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Technical Report

Operational Characteristics Study
Instrumentation Systems

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The driving cycles used in the EPA test procedure for light-duty vehicles were developed ten years ago. Since then, significant changes have occurred which may affect vehicle use; for example, fuel costs have increased, car pooling has increased, and smaller vehicles are now more prevalent. In order to investigate current vehicle use and to compare this use to the test cycles used for exhaust emissions and fuel economy measurements, EPA initiated the Operational Characteristics Study (OCS).

The first stage of the Operational Characteristics Study was to develop instrumentation to accurately monitor vehicle use. In addition, it was necessary to develop the capability to transcribe the data to a large computer system for analysis. This report describes the three basic systems which have been developed: the data collection system, the data transcription system, and the analysis system. All documentation on the equipment and software of these systems available at the present time has been collected and is presented in the Appendices. In addition to the systems descriptions, a brief evaluation of each system is presented, with suggestions for improvements. It is intended that this report will be a working document that is expanded as more information is acquired and system modifications are made.

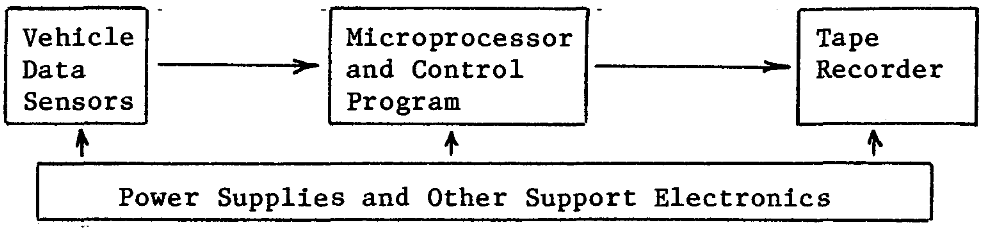
The instrumentation systems will be used in at least two EPA data collection programs, both in conjunction with EPA Emission Factors programs. In an emission factors program EPA obtains in-use vehicles and performs emissions tests on these vehicles while providing the program participant with an alternate vehicle for use during the test period. Consequently the Emission Factors programs provide low cost access to vehicles for the OCS instrumentation.

In the 1982 MVEL Emission Factors program several vehicles will be equipped with the OCS instrumentation. If a program participant is willing, the participant will be asked to take one of the instrumented vehicles as the loan vehicle. This program will act as a pilot study to test the durability of the instrumentation and the capability of the analysis systems. Problems with the instrumentation can be investigated and resolved while the instrumentation is still under the direct operation and control of MVEL personnel familiar with the systems.

The second application of the OCS instrumentation will be the 1983 Non-Detroit Emission Factors program. The location of this program is not presently known because the contract has not yet been awarded. In this program the instrumentation will be placed in the vehicles of those Emission Factor Program participants who are also willing to participate in the OCS program. This program will provide data obtained directly from owner operated in-use vehicles.

I. Data Collection System

The data collection system was developed by MB Associates of San Ramon, California under an EPA contract. This system consists of the data sensors on the vehicle, a microprocessor which modifies the sensor signals, and a tape recorder which stores the information from the microprocessor. The signal interfacing is accomplished through a control program stored in the read only memory addressed by the microprocessor. A block diagram of the instrumentation system is shown below:



A. Vehicle Data Sensors

Five types of vehicle data are monitored: 1) vehicle ignition switch state (on/off), 2) vehicle speed, 3) engine speed, 4) temperatures at six different locations on the vehicle, and 5) the position of an urban/rural switch. In addition, a real-time clock is maintained and monitored.

The ignition switch sensor simply monitors the voltage of the ignition system. If voltage is present, the ignition switch is obviously on, and the engine is presumed to be running.

The vehicle speed sensor is an optical encoder driven from a "tee" in the speedometer cable. This encoder is a standard industrial unit which generates 1000 pulses/revolution. Unfortunately, the unit is large, and has been difficult to install in one of the vehicles used in the pilot program. Also, several speedometer cable failures have occurred after the encoder was installed in this vehicle. These failures occurred in the section of cable before the encoder, indicating that a standard speedometer cable may not be strong enough to drive both the encoder and the speedometer. We are presently improving the encoder installation by removing this cable. In addition, one encoder failure has occurred, either because of an initial assembly problem, or because of the shock and vibration of the automotive environment. This failure was repaired by the encoder manufacturer.

Six temperature probes are part of the OCS data collection instrumentation. All of the temperature sensors are thermistors. When supplied by MBA, these thermistors were covered with plastic heat-shrink tubing. It was soon discovered that the heat shrink tubing inadequately protected the thermistors, or its shrinkage caused sufficient mechanical stress to destroy the wire connections to the thermistor beads. Removing the heat shrink tubing and embedding the thermistors in a thermally conductive epoxy has eliminated the thermistor breakage problem. The thermistors and epoxy currently being used are specified in Appendix A-1.

The thermistors themselves are marginally satisfactory, since their temperature rating is from 0°C to 100°C. They can be used somewhat outside this range without damage, but the temperature signals will be non-linear. Unfortunately, oil temperatures can easily exceed 100°C, and temperatures could be below 0°C during winter operation in any northern U.S. city. We are currently investigating alternate thermistors or other temperature sensors.

The final sensor is a switch located near the vehicle driver's seat which the driver uses to indicate whether he considers his driving to be urban or rural vehicle operation. Installing the switch box is a minor mechanical problem because of the need to firmly attach it so that the switch can easily be operated by the driver with one hand. Also, installing the switch box requires locating an acceptable access to the passenger compartment.

All documentation on the data sensors, provided by MBA, or researched by EPA, is presented in Appendix A-1.

B. Microprocessor and Control Programs

The microprocessor board used in the OCS instrumentation system is a development board manufactured by RCA. This board is one of several development boards in the RCA 1802 family. This microprocessor family was chosen by MBA because it was the only CMOS processor available when the project started. CMOS integrated circuits are necessary for this project because they require very little power.

The signal interfacing and most of the signal conditioning is done on the main processor board in the area provided by RCA for "user development." The documentation supplied by RCA and MBA for this board, and for the 1802 processor itself is given in Appendix A-2.

The microprocessor is controlled by the software program stored in an Intel 2716 UV eraseable EPROM (electrically programmable read-only memory). A data sheet on this EPROM is included in Appendix A-2. The program is responsible for counting the vehicle and engine speed pulses, applying a calibration factor to them, converting the temperature data into calibrated units, and most importantly the general formatting and transfer of the data to the cassette tape recorder. This program was written by Tom Pittman, a well-known microprocessor programmer, under a subcontract to MBA.

There are several notable aspects of the program. First, all data are partially encoded. For example, vehicle speed can only appear as a two byte word, and the first hexadecimal character of the first byte must always be zero. Unfortunately, the speed is not the only data that can appear with a leading zero; this can also occur in the time, day, or vehicle ID strings. Fortunately these data, which might be confused with vehicle speed should only occur after an "FD" identifier code. However, anywhere from zero to eight temperature data bytes can also appear following the "FD" code. No code is provided to identify the number of the temperature data to expect, which sensor the data come from, or end of the temperature data string. Because of the complexity of the data encoding and the variable length of some of the data strings, it is very difficult to write automated transcription decoding routines.

The software is used for almost all routine instrumentation functions, such as pulse counting for the vehicle and engine speeds. Consequently, it is complex because of the critical time nature of these real-time functions. Unfortunately, the documentation, which is presented in Appendix A-2, explains the program in general terms, but not in sufficient detail that they may be easily modified.

An example where a technically easy modification would be beneficial is in the temperature data. The instrumentation software was to convert the temperature sensor voltages into units which were linearly related to the true temperature in degrees Celsius. However, after the original program was written, MBA changed the temperature sensors to thermistors having slightly different characteristics but did not change the software. As a result of this change, the conversion routine in the program is incorrect, and the temperature data recorded on the tape are not linear with true temperature. If the microprocessor programs were well understood or thoroughly documented, it would be easy to modify them so that true temperatures were recorded.

In addition to the minor problems, such as the temperature nonlinearity, there appears to be at least two errors or "bugs" in the instrumentation software. The most significant problem is the inability of the software to accurately detect transmission gear changes. The microprocessor tries to use the engine speed signal and the vehicle speed signal to determine when a transmission gear change (shift) occurs by computing the ratio between the engine speed pulses and the vehicle speed pulses. This ratio is then multiplied by a scaling factor and truncated so that the result will be one hexadecimal number representing each gear. All the numbers fall between 4 and E. Whenever this character changes the new value is sent to the data tape, and should indicate a gear change.

At the present time more than one hexadecimal number often appears for a single gear, and usually one number appears for two different gears. Initially this problem was believed to be related to electrical noise, and therefore the system was tested using "clean" pulses from a signal generator. The gear change sensing was not accurate even with the test pulses, therefore it is concluded that the problem is most likely a precision or truncation problem in microprocessor software. Until this problem is resolved, the gear change data are not useful, and the engine speed sensor has been disconnected to conserve data tape space.

The second, less critical, software error is in the routine which counts the one second time pulses and converts the accumulated total to "real clock time". As a result of some error, whenever the hour is incremented, the most significant digit of the day is decremented by three, unless this results in a negative day, in which case no change is made. Unfortunately, because of the poor documentation there is no easy way to locate and correct this error in the program. Consequently the data will be corrected during the data analysis.

C. The Cassette Recorder

The cassette recorder is a high-density Memodyne incremental cassette tape recorder. The recorder is well suited for this application; however, a special reader unit is required because an uncommon data recording format is used to maximize the data storage capacity of the tape. Documentation on the Memodyne recorder is presented in Appendix A-3.

D. Operation of the Instrumentation

Operation of the instumentation is relatively simple, but there are several aspects which must be carefully followed if useful data are to be obtained.

Digital tape cassettes generally have a clear leader at the ends of the magnetic tape. These tapes must be manually preset to the beginning of the magnetic oxide coating. If this is not done, the calibration symbols will not be recorded and there will be no way to verify that the vehicle speed sensor calibration occurred. The speed sensor must be calibrated every time the unit is switched off. If this is not done an unknown random number, generated by the microprocessor during the power-up cycle, will be used as a calibration factor.

A second aspect that must be carefully followed is that the reset and rerun switches of the unit must be activated twice (or more) when starting. This is a bizarre quirk of the software required because of the sophisticated but complex and problematic method used to count the engine and vehicle speed pulses.

Finally, when the unit is turned off, several minutes of operation must be provided to "dump" any useful data stored in internal buffers or these data will be lost. It is also desirable to provide a similar time when the unit is powered up to allow for possible initial loss by the reader.

Detailed instructions for tape initialization, instrumentation operation, and speed calibration are provided in Appendix A-4.

II. The Transcription System

The computer system used by EPA, the Michigan Terminal System (MTS) of the University of Michigan, does not directly support cassette tapes. Consequently a system is required to transmit the data stored on the cassette tapes to MTS for analysis. This system consists of several hardware components and software to run the equipment.

A. Hardware

The first element of the data transcription system, a tape reader unit, was supplied by MBAssociates as part of the EPA instrumentation contract. This tape reader is based on the same RCA microprocessor board that is used in the recording unit. The reader microprocessor, however, is simply programmed to take serial binary data from the cassette tape, combine these data into 8 bit bytes, separate each byte into two hexidecimal characters, and then covert these characters into the American Standard Code for Data exchange (ASCII). The ASCII code is then transmitted serially through the interfaces of the reader. Both RS232 and 20 milliamp current loop interfaces are provided.

Several approaches were possible to interface the reader signal to MTS. The reader could be reprogrammed to emulate a computer terminal and then be directly connected to MTS, the data could be transcribed to a medium directly supported by MTS, or the data could be transcribed to a device which can communicate with MTS.

Modification of the MBA unit was rejected primarily because the limited documentation available on the reader program would make its modification difficult and uncertain. Even if modifications were successful it would be an expensive approach because the reader operates at such a slow speed that long computer connection times would be required for data transmission. Transcription to a medium directly supported by MTS, such as 9-track computer tape, was rejected because of the high cost of 9-track tape drives ($5,000 - $18,000). Also, this approach would not provide any easy method to preview data for general equipment malfunctions. The final method, data transcription to equipment which then rapidly transmits to MTS, was chosen. This approach had the advantages that some of the necessary equipment already existed at EPA, and the additional transcription step would provide an opportunity to observe the data and perform preliminary data analysis.

The system selected includes a mirocomputer for data manipulation, a video monitor for data display, and a Techtran tape recorder to receive the data. The Techtran recorder can be connected to the MTS to transmit the reformatted data tapes. The documentation on this equipment is provided in Appendix B-1.

In the simplest system configuration the data tapes are directly transcribed from the reader onto the Techtran tape. The contents of the tape are displayed using the RCA terminal keyboard and the RCA mirocomputer monitor. This display provides a rapid, quiet and low cost method of previewing the data and detecting equipment malfunction. This is the approach being used for the emission factors pilot program.

One idiosyncrasy of the reader unit should be noted. The reader responds to the beginning of tape (BOT) and end of tape (EOT) marks (holes) present on many digital cassette tapes, while the recorders in the data collection systems do not. Consequently if the cassette tapes are not manually advanced beyond the BOT hole, about 18 inches into the tape, the recorder will record over the tape marker, but the reader will not read beyond this point. The tape can be manually advanced beyond the BOT marker and the reader restarted at this point, but the data in the vicinity of the tape marker will always be lost. Consequently, tapes without BOT/EOT holes should always be used.

In addition to simple transcription of the data to a Techtran tape, the transcription system contains a microcomputer, an RCA Microboard Computer Development System CDP18S694, which can be used for preliminary analysis. The MCDS is also based on the RCA 1802 microprocessor. This was selected so that knowledge learned from the transcription processes would be directly applicable to the data recording instrumentation and the tape reader.

B. Software

In the single direct transcription process, the equipment provides the necessary interfacing and no control programs are necessary. A decoding program is still required to convert the data into engineering units, but this program runs only on the MTS computer. This program has been written and is presented in Appendix B-2 along with examples of the program input and outputs.

There are two disadvantages of the direct data transcription. First, and most significant, it is very difficult to preview the data since it is both in the hexidecimal number system and encoded by the data collection system. The other disadvantage is that the current decoding program is written in FORTRAN which is relatively inefficient for the individual bit data manipulation required for the data decoding. This inefficiency makes the program expensive to run using the relatively large data sets anticipated for the project.

Data decoding can be accomplished during the transcription process by the MCDS. In this case, the microprocessor program translates the encoded data written by the data collection instrumentation into standard engineering units. This greatly facilitates review of the data and early detection of equipment errors. In addition, it reduces the external computing time required by the MTS system and thereby reduces the program cost.

The decoding program for the microcomputer is relatively complex because, as discussed earlier, different data elements are encoded with different systems. Also, some parameters such as engine on/off, gear changes, and urban/rural switch changes can occur almost anywhere in the data field. This decoding program is not yet completely operational, however the current program is presented in Appendix B-2. The remaining problems are in interface areas and should be resolved before the non-Detroit Emission Factor Program begins. When these problems are resolved the decoding program will transcribe all data into engineering units and reformat it. In its new format the data will be recorded on to a tape on the Techtran recorder, then that unit will be used to put the data into an MTS line file.

III. The Analysis System

The final data analysis will be done under MTS on the computer of the University of Michigan. The computer is an Amdahl 470, a large mainframe system. The details of the computing equipment are unimportant to the user, however, since all analysis programs are written in standard FORTRAN and executed from a terminal.

The analysis programs serve two basic purposes. First, the data are analyzed for many trip parameters: average speed, time in various speed bands, etc. Finally, the statistics of these parameters will be calculated and compared with the statistics of the same parameters computed from the current EPA driving cycle.

There are five analysis tasks: 1) cross-field and range checking, 2) calculation of trip and trip-segment statistics, 3) calculation of driver statistics, 4) analysis of these statistics, and 5) graphic display generation. The first three of these are programmed in FORTRAN, the analysis is implemented in the Michigan Interactive Data Analysis System (MIDAS), and most of the graphics will be generated using CALCOMP, an MTS-supported package of FORTRAN subroutines. A few of the graphic displays may also be generated using MIDAS.

A. Crossfield and Range Checking: OCSPGM1

The program OCSPGM1 is used to conduct certain crossfield and range checks on the data. The program has been written in a modular construction, that is, subroutines are extensively used to allow modifications or the addition of other crossfield or range checks if necessary.

There are seven subroutines in OCSPGM1, one each for input and output plus five data checking routines. The primary purpose of these subroutines is to check for erroneous data, test for abnormal values of speed and temperature, for abnormal changes in these parameters and for abnormal differences between related parameters. In addition, a check is made to verify that time always increases. Whenever an "error" condition is detected these subroutines output detailed information on the error location and the number of times it occurred to one of the output files. For example, each time that the subroutine DELTMP finds a temperature record in which the difference in the ambient and fuel tank temperature is greater than 20°C (36°F), the following information is written to a single line in this file:

- occurrence number within trip (1, 2, 3,...)

- time (given as number of minutes after time that trip began: 7 min., 103 min., etc.)

- ambient and fuel tank temperature (°C)

- absolute value of difference in above temperatures.

In addition to testing for abnormal data values, each subroutine calculates the extreme value of the checked variable (usually the maximum value) and the number and frequency of the occurrence of the extremes.

A listing of OCSPGM1 appears as Appendix C-1. This program has been tested on a "dummy" data set formed by inserting time and temperature data at one-minute intervals through the LA-4 driving cycle. Erroneous speed data were also substituted for several of the speeds specified by the LA-4 cycle. All of the subroutines correctly detect the "error" conditions described above.

B. Calculation of Trip Statistics - OCSPGM2

The program OCSPGM2, like the crossfield and range checking program, consist of a calling program and a number of subroutines. These routines read in the data obtained from one tape (one study participant) and calculate a number of statistics describing the trips and between-trip periods.

Statistics calculated for each trip include: duration of trip, total distance, mean speed, maximum speed, amount of time at idle, mean and maximum acceleration and deceleration, mean of absolute values of all accelerations and decelerations, percent time in acceleration, cruise and deceleration modes, number and mean duration of full stops (idles) within trip, hot or cold start, and times of day trips began and ended.

Each trip will be divided into modes of operation and trip segments. The modes of operation are acceleration, cruise, and deceleration. A trip segment is defined as a subset of the speed data that begins and ends with a full stop. Three-minute duration trip segments will also be formed from the first three three-minute blocks of time in a trip. Most of the statistics calculated for entire trips are also calculated for these trip segments and modes of operation.

The program OCSPGM2 is still under development. While none of the statistical measures are difficult to calculate, implementing all of the desired calculations in an optimal manner and creating a well-designed data base are not trivial problems. Appendix C-2 contains a listing of the draft OCSPGM2 program. Later revisions of this document will contain the final version.

C. Operator Statistics

The trip statistic output files from OCSPGM2 are used as input to OCSPGM3. This FORTRAN program determines the multi-trip mean values and frequencies of the parameters analyzed for each study participant. Such "participant summary," or multi-trip statistics include trips per day, mean distance per trip, miles travelled per day, and other variables based on all of the data obtained from one study participant.

OCSPGM3 is still in relatively early development. As more OCS data become available significant improvements in the design structure of this program may be desirable and may result in significant program revisions.

Appendix C-3 is reserved for OCSPGM3 and it will be presented in future revisions of this document.

D. Analysis of the Statistics: OCSPGM4

OCSPGM4 merges the analysis of the vehicle operation data with the participant's answers to the questionnaire. This combined data set is then analyzed to observe the distributions of driving characteristics for the entire program.

OCSPGM4 is not a true program in the usual FORTRAN sense, but is a series of MIDAS (Michigan Interactive Data Analysis System) commands in a control file. Use of MIDAS greatly simplifies the programming effort required. Also since MIDAS is a relatively efficient system many analyses can be conducted quickly at a relatively low computer time cost.

This final analysis control file is the most straightforward of the programming tasks. However, it is the last to be used and since it requires complete knowledge of the structure of the data files, it has not been developed yet. Appendix C-4 is reserved for inclusion of a listing of OCSPGM4 when it is completed.

E. Generation of Graphic Displays

Most of the final data analysis results can best be understood in the form of graphic displays. These will include histograms, distributions and displays of variable regressions. Initially, these histograms, distributions, and regressions will be produced using MIDAS.

Previewing these MIDAS outputs will allow parameters to be changed, if appropriate, before generating the final graphics using the MTS CALCOMP System.

CALCOMP provides great user control and produces high quality graphics. The programs for creating graphics through CALCOMP are FORTRAN programs consisting primarily of calling statements to the many CALCOMP subroutines. As with the statistical analysis, the programming will be straightforward, but require detailed information of the data analysis files. Therefore, these programs will not be developed until data have been collected and the data analysis files created. Appendix C-5 is reserved for listings of these programs and sample outputs.

IV. System Evaluation - Recommended Improvements

A. Data Collection System

The MBA instruments are performing well. Very few problems have arisen with the basic unit even though occasional accidental user abuse, such as shorting out the main power regulators has occurred. In contrast, most of the vehicle data sensors provided by MBA have failed or have been unsatisfactory in some manner. The thermistor probes had to be imbedded in epoxy to prevent breakage, the optical encoder used for the vehicle speed sensor has caused speedometer cable failures, and the gear change sensing circuit does not function reliably. In general, the electronic apsects of the unit function far better than the automotive interfaces. The first, and most important, recommendation is that the automotive sensors be improved. This is essential if long term reliability of the data collection is expected. Efforts are in progress to improve the temperature sensors and the installation of the vehicle speed sensors.

A major problem area is the detection of gear changes. The selection of gear shift points is an important aspect of the EPA test procedure and area of past and present concern. Because this area is important, it is recommended that efforts be made to investigate the present difficulty and to develop a solution. This could be accomplished in several months using auxiliary equipment and would not delay the present program. Total equipment cost would be between $500 and $1,000.

Numerous software improvements are possible. Unfortunately, even though these changes may be simple they will be time consuming because of the lack of detail in the software documentation provided by Tom Pittman/MBA. It is recommended that improvements in this area be attempted only after the gear change sensor problem is resolved. If the gear change problem is satisfactorily solved, then software changes in the instrumentation program will probably be necessary to implement the solution and other improvements can be made at that time.

B. Data Transcription System

The data transcription system is working satisfactorily. That is, tapes can be transcribed and analyzed. A significant improvement would be to provide decoding and preliminary analysis of the data during the transcription process. This improvement is well underway and should be functioning shortly. Since this entire system was developed at EPA, we are able to easily incorporate changes and improvements in whenever they appear beneficial.

C. Data Analysis

The data analysis programs cannot be considered completed until sufficient data have been collected by the project to verify their capability. Therefore, the data analysis programs must be considered as still under development. Even for the programs which have been written and tested, it is known that some changes in input and output formats will be required.

When this sytem is used and desired modifications become apparent this will be the easiest system to modify since it was developed by EPA and since all of the programs are written in FORTRAN or are part of a University of Michigan interactive command system.

Appendix A-1

1. EPA Operational Characteristics Study Instrumentation Phase III Final Report. Prepared for EPA by MBAssociates

2. Blueprints of instrumentation

3. Manufacturer's data sheet - optical encoder

4. Manufacturer's data sheet - epoxy used to encase the thermistors