

Fuel Efficiency Automobile Test

Quality Assurance Narrative

Standard Operating Procedures

Help Notes

Roadside Check List

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QUALITY ASSURANCE NARRATIVE

Quality Assurance protocol

The complete remote sensing system as normally configured consists of four components namely:

- 1) IR/UV light source
- 2) Detector unit fiber optically coupled to monochromator
- 3) Computer
- 4) Video system

Daily QA checks are performed on each system, and on any generators which are sometimes used to provide power for the systems. If using generator power, all generators are checked to ensure that operating voltage under load is between 105 and 125 volts using a digital volt meter. Voltages outside this range are corrected according to the generator manual.

The system is set beside the road with proper permission from the local highway authorities and with proper protection, using orange plastic road cones. The IR source is set up and turned on. Turn on UV after IR is hot and operating. If UV does not come on the voltage is usually too low. The light from the filament is checked visually. The SiC filament is subject to burnout and several replacements are always kept on hand. The source is aimed at the entrance to the detector using the leveling screws. The beam altitude at the center of the road is set between 6 and 20 inches.

All cables are color-coded to the correct terminals on the data acquisition system and detector. All data cables have BNC termination at both ends. The video cables are color-coded clear for ease of connection.

The detector unit is set up similarly to the IR/UV source, with the body aimed at the source telescope. The HC/CO units require approximately three minutes to fully warm up the electronics. The computer is booted by turning it on. It is normally set to automatically boot the program required for the application. The software used is copyrighted in the name of the University of Denver. When the program boots, it automatically asks the user for file designators for the location and type of measurement. These file designators automatically include the date and time, and thus are saved separately for future analysis.

The voltages observed at the test points from the six detectors are optimized by minor adjustments of the across-road alignment. The zero voltage on the CO₂ channel (color-coded blue for CO₂ throughout) is checked by blocking the IR beam, and adjusted if necessary to 0.5 ± 0.2 volts. This voltage is out of specifications if it drifts below zero volts. If such drift is sensed by the computer, the system shuts down and a message to check the CO₂ zero is placed on the screen. If the zero drifts upward, this is not important unless the signal plus zero exceeds 9.5 volts. In this case the

system also ceases on-road measurement and the appropriate error message is generated. Similar voltages are required on CO, CO₂, reference and HC channels. The zero levels for CO, HC, Ref and CO₂ are all read by manually blocking the beam and using a volt meter applied to the appropriate color-coded test ports. (Red, Reference: Blue, CO₂: White, CO: and Yellow, HC). If outside the range between 0.3 and 0.7 volts, the zeros must be set closer to half a volt using the appropriately labeled potentiometer inside the back cover.

UV is aligned after IR by visually placing the UV spot over the fiber tip. The computer menu is set on 3) "Reset/Re-cal Spectrometer" and the operator follows instructions on the monochromator readout.

The video camera is turned on according to the manufacturer's specifications, and set to 1/1000 second exposure, manual focus. If extra lighting is required, spotlights are mounted on their tripod close to the video camera.

There are three QA checks to be performed as soon as the system is set up:

- 1) Error routine check...Block the beam with a hand or other opaque object when a vehicle is not present. This will generate an "X X X X" (all channels invalid) code on the CO/HC/NO units). If not, re-boot system.
- 2) Zero check...Block the beam with an opaque object, and on unblocking the beam when no cars are in the area, exhale into it during the next half second. Since human beings operate according to the same combustion process as automobiles, a non-smoking human adds CO₂ to the beam without CO. Depending on the skill of the operator in conducting this exercise either an X error code, or a reading of a clean car will be registered. This clean car reading must be between $\pm 1\%$ CO of 0%CO and less than 0.2 %HC and %NO. These readings are noted in the operator's note book for that day's runs. If the zero readings are outside the error bounds above, then there is a persistent and variable plume of exhaust crossing the road at that site, and another site or another time must be chosen such that the interfering plume is not present. If the plume is from one of the FEAT generators, then generator placement needs to be changed. Valid data cannot be obtained when this check is out of specification.
- 3) Span...The measurement computer screen offers two utilities, exit (with automatic save), and calibrate. Calibrate consists of an instrument span check followed by manual entry of new calibration factors if appropriate. The system span is carried out with a certified cylinder containing a known, and manufacturer certified content of CO, CO₂, propane and NO. The cylinder is connected to the calibration solenoid valve, and a pressure of 20 ± 5 psi is introduced into the line. A small rectangular "calibration flute" is added to the front of the instrument and held on with a small Velcro tag. On depressing the calibration command, the system takes its own zero and span voltage readings from the next passing car, but it waits for a command from the computer before looking for the half-second of exhaust. When the operator sees that there are no more vehicles about to break the beam, hitting any key on the computer releases a puff of calibration gas. After the line has purged from any previous calibration gas that has been used, the readings should settle

down to a predetermined ± 1 %CO range, dependent on the site and the sensor/source separation (10 to 40 ft. possible). At the longer distances the opacity of the atmospheric CO₂ causes the observed vehicle emission readings to be higher than for shorter distances. The correction factor for the site is determined by the calibration at the site, done during the initial set up and noted in the operating note book. The data from all calibrations are automatically saved in a separate file, and the final results are also noted in the note book. NOTE that the FEAT system measures ratios of the various pollutants, not their absolute values. From the measured ratios the computer calculates the appropriate solution to the combustion equation which generates the observed ratios. If the cylinder contents are not a valid solution to the combustion equation for gasoline, then the ratios will be used to determine the correct solution. If a FEAT system is calibrated in the laboratory with a cylinder containing 10% each of CO and CO₂ and 1% propane, 0.5 %NO then if no site correction is needed the unit would report 8.67 %CO, 8.67 %CO₂, 0.87 %HC and 0.44 %NO. These readings have the same ratios as the cylinder contents but are a possible solution to the combustion equation.

If it is apparent while carrying out these tests that the video system is not adequately imaging the license plates, then the operator needs to adjust the aim, zoom, and iris according to the manufacturer's instructions to obtain the best possible pictures.

After the above checks have been carried out, the VCR is turned on, a tape labeled for the time and place is inserted and the recorder started. The VCR and monitor are both observing the S-VHS signal directly.

For initial setup at a given location, and after each day of measurements, the instrument is zeroed and spanned from the computer using the span gas in a certified cylinder of known value of Q (CO/CO₂), Q' (HC/CO₂) and Q'' (NO/CO₂). A linear calibration correction factor is derived from the observed calibration and zero readings. Readings from passing vehicles are directly compared to the span gas readings through this calibration factor and the laboratory developed curves which are built into the software. Calibration correction factors may be entered directly in the software after the morning calibration. This way the video will display calibration corrected data. Later calibrations will show lines which do not go through the data, but rather are offset by the calibration factors which default to 1.0. Data files which have been calibration corrected show the correction factors in the first data line.

Data collected on the hard disk are backed up onto an appropriately labeled floppy disk at the end of each day of operation. Data are automatically saved every 25 vehicles, so if the program is not exited correctly, or if there is a power or system failure, no more data than for 25 vehicles are lost.

A set of standard operation procedures (SOPs) is attached here as a component part of the Q/A narrative. A standard form to fill out for every location, and every day when remote sensing is undertaken is also enclosed at the end of the SOP narrative. The form has been reviewed by the SAE In-use Emissions monitoring committee. Appendices show typical data formats from a complete analysis including plate reading and DMV matching.

FEAT STANDARD OPERATING PROCEDURES

The complete remote sensing system as normally configured consists of four components namely:

- 1) IR/UV light source
- 2) Detector unit fiber optically coupled to monochromator
- 3) Computer
- 4) Video system

The data acquisition daughter board is wired to the computer through a ribbon cable. When calibrations are undertaken a calibrator box is wired to the computer through a nine pin connector. The calibrator box is wired to the 110 volt outlet and the solenoid valve on the flute is powered from the relay-controlled outlet on the box.

See Figure 1 for the wiring diagram. Daily QA checks are performed on each system, and on any generators which are sometimes used to provide power for the systems.

If using generator power, all generators are checked for proper levels of oil and fuel and to ensure that operating voltage under load is between 110 and 125 volts using a digital volt meter. Voltages outside this range are corrected according to the generator manual.

The IR source is set up and turned on. The light from the filament is checked visually. The SiC filament is subject to burnout and several replacements are always kept on hand. The source is aimed at the detector using the leg length adjustment for major alterations and the leveling screws for final alignment. The source height is set beside the road with proper permission from the local highway authorities and with proper protection, using orange plastic road cones. The beam altitude at the center of the road is set between 6 and 20 inches. For details see the alignment section of "help notes" component of this document. The UV source is turned on after the IR source has warmed up.

All cables are color-coded to the correct terminals on the data acquisition system and detector. The video cables are also color coded clear and are in some cases distinguished by the fact that they use video termination at one end, whereas the detector cables are BNC at both ends.

The detector unit is set up similarly to the IR/UV source. See help notes for details. The power supply is plugged in and the detector unit turned on. The analog voltages observed from four detectors are optimized by minor adjustments of the across-road alignment. The video camera is turned on according to the manufacturer's specifications, and set to 1/1000 second exposure, auto white balance, auto iris, auto S-VHS and manual focus. If extra lighting is required, the spotlights are mounted on their tripod close to the video camera.

The computer is booted by turning it on. It is normally set to automatically boot the program required for the application. The software used is copyrighted in the name of the University of Denver. When the program boots, it automatically asks the user for file designators for the location and type of measurement. These file designators automatically include the date and time, and thus are saved separately for future analysis.

There are three QA checks to be performed as soon as the system is set up:

- 1) Error routine check...Block and unblock the beam when a vehicle is not present. This generates a *,*,*,* video readout and invalid "X" flags in the data system. If not, re-boot system.
- 2) Zero check...Block the beam with an opaque object, and on unblocking the beam when no cars are in the area, exhale into it during the next half second. Since human beings operate according to the same combustion equations as automobiles, a non-smoking human adds CO₂ to the beam without CO. Depending on the skill of the operator in conducting this exercise either a * error code, or a reading of a clean car will be registered. This clean car reading must be within 1%CO of 0%CO. These readings are noted in the operators notebook for that day's runs. If the zero readings are outside the error bounds above, then there is a persistent and variable plume of CO crossing the road at that site, and another site or another time must be chosen, or a generator relocated such that the interfering plume is not present. Valid data cannot be obtained when this check is out of specification.
- 3) Span...The computer screen offers two utilities, exit (with automatic save) and calibrate. For details on calibration and arithmetic see the help notes calibration section. The data from all calibrations are saved in separate files, and the final results are also noted in the note book.

If it is apparent while carrying out these tests that the video system is not adequately imaging the license plates, then the operator needs to adjust the aim, zoom, and iris according to the manufacturer's instructions to obtain the best possible pictures.

After the above checks have been carried out, the VCR is turned on, a tape labeled for the time and place is inserted and the recorder started. To check that the recorder is receiving a good signal, the monitor is switched from RGB (the incoming signal) to line A, B or Y/C (the video signal) as it is being recorded. For systems with S-Video (Y/C) hookups the monitor is directly recording the output from the VCR and the above check is not necessary.

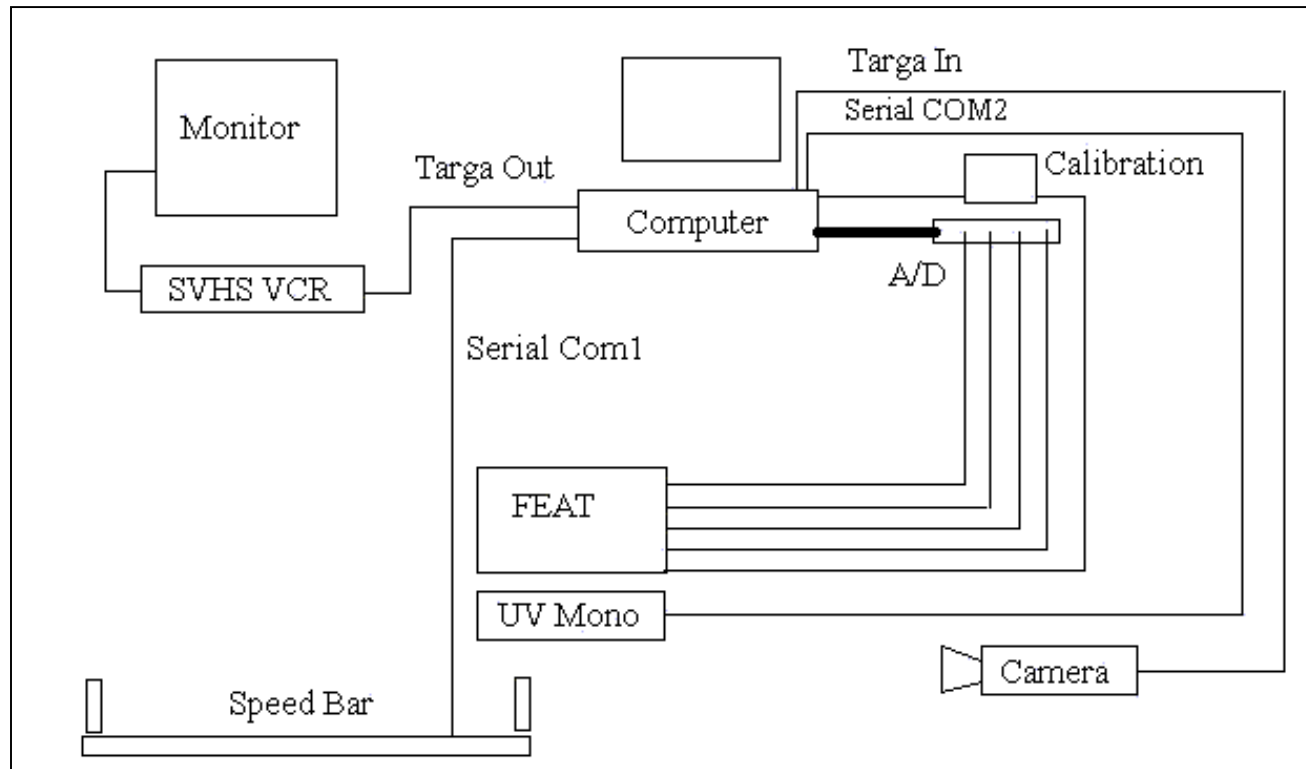
For initial setup at a given location, and after each day of measurements, the instrument is zeroed and spanned from the computer using a single span gas in a certified cylinder of known values of Q, Q' and Q". A linear calibration correction factor is derived from the observed calibration and zero readings. Ratio readings from passing vehicles are directly compared to the span gas readings through the calibration factor.

Data are usually collected on the hard disk. These data are backed up manually onto an

appropriately labeled floppy disk at the end of each day of operation. It is appropriate to note that the data are automatically saved every 25 vehicles, so if the program is not exited correctly, or if there is a power or system failure, no more data are lost than for 24 vehicles.

Users should note that the FEAT 3001 through 3008 series do not give correct HC readings in the presence of exhaust plumes containing liquid water (often referred to as "steam"). This fact arises because as well as scattering all wavelengths (taken into account by the reference channel), the liquid water has a specific absorption at the wavelength used to analyze HC (3.4 microns), thus very high HC readings can result. The accuracy of the CO readings is not significantly effected. "Steam" plumes can easily be observed on the video images and the data eliminated during the license plate reading step. We anticipate that newer versions will have hardware and software to eliminates this effect.

FEAT Help Notes



Setup: With the instrument and source setup opposite one another, the above drawing gives the wiring diagram. All of the wires to the left of the computer are coming out of the TARGA video board port which is labeled **OUT**. The only line going into the TARGA board is from the camera. The Sony monitor has the ability to select the RGB input or LINE A/B inputs. When you switch between inputs a different type of SYNC signal is needed. This change is accomplished by toggling the EXT. SYNC button on the front.

The cable from the A/D must be firmly latched into the keyed plug at the back of the computer. The wires between the external box and FEAT are color coded, along with the box and FEAT plugs, Red to Red etc... The instrument BNCs are color coded by the corresponding test plug which is directly opposite each BNC. They are in order from top to bottom, Red – Reference, Yellow – HC, Blue - CO₂, and White – CO.

The **ALPHA** output line from the TARGA board is plugged into the **VIDEO IN** jack found at the back of the VCR. This allows the picture to be recorded to tape. For feedback and information on the picture quality it is highly recommended that the **VIDEO OUT** plug located next to the input be cabled back to the Sony monitor using line A. When line A is selected on the monitor you will be able to view exactly what the VCR is recording. If you don't get a picture a common problem is that the VCR input selection has been switched

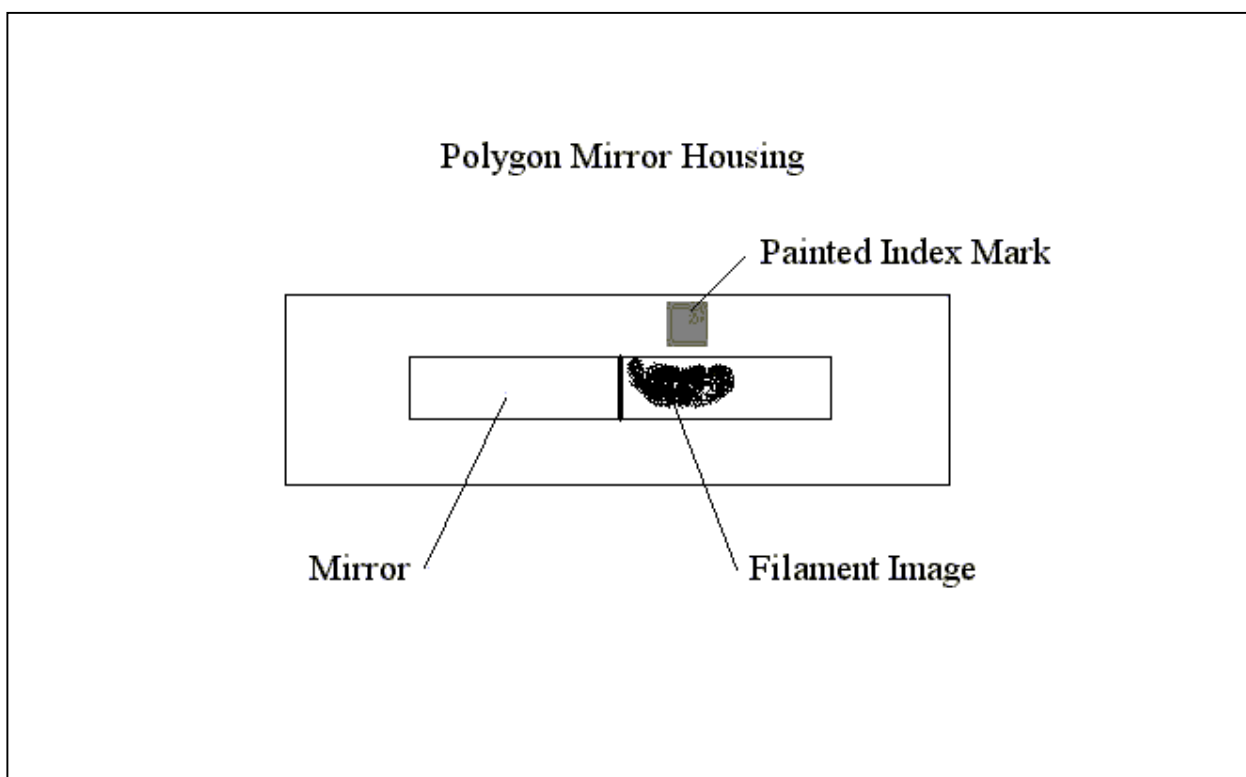
from the Video plugs to the tuner etc.. (Check the manuals, on the Panasonic VCR the inputs are labeled **line** on the JVC they are labeled **AUX**). A sample S-VHS tape has been put inside the camera case. These tapes have been costing us ~\$7.00 U.S. in case quantities (20 tapes). We recommend these tapes over regular VHS because of the improved resolution, about 45% more. We also recommend only recording the tapes in the SP mode (2 hour/tape) this also improves resolution. **NOTE: The computer will prompt you to start recording a tape, it will not prompt at the end of the record period to change the tape.** If you have any clever idea's on how to do this let us know!

The camera is powered using an external power supply which also provides the video hook-up. The **clear** labeled cable is the video cable (100 ft.) which has a different ohm rating than the signal cables. Turn on the camera and select a shutter speed of at longest 1/500th of a second. The value will flash on and off within the view finder. We typically set our system to manual focus, auto iris, auto white balance and auto S-VHS select. Be sure to use a tripod which allows the legs to be adjusted out to provide a sufficient base to keep the camera from being blown over. We use a Bogen professional tripod #3036 which sells for around \$250 (remember it is a \$1400 camera, so don't short change yourself with a cheap tripod).

Use of an optical device for speed and acceleration is an optional feature. The speed bars are connected to the computer through a serial port. Note that speed and accelerations are only displayed when a successful block and vehicle measurement is completed.

The copyrighted programs supplied are named **FEATU45*** and **FTGRAPH*** (the * signifies an alphanumeric A,B,C..., which should match the detector unit number 1,2,3...) and they are located in the directory FEAT. It should be stressed that the software is matched to each instrument and is therefore not interchangeable. The program **FEATU45***, which is the on-the-road program, will automatically load and run with the current **autoexec.bat** file provided. **FTGRAPH*** is a program which is very similar to **FEATU45*** except it allows access through graphics to most of the data from the individual measurements. It has been included to aid in possible diagnosis of problems and to allow the user to view the data. **FTGRAPH*** is not a finished program and is provided as is, bugs and all, for your use. The **SHIFT-C** command is operational in most versions of **FTGRGAPH*** and can be used to store raw data.

Power failures will usually result in some data loss, however, the software carries out an automatic save every 25 vehicles. At the most 24 measurements can be lost. Upon exit of the software (Shift-X) any remaining measurements will be saved. **Please be sure to back up all data, programs and setup files to floppy disks as transportation of hard disks is a risky business.** Our systems have been dropped by airline baggage handlers leaving nice dents in the sides of the computer case forcing the hard disk to be reformatted and therefore losing any information that they contained.



ALIGNMENT: Before attempting alignment, all of the cables should be connected prior to powering up the instruments and computers. The FEAT instrument will need **5 minutes** of running to guarantee signal levels. You will want to position the infrared beam at around 10" off of the road surface, this position is not critical. From the source side of the highway, position the source such that when sighting along the edge of the tube you will be able to see the glow on the reflective tape on the front of the detector unit. Fine adjustment of the source has to be confirmed from the detector side of the setup. This entails visual confirmation that the source filament is centered, vertically and horizontally, in the plane of the detector receiving mirror. From the FEAT side of the highway align the instrument until you achieve maximum voltage on the **YELLOW** (HC) channel. An analog 0-10v voltmeter is useful here. Confirmation of a positive alignment can also be achieved by viewing through a small hole next to the mirror at the back of the unit. This allows a direct view of the rotating mirror inside. You should see a glowing filament positioned on the upper part of the mirror (See diagram). The instrument should deliver 7+ volts on ref, CO and HC at a distance of 15 - 20ft and around 4 volts at 40+ feet separation. The CO₂ voltage will vary with location, distance, altitude etc.

After having achieved maximum voltages on the Yellow test plug you will now need to make sure that similar voltages are found on the **RED** test plug and the **WHITE** test plug. Usually these will be very close, but often the white plug will be lower than the red channel. Balance the voltages between the two channels at the highest possible level. The adjustment needed here is a slight side to side angle adjustment if any. At this point the only requirement for operation is that the **RED CHANNEL MUST BE ABOVE 4**

VOLTS TO OPERATE. If the level is below this the computer will alert you to this fact but only after a one or two minute delay. Some simple tests which can be performed are 1) blocking and unblocking the beam, this should generate invalid data on all channels because of the lack of any CO₂; 2) blocking and unblocking the beam while exhaling into the beam path, this should provide the instrument with a sufficient amount of CO₂ to perform a measurement with the result being a clean car (CO values < 1%).

The audio voltmeter is provided to aid in the alignment procedure. Use it to align the IR then plug it into the UV monochromator and go back across the road a repeat the alignment to optimize the UV signal. This last step is **ABSOLUTELY ESSENTIAL** if the NO data are to be of any value at all. Careful alignment of the UV, **AFTER** IR alignment is **REQUIRED**. When in the “reset/recal mode follow instructions on the monochromator output panel.

CALIBRATION: Hook up the calibration control box by attaching the computer cable to the 9-pin serial plug located at the back of the computer (labeled Cal Plug), plug the box into an 110v outlet and connect the box to the solenoid with a 110v power cable. Hook the gas cylinder to the solenoid Swagelok fitting, set regulated output pressure to around 15-25 psi. Bleed line for 10 seconds via the manual switch on the box and then set switch to computer control. Activate Cal sequence from the computer keyboard by pressing **SHIFT-C** and waiting for the beam to be blocked after which the cal gas will be released by pressing any key. Metal connecting tubing is best if NO calibrations are desired or failing that use as short a piece of plastic tubing as possible and remember to flush the gas through it to eliminate air from reacting with the NO. It takes more puffs to get useful NO cals than CO or HC.

A careful calibration sequence will include a pause after flushing the line for the expelled gas to disperse before starting the sequence. Calibrations should all be carried out under similar measurement conditions, however, isolated vehicles allow for the most consistent calibration conditions. Once a vehicle breaks the beam and starts a cal sequence, ideally one will pause several seconds before releasing the gas. This requires clear roadway. Repeat as deemed necessary (5 -10 times per day, before/after etc. until consistent results are observed). Inconsistent calibrations are usually the result of mixing vehicle plumes with the gas from the cylinder and can be eliminated by allowing more time before and after passing vehicles. Mental notes on the data scatter should be made in order to spot any potential alignment difficulties. Most notable would be loops in the straight line calibration plots which signal a difference between two of the detector's lines of sight. Serious looping and realignment of the pickup mirrors is required. This is not an operation which can be performed in the field.

If any intercomparisons are to be performed between the FEAT instrument and another analyzer please take care to use a common calibration cylinder. Significant differences can exist between cylinders even from the same manufacturer. Also note that all intercomparison of FEAT data with any other data source should be performed on the

pollutant ratios to CO₂ not to the reported % readings. This is important because air pumps and exhaust air leaks can lower the readings from all conventional analysis systems but do not effect the measured FEAT ratios.

TROUBLE SHOOTING

PROBLEM	CAUSES
FEAT works but picture blurred	High speed shutter not set on camera, if camera ever loses power all functions reset to the defaults. We use manual focus, auto white balance, auto iris, 1/500 or 1/1000 shutter depending on lighting.
No picture on monitor	Bad connection between camera and TARGA, TARGA & monitor. Ext. sync not properly connected or button on monitor is in wrong position. TARGA plugs reversed at rear panel of computer (OUT plugged into IN).
ERROR "TARGA board not found"	TARGA board has been jarred out of its edge connector after transportation. Open up computer case and remove/clean (with a pencil eraser) the TARGA edge connector and reseat the board. Also a symptom of a "sick" TARGA board.
FEAT works but VCR not recording	Make sure VCR input selector is in the proper position and the ALPHA output cable is connected for proper monitoring of input signal. Check by observing line A on the monitor. NOTE: the JVC VCRs reset all functions to the default values on power off!
Low voltage error	Too much CO ₂ , too long a path (needs to be less than 50ft probably) or possibly zero setting of a detector has moved and needs to be reset. Polygon mirror not spinning. Check all voltage levels with the light blocked, they should all be set around 0.5 volts. Controller card may be loose in its edge connector. Source burned out, or out of alignment (this can happen if installed on frozen ground and during the day the ground thaws and the legs sink).
High voltage error	Too much signal or too short a path. Also possible with noisy 110v generators which will produce signal spikes.
Noisy calibration data	Possible overheating of detectors (It has been estimated that 100°F is the maximum operating

temperature). Check the temperature LED located inside the rear of the case. If the red LED is on, the unit is overheated, green LED is acceptable.

Intermittent operation

This is characterized by the system not reading cars as they pass, or making invalid measurements when there are no cars present. If the FEAT unit is being operated at voltages very close to the 4 volt lower limit this situation can exist without any error messages. The 4 volt limit is a magic number for the software for determining beam blocks. If the signal levels are hovering around this edge it will cycle the instrument in and out of the blocked/no block/make a measurement mode. Try and shorten the operating distance or improve the alignment.

Computer will not boot

Cold temperatures can cause this to happen. We have used these systems down to -10°F, however below ~40°F the computer will have to be turned on for approximately 10 - 20 minutes before the hard disk will be at an acceptable operating temperature. Turn it on and let it sit and then using the reset button repeat the boot process. Also disk failure, loose cable connector or loose controller card.

Date/Time missing from video picture

The TARGA board requires some setup information to be supplied upon power on. This information has been installed on the hard disk and is included in the autoexec.bat file located in the root directory. If this file is altered, erased or by-passed by booting the computer from a floppy disk the board's screen resolution will not be initialized properly and thus information will be pushed off the edges of the display monitor. Re-boot the system with the proper setup files. A similar situation occurs when the S-VHS selector button on the camera has been switched from auto to normal. Return the selector to the auto position.

Negative %CO₂ readings

A/D converter has reassigned the voltage channels. This is known to be caused by voltage spikes and/or plugging the A/D daughter board into the computer **after** the computer has been powered up. To fix turn the computer POWER OFF and then repower it to

reset the converter channels. This fault is thought to have been eliminated in software installed after Feb 1992.

FEAT FILE FORMATS

DIRECTORY NAMES: Created using 4 character user supplied prefix and the current date, i.e. DUFT1026.90.

DATA FILES: ASCII text file stored under user supplied name

Line 1 : **Comment**, up to 80 characters in length

Line 2 : Program settings

Video_on, denotes whether video was used

(integer, 1=in use, 0=not in use)

MPH_on, denotes whether the speed bars were used

(integer, 1=in use, 0=not in use)

Adjust_flag, denotes whether % values were adjusted

(integer, 1=adjustments applied, 0=no adjustments)

CO_value, if adjust_flag=1 this is the CO/CO₂ adjustment observed ratios are divided by this factor before calculation, default value is 1.

(real, value or zero if not used)

HC_value, if adjust_flag=1 this is the HC/CO₂ adjustment observed ratios are divided by this factor before calculation, default value is 1.

(real, value or zero if not used)

NO_value, if adjust_flag=1 this is the NO/CO₂ adjustment observed ratios are divided by this factor before calculation, default value is 1.

(real, value or zero if not used)

Serial #, Instrument serial number with which the software has been internally linked with. Mixing of the software with other instruments will produce uncertain results.

Line 3 : Data (remainder of file will be data lines, all fields are delimited by spaces)

Date, Date of measurement

(character string in the form MM\DD\YYYY)

Time, Time of measurement

(character string in the form HH:MM:SS)

%CO, Percent Carbon Monoxide

(real, zero if invalid data)

CO_err, +/- error on the %CO measurement

(real, zero if invalid data)

%CO₂, Percent Carbon Dioxide

(real, zero if invalid data)

CO₂_err, +/- error on the %CO₂ measurement

(real, zero if invalid data)

%HC, Percent Hydrocarbon in propane equivalents

(real, zero if invalid data)

HC_err, +/- error on the %HC measurement
 (real, zero if invalid data)
%NO, Percent Nitrogen Oxide
 (real, zero if invalid data)
NO_err, +/- error on the %NO measurement
 (real, zero if invalid data)
%Opacity, Percent light extinction at 4 microns
 (real, zero if invalid data)
Opacity_err, +/- error on the %Opacity measurement
 (real, zero if invalid data)
Restart_cnt, Number of beam blocks before successful measurement
 1 or more for high vehicles
 (integer, seldom used number left over from development)
CO_flag, Data valid flag for the %CO value
 (character, V=valid data, X=invalid data)
CO₂_flag, Data valid flag for the %CO₂ value
 (character, V=valid data, X=invalid data)
HC_flag, Data valid flag for the %HC value
 (character, V=valid data, X=invalid data)
NO_flag, Data valid flag for the %NO value
 (character, V=valid data, X=invalid data)
Opacity_flag, Data valid flag for the %Opacity value
 (character, V=valid data, X=invalid data)

If you are using the "light speed" system the variable MPH_on will equal 0 and this additional data will be added.

Spd_flag, Data valid flag for the average vehicle Speed and Acceleration
 (character, V=valid data, X=invalid data)
Speed, Average Speed measurement in MPH
 (real, zero if invalid data or speed < 8 MPH)
Accel, Acceleration measurement in MPH/second
 (real, zero if invalid data)

FACTOR1, Reference channel normalization voltage
 (real)
FACTOR3, CO₂ channel normalization voltage
 (real)

CALIBRATION FILE:

ASCII text, file name is 'HHMMSS.CAL', All fields are delimited by spaces.

Line 1: **Date**, Date of calibration

(character string in the form MM\DD\YYYY)

Time, Time of calibration

(character string in the form HH:MM:SS)

Line 2: Program settings

Adjust_flag, denotes whether % values were adjusted

(integer, 1=adjustments applied, 0=no adjustments) NOTE: A proper calibration requires this value to be zero.

CO_value, if adjust_flag=1 this is the CO/CO₂ adjustment

(real, value or zero if not used)

HC_value, if adjust_flag=1 this is the HC/CO₂ adjustment

(real, value or zero if not used)

NO_value, if adjust_flag=1 this is the NO/CO₂ adjustment

(real, value or zero if not used)

Serial #, Instrument serial number with which the software has been internally linked with. Mixing of the software with other instruments will produce uncertain results.

Line 3,52: Raw data voltages and Converted voltage values

Ref, Zero corrected Reference channel voltage values

(real, 0 - ~9.5 volts)

CO, Zero corrected CO channel voltage values

(real, 0 - ~9.5 volts)

CO₂, Zero corrected CO₂ channel voltage values

(real, 0 - ~9.5 volts)

HC, Zero corrected HC channel voltage values

(real, 0 - ~9.5 volts)

Convert_CO, Converted CO voltage values

(real, arbitrary %CO values)

Convert_CO₂, Converted CO₂ voltage values

(real, arbitrary %CO₂ values)

Convert_HC, Converted HC voltage values

(real, arbitrary %HC values)

Convert_NO, Converted NO voltage values

(real, arbitrary %NO values)

Line 53: Calculated results and normalization factors

%CO, Percent Carbon Monoxide

(real, zero if invalid data)

CO_err, +/- error on the %CO measurement

(real, zero if invalid data)

%CO₂, Percent Carbon Dioxide
(real, zero if invalid data)
CO₂_err, +/- error on the %CO₂ measurement
(real, zero if invalid data)
%HC, Percent Hydrocarbon in propane equivalents
(real, zero if invalid data)
HC_err, +/- error on the %HC measurement
(real, zero if invalid data)
%NO, Percent Nitrogen Oxide
(real, zero if invalid data)
NO_err, +/- error on the %NO measurement
(real, zero if invalid data)
FACTOR1, Reference channel normalization voltage
(real)
FACTOR2, CO channel normalization voltage
(real)
FACTOR3, CO₂ channel normalization voltage
(real)
FACTOR4, HC channel normalization voltage
(real)

Line 54: Data flags

CO_flag, Data valid flag for the %CO value
(character, V=valid data, X=invalid data)
CO₂_flag, Data valid flag for the %CO₂ value
(character, V=valid data, X=invalid data)
HC_flag, Data valid flag for the %HC value
(character, V=valid data, X=invalid data)
NO_flag, Data valid flag for the %NO value
(character, V=valid data, X=invalid data)

FEAT MATH

It is important to understand that FEAT actually measures the ratios of gases, CO/CO₂ and HC/CO₂, and not the actual absolute percent values. Therefore when any adjustments or alterations of the data are desired, for example using the determined calibrations factors to adjust the data, you will need to use the ratios %CO/%CO₂ and %HC/%CO₂. This process is a three step process which requires converting the percent values into ratios, adjusting the ratios by the calibration factors and then converting the ratios back into the respective percent values. Note: %HC is given in propane equivalents!

See text at the end for other calculations which can be carried out using the FEAT supplied data. The attached arithmetic is for fuel of empirical formula CH₂ burning in air of formula 0.21 Oxygen, 0.79 Nitrogen. Slightly different coefficients are used for gasolines of other effective carbon to hydrogen ratios, when the fuel is known to be oxygenated, and if other engineering assumptions are made concerning the chemistry and analysis of the HC. For these equations the chemistry is calculated as if the HC product is C₃H₆ with IR absorption properties identical to propane C₃H₈.

Determining Calibration Values:

- Step 1) Carry out calibration routine as previously described with a known gas mixture to determine the instrument measurement ratios.
- Step 2) Calculate the %CO / %CO₂, %HC / %CO₂ and %NO / %CO₂ ratios from the cylinder label.
- Step 3) Divide instrument reported ratios by the cylinder ratios to obtain the appropriate cal factors.

To Adjust Data with Calibration Values:

This adjustment may only be made if the original data collection session was carried out without any initial adjustment. The data file will contain any previous data adjustment values, otherwise they will be listed as zero, which indicates that the default factor of 1 was used.

- Step 1a) $Q = \%CO / \%CO_2$
 $Q' = \%HC / \%CO_2$
 $Q'' = \%NO / \%CO_2$
- Step 2a) $Q_c = Q / (CO / CO_2 \text{ cal factor})$
 $Q'_c = Q' / (HC / CO_2 \text{ cal factor})$
 $Q''_c = Q'' / (NO / CO_2 \text{ cal factor})$

$$\begin{aligned}
\text{Step 3a)} \quad & \text{Adjusted \%CO}_2 = 42 / (2.79 + 2 * Q_c + 0.84 * Q' + Q'') \\
& \text{Adjusted \%CO} = \text{Adjusted \%CO}_2 * Q_c \\
& \text{Adjusted \%HC} = \text{Adjusted \%CO}_2 * Q'_c \\
& \text{Adjusted \%NO} = \text{Adjusted \%CO}_2 * Q''_c
\end{aligned}$$

For the situation where only the CO and CO₂ flags are valid:

$$\begin{aligned}
\text{Step 1b)} \quad & Q = \%CO / \%CO_2 \\
\text{Step 2b)} \quad & Q_c = Q / (CO / CO_2 \text{ cal factor}) \\
\text{Step 3b)} \quad & \text{Adjusted \%CO}_2 = 42 / (2.79 + 2 * Q_c) \\
& \text{Adjusted \%CO} = \text{Adjusted \%CO}_2 * Q_c
\end{aligned}$$

For the situation where the HC and CO₂ flags are valid and the CO flag is invalid, all of the data are considered invalid. This is because without valid information from the CO content of the exhaust we cannot complete the carbon balance, which is critical in assigning the HC values.

There are many other possible solutions of the above equations. Some which might prove useful to a user follow:

To derive Q from %CO and %HC:

$$\begin{aligned}
Q &= 2.79 * \%CO / (42 - 2 * \%CO - 0.42 * \%HC) \\
Q' &= 2.79 * \%HC / (42 - 2 * \%CO - 0.42 * \%HC)
\end{aligned}$$

To derive mass emissions in gm/US gallon of fuel:

$$\begin{aligned}
\text{CO}_2 \text{ gm/gal} &= 8677 / (1 + Q + 6 * Q') \\
\text{CO gm/gal} &= 5521 * Q / (1 + Q + 6 * Q') \\
\text{HC gm/gal} &= 8677 * 2 * Q' / (1 + Q + 6 * Q') \\
\text{NO gm/gal} &= 5916 * Q'' / (1 + Q + 6 * Q')
\end{aligned}$$

To derive mass emissions in gm/kg of fuel from Q and Q'

$$\begin{aligned}
\text{CO}_2 \text{ gm/kg} &= 3153 / (1 + Q + 6 * Q') \\
\text{CO gm/kg} &= 2007 * Q / (1 + Q + 6 * Q') \\
\text{HC gm/kg} &= 3153 * 2 * Q' / (1 + Q + 6 * Q') \\
\text{NO gm/kg} &= 2150 * Q'' / (1 + Q + 6 * Q')
\end{aligned}$$

The vehicle's instantaneous air to fuel ratio is:

$$\text{A/F by mass} = 4.93 * (3 + 2 * Q) / (1 + Q + 6 * Q')$$

FEAT Hardware Configurations

Scientific Solutions board

Motherboard - I/O mapped, 0710 hexadecimal (1808 decimal) address, wait states disabled, interrupts disabled, DMA disabled and both 12-bit D/A units are set to ± 5 volts.

Daughterboard - Unit is a 40 Khz 12-bit DAS with no other options, single ended inputs, unipolar conversions with the range set at 0 - +10v, normal sampling mode, binary data representation and no hardware gains.

Truevision TARGA board

All settings are the factory default settings for the board as explained in the blue pages of the User's Guide. Two 9-pin D connectors, top one is the input and the bottom one is the output. Old style boards these plugs are labeled the new style boards they are not.

FEAT Calibration 9-pin D connector

Pin 1 - Output for DAC 0
Pin 2 - Output for DAC 1
Pin 9 - Ground

Monochromator Communications Cable

FEAT Com2 Female 25 pin D connector

Pin 1 Shield
Pin 2 Transmit Data
Pin 3 Receive Data
Pin 7 Ground
Pin 20 DTR
Pin 22 RI

Mono Com1 Female 9 pin D connector

Pin 2 Receive Data
Pin 3 Transmit Data
Pin 5 Ground
Pin 9 RI
Pin 4 DTR

Speed Bar Communications Cable

FEAT Com1 Female 9 pin D connector

Pin 2 Transmit Data
Pin 3 Receive Data
Pin 5 Ground

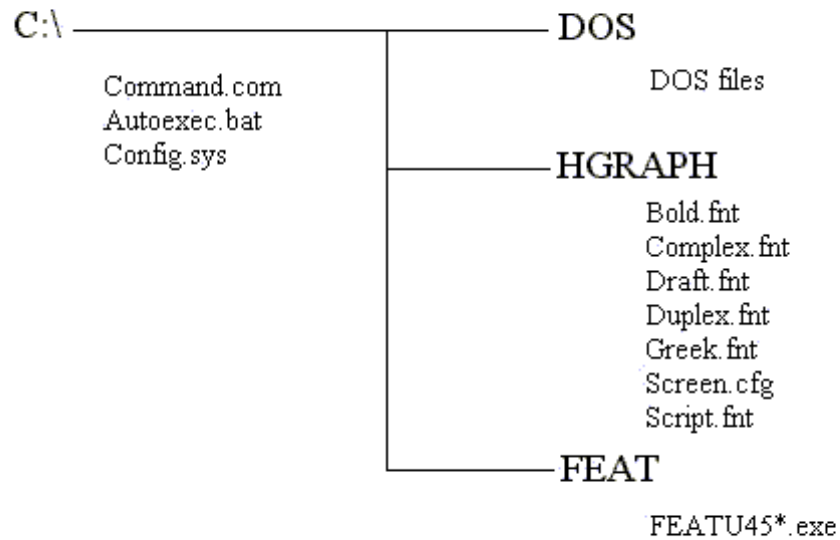
Speed Bar RJ-11 (phone) connector

Pin 3 Receive Data (green)
Pin 2 Transmit Data (red)
Pin 1 Ground (black)

FEAT Software Configurations

Hard Disk Organization

This is the minimum directory and file listing necessary to run the remote sensing unit!



File Descriptions by Directory

Root:COMMAND.COM - MS-DOS command file, part of the operating system.

AUTOEXEC.BAT - A batch file which is used to auto start the system and perform all of the necessary initializations. **The AUTOEXEC.BAT FILE FOR UNIT 3007 IS SLIGHTLY DIFFERENT! SEE NOTES BELOW.**

AUTOEXEC.BAT contents:

```
echo off
path C:\DOS;C:\HGRAPH;C:\FEAT
prompt $p$g
SET TARGA=247
SET TARGASET=T16GEP241
CD\FEAT
FEATU45*.EXE
CD\
```


NOTES FOR INSTRUMENT 3007:

3007 - This system contains a new upgrade of the TARGA board and as such requires a number of changes in the autoexec.bat file and requires a new file called config.sys. Also a new directory has been added named TPLUS which contains the files for the TARGA+ board. The SET TARGA command is different because the computer video system is VGA which requires the TARGA+ memory to be mapped at address D000. Config.sys file must be located in the root directory

Autoexec.bat	Config.sys
echo off	device=c:\tplus\targap.sys mD r0 w0 s0
path C:\DOS;C:\HGRAPH;C:\FEAT;C:\TPLUS	
prompt \$p\$g	
SET TARGA=247	
SET TARGASET=T16GEP241	
tplusini c:\tplus\t16.ini	
CD\FEAT	
FEATU45g.EXE	
CD\	

DOS: All of the utilities that came with MS-DOS.

HGRAPH:

All of the files ending in FNT are font files. The SCREEN.CFG file is the screen driver for the video graphic's card.

FEAT:

FEATU45*.EXE - This is the on-road measurement program for the remote sensor where the '*' indicates the version of your instrument, i.e. 3001 - A, 3002 - B etc...

Maintenance Items

Detector Unit / Source

We routinely dust off all of the mirror and beam splitter surfaces after a field project using either "Dust off" spray (don't use a compressed air source because the pressures are so high that any oil or dirt in the lines could damage the mirror surfaces) or cotton swabs with a little ethanol. Here again be gentle, don't scrub with the swab. Also check before and after transportation that the electronic circuit boards are firmly seated in the edge connectors in the rear card cage. Periodically check the wires leading to the source igniter holder as they will burn and oxidize to the point of breaking after extended use. Before field use we do a full co-alignment of the UV/IR light paths. Also integration gates and frequency controls for the spinning mirror are checked.

Computer

Before, after transportation, and periodically during local use all of the electronic circuit boards are firmly seated in the edge connectors. We also routinely use a hard disk maintenance package (SPINRITE, Gibson Research) to keep up with any damage to the disk surface which can result from the temperature extremes and transportation that is encountered. Also periodically clean the floppy disk drive heads and blow out the air passages in the hard disk casing and the power supply fan area.

VCR / Camera

The road dust that will be encountered is often extreme and the VCR is probably the most sensitive item to dust. We have our VCR thoroughly cleaned and lubricated after every field trip by a local service center. Most of these measurement trips will run 50 - 150 hours of tape by the heads. You can stretch the maintenance interval if you have been mostly analyzing data. The camera should have virtually no maintenance requirements unless the recorder is being used, therefore regular head cleaning and lubrications may be desired.

FEAT Expendables List

Source

Igniter - Found at local appliance part stores, two brands which we have used are General Electric #WE4X444 or Maytag #303376. Both brands are identical ignitors we have found the Maytag brand to be ~\$8.00 less expensive.

Igniter Holder - Found at local appliance part stores. General Electric #WE1X941.

Xenon Arc lamp - Osram XBO W/2 Part 69231 from Bulb Direct 1-800-722-5267 \$158 ea.

Monochromator

Fiber bundle – CeramOptec Inc. 515 A Shaker Rd., East, Longmeadow, MA. 01028.
(413) 525-0600. ~\$750.00.

Cables

Signal - 50ft. RG-58 coax. Light Speed, 50 ft. Telephone cord

Video - 100ft. RG-59 coax (RG-59 is ohmed for video signals)

Calibration Gas

The choice of concentrations for this gas are up to individual choice and availability. We have used Praxair, Scott and Matheson certified gases with equal success. We are currently using a Praxair cylinder which contains 6% CO, 6% CO₂, and 6000 ppm propane, 3000 ppm NO with the balance being nitrogen. In the laboratory when the cal factors are in fact one, this cylinder gives a CO/CO₂ ratio of 1 and a HC/CO₂ ratio of 0.1. Because the cylinder concentrations are not solutions of the combustion equation the CO, CO₂ and HC concentrations will be reported as 8.67, 8.67 and 0.87% respectively. We are currently using Praxair, only because they use aluminum cylinders which are lighter to carry than the steel cylinders supplied by other vendors. With the addition of NO capability NO is added to the cylinders typically at half the HC value.

E-23 Measurement Procedures: The data definition/dictionary explains the codes, units and other information about each field. See appendices

Category	Mandatory	Desired
Site Description	1. Include in the report a road map with features affecting traffic flow 2. Report any change in the position of the light source, detector, etc., from previous year(s). The site should be set up the same as in the previous year(s). 3. Report any change in traffic flow from previous year(s). 4. Report the altitude of the site and the road grade. Include a field in the database showing the road grade in percent for all measurements. 5. Picture of site (digital) including all cones, etc., that would influence motorists' driving patterns.	1. Note whether motorists change driving behavior as a result of the remote sensing measurements. Compare motorist behavior with previous years' measurements.
Instruments	1. Report a description of remote sensing equipment used; report any changes from previous year(s). 2. Name of operator and van. If more than one operator or van are used, key and record which operator and/or van was used for each measurement. 3. Calibration procedures and frequency. Frequency at least twice per day. Report the times of calibration.	
Measurements	1. Report remote sensing: %CO₂, %CO, %NO, %HC, maximum CO₂, and all error terms; restarts; report negative emission numbers. Include a field showing whether HC is reported as propane or hexane (P or H) 2. Report Speed, acceleration. 3. Report Time and date of measurement. 4. Report license plate: record all plates including in-state, out-of-state (OS); dealer plate (D); paper plate (PP); obscured plate (OP), and no plate visible (NVP). 5. Report hourly temperature, barometric pressure, and relative humidity. 6. Describe how plume strength is determined and flagged and report criteria for rejecting measurement attempts.	1. General wind direction and speed. 2. Any other factors that could affect measurements, such as when there was water on the road.
Database Format	Use format and units described in LA 1998 report.	Appreciate if field names could be reduced to 8 letters to fit in SAS.
DMV Data	1. Report date DMV data returned from DMV. 2. Report how current the DMV data in that file are (i.e., when was the most recent DMV update to the file received by the investigators, especially for vehicles that have changed ownership). 3. Report VIN, Model Year, Make, Model, Fuel Type, Vehicle Type (define terms used by DMV), Zip Code if available.	1. VIN decoded data. 2. Other information supplied by DMV.
Report Changes That Could Affect Analysis	1. Fuel. 2. I/M program.	1. Local economy. 2. Site socioeconomics.

REMOTE SENSING CHECK LIST

Equipment

Device being used Manufacturer _____
 Serial No. _____
Calibration Material Cylinder _____ Concentrations _____
 Sealed Cell _____ Concentrations _____
 Ratios to CO₂ _____
 Traceability _____
Power Supplied 110v _____
 Generators _____

Location

State _____ City _____
Study Type: Roadside _____ Track _____ Lab _____ Parking Lot _____ Other _____
Road Location and Grade _____
Distance from a Fixed Landmark _____
Sensor Beam Height Above Road _____
Optical Path Length. Total including inside detector _____
Posted Speed Limit _____
Traffic Control Measures, lane closure? _____

Comments

Weather (Precip., Wind, Temp) _____
Vehicle Speed/Accel (how observed) _____
Estimate of distance from possible cold-start vehicles _____
Other controlled vehicles? Repairs, Fuels, Modifications _____
Reason for study _____
Sponsored by _____
For Purposes of _____

Data File Information

APPENDIX A: FEAT criteria to render a reading “invalid” or not measured.

Not measured:

- 1) beam block and unblock and then block again with less than 0.5 seconds clear to the rear. Often caused by elevated pickups and trailers causing a “restart” and renewed attempt to measure exhaust. The restart number appears in the database.
- 2) vehicle which drives completely through during the 0.4 seconds “thinking” time (relatively rare).

Invalid :

- 1) Insufficient plume to rear of vehicle relative to cleanest air observed in front or in the rear; at least five, 10ms averages $>0.25\%$ CO₂ in 8 cm path length. Often HD diesel trucks, bicycles.
- 2) too much error on CO/CO₂ slope, equivalent to $\pm 20\%$ for %CO. >1.0 , 0.2% CO for %CO <1.0 .
- 3) reported %CO, $<-1\%$ or $>21\%$. All gases invalid in these cases.
- 4) too much error on HC/CO₂ slope, equivalent to $\pm 20\%$ for HC >2500 ppm propane, 500ppm propane for HC <2500 ppm.
- 5) reported HC <-1000 ppm propane or $>40,000$ ppm. HC “invalid”.
- 6) too much error on NO/CO₂ slope, equivalent to $\pm 20\%$ for NO >1500 ppm, 300ppm for NO <1500 ppm.
- 7) reported NO <-700 ppm or >7000 ppm. NO “invalid”.

Speed/Acceleration valid only if at least two blocks and two unblocks in the time buffer and all blocks occur before all unblocks on each sensor and the number of blocks and unblocks is equal on each sensor and $100\text{mph} > \text{speed} > 5\text{mph}$ and $14\text{mph/s} > \text{accel} > -13\text{mph/s}$ and there are no restarts, or there is one restart and exactly two blocks and unblocks in the time buffer.

APPENDIX B: Explanation of the ill_2002.dbf database as an example.

The ill_2002.dbf is a Microsoft Foxpro database file, and can be opened by any version of MS Foxpro, regardless of platform. The following is an explanation of the data fields found in this database:

License	Illinois license plate
Date	Date of measurement, in standard format.
Time	Time of measurement, in standard format.
Percent_co	Carbon monoxide concentration, in percent.
Co_err	Standard error of the carbon monoxide measurement.
Percent_hc	Hydrocarbon concentration (propane equivalents), in percent.
Hc_err	Standard error of the hydrocarbon measurement.
Percent_no	Nitric oxide concentration, in percent.
No_err	Standard error of the nitric oxide measurement
Percent_co2	Carbon dioxide concentration, in percent.
Co2_err	Standard error of the carbon dioxide measurement.
Opacity	Opacity measurement, in percent.
Opac_err	Standard error of the opacity measurement.
Restart	Number of times data collection is interrupted and restarted by a close-following vehicle, or the rear wheels of tractor trailer.
Hc_flag	Indicates a valid hydrocarbon measurement by a “V”, invalid by an “X”.
No_flag	Indicates a valid nitric oxide measurement by a “V”, invalid by an “X”.
Opac_flag	Indicates a valid opacity measurement by a “V”, invalid by an “X”.
Max_co2	Reports the highest absolute concentration of carbon dioxide measured by the remote sensor; indicates the strength of the observed plume.
Speed_flag	Indicates a valid speed measurement by a “V”, an invalid by an “X”, and slow speed (excluded from the data analysis) by an “S”.
Speed	Measured speed of the vehicle, in mph.
Accel	Measured acceleration of the vehicle, in mph/s.
Ref_factor	Reference detector voltage. Used along with “CO2_factor” to observe calibration shifts.
CO2_factor	CO ₂ detector voltage. Used along with “Ref_factor” to observe calibration shifts.
Lic_type	Value of 0 or 1. Indicates license plate type.

Exp_month	Indicates the month the current registration expires.
Exp_year	Indicates the year the current registration expires.
Address_2	Indicates the city, state, and zip code of the registrant's address.
Year	Model year of the vehicle.
Make	Manufacturer of the vehicle.
Body_style	Type of vehicle.
Vin	Vehicle identification number.
Owner_code	Illinois DMV ownership codes (1 – individual, 2 – multiple individuals same last name, 3 – multiple individuals different last names, 4 – corporate owner, 5 – combined corporate and individual, 6 – multiple corporate ownership, 7 – local government, 8 – state government and 9 – Federal government
Make_abrv	Abbreviated manufacturer.