this relationship. Ninety-nine percent of the motorists believe that maintenance is important and most maintain their cars at regular intervals. Ninety-five percent thought that a well maintained car saves money.

3. "Did the sign influence intentions to respond to the emission information in ways such as repairing the vehicle?" The data indicates that 8% of the motorists plan to do something in response to the sign, more in the poor stratum (31%) plan to do something as compared with the other strata. The poor stratum was almost twice as likely to respond to the system as those in the fair stratum (1 6%) and five times as likely as those in the good stratum (6%). Most plan to have their car maintained, or at least checked. This is a good indication the stratum most in need of information from the sign is the one most likely to respond.

4. “ Did the sign influence the motorists to actually do anything (action) in response to the sign?” The data indicate that the RSIS has had some influence an the motorists to actually fix or repair their car. Approximately two percent of the weighted population (1.6% of the overall fleet*) report having already taken some action. This is a good indication that the system is having some influence on the motorists to actually do something to their car. Since the sign has delivered three million readings to about 232,000 unique vehicles, to the extent that the 1.6% can be extrapolated to the whale measured population, more than 4,400 voluntary repairs can be predicted.

*The 3% repair fraction from the sampled population was recalculated to normalize from the sampled fleet (43% good, 43% fair, and 14% poor) to the total overall fleet (86% good, 10% fair, and 4% poor, i.e. weighted sample). The total number of unique vehicles sampled from the 3,000,000 measurements was obtained from the survey results. The 474 telephone survey participants reported that they were responsible for about 5,300 readings. From these data we predict that there have been 3,000,000 x 474/5300 = 232,000 unique vehicles passing the RSIS.

Phase II

The Phase I recommendations included conducting focus groups especially among the poor and fair groups to enhance the responses from the target ‘sample’ population.

The primary purpose of the focus groups described in this report was to gain more of an in-depth understanding of driver perceptions of the sign and its motivational properties. Of particular interest were drivers who received “poor” ratings from the sign, and those who received more than one rating (i.e. “flippers). In the survey sampling, those who received “poor" ratings were under-represented due to higher than average refusal rate. Because their response to the sign was positive, even in terms of reported behavior to fix their cars, it was felt to be important to gain convergent validity with regard to attitudes and behavior resulting from exposure to the sign. Content issues of importance besides sign information were focused on the brochure and hotline. Survey responses indicated few drivers had accessed or been exposed to either. Finally, physical issues such as sign placement and readability were of interest as factors that enhanced or detracted from the sign’s effectiveness.

RECOMMENDATIONS

Throughout the conversations, participants provided a variety of recommendations regarding how to improve the program. It is important to realize that their overall **reaction** to the program was very positive, especially once they understood it and became aware of the different components. The information was seen as useful, particularly as a “signal” or a pretest before going to central emissions. The voluntary component was very positively received. The positive results from the “poor” group found in the telephone Survey evaluation were supported. “Poors” do care and report a willingness to take action.

But, participants viewed their mission in the groups as providing a critical analysis that might lead to program improvements. As such, they provided a number of thoughtful recommendations:

- Logistics
  - ◊ Location of sign should be in less congested area. Allows for more concentration and greater assurance the reading is connected to the right car.
  - ◊ Location of sign on the curve is too far forward toward merging traffic.
  - ◊ Hotline phone number is a problem because it is even closer to merging traffic.
  - ◊ There needs to be some kind of message before the SMART sign preparing people to read it.

- Style
  - ◊ Messages should be personalized.
  - ◊ Mixed recommendations on the value of positive vs. negative tone and incentives. One recommendation by the female group was to "‘publish the polluters." Everyone agrees positive is good. No consensus on the value of negative.

- Credibility
  - ◊ Viewed as the single most important characteristic of the program.
  - ◊ Trust is vital to message acceptance and action.
  - ◊ Government and university sponsors are credible. Private sector sponsors can also be credible, but in combination with others.
  - ◊ Message consistency increases credibility.

- Information
  - ◊ Clarify what good, fair, and poor means and what is measured, Maybe the introduction of a scale to show relativity of reading.
  - ◊ Educate with regard to who, why, and what the program is about.
  - ◊ Clarify purpose, "Health" should be dropped and replaced with "‘emissions".
  - ◊ More specific and direct messages, including numbers,
  - ◊ Radio was perceived to be a potentially useful way to provide additional information.

- Incentives
  - ◊ Development of grants program for low income drivers.
  - ◊ Coupons provided by private sector.
  - ◊ Hotline phone number is a problem because it is even closer to merging traffic.
  - ◊ There needs to be some kind of message before the SMART sign preparing people to read it.
  - ◊ Mixed recommendations on the value of positive vs. negative tone and incentives, One recommendation by the female group was to "publish the

polluters." Everyone agrees positive is good. No consensus on the value of negative.

DIRECTIONS: From downtown Denver: Go north on Speer and take I-25 southbound (right turn onto cloverleaf), then immediately exit to southbound Speer (Exit 212A) and pull off to the left.

From southbound I-25: Exit to southbound Speer (Exit 212A) and pull off to the left.

From northbound I-25: Exit to northbound Speer (Exit 2 12B) , then take I-25 southbound (right turn onto cloverleaf), and immediately exit to southbound Speer (Exit 212A) and pull off to the left.

From southbound Speer: Take I-25 southbound and pull off on the left side of the entrance ramp. You don’t have to cross the road to see the sign, but you must turn around and shoot through a screen of trees. This is the safest location.