Review of Federal Test Procedure Modifications Status Report

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Certification Division
Office of Mobile Sources
Office of Air & Radiation

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Overview and Background

The cornerstone of the Clean Air Act (CAA) is the effort to attain and maintain National Ambient Air Quality Standards (NAAQS). Regulation of emissions from on-highway, area, and stationary sources prior to enactment of the Clean Air Act Amendments of 1990 has resulted in significant emission reductions from these sources. However, due to factors such as the growth in air pollution sources, including dramatic increases in vehicle miles traveled (VMT), many air quality regions have failed to attain the NAAQS, particularly those for ozone and carbon monoxide (CO).

The Clean Air Act, as amended (CAA or Act) contains numerous provisions that are intended to remedy these continuing air quality problems. As part of this effort, Section 206(h) of the CAA requires the Environmental Protection Agency (EPA) to "review and revise as necessary" the regulations governing the Federal Test Procedure (FTP) to "insure that vehicles are tested under circumstances which reflect the actual current driving conditions under which motor vehicles are used, including conditions relating to fuel, temperature, acceleration, and altitude."

The FTP is the test procedure used to determine compliance of light-duty motor vehicles with federal emission standards.[1] The FTP is conducted on preproduction vehicles during the motor vehicle certification process, used to establish that each vehicle is designed to comply with the appropriate standards for its full useful life. It is also used to test production line and in-use vehicles for compliance with emission standards.

The regulations that encompass the many aspects of the FTP are generally contained in 40 CFR Part 86, Subparts A and B.

The procedure provides a way to consistently and repetitively measure concentrations of hydrocarbons, oxides of nitrogen, carbon dioxide, and carbon monoxide emissions which occur when a vehicle is driven over a simulated urban driving trip.[2] The principal elements of the test are designed to test the evaporative and exhaust emissions under several simulated situations. Evaporative emissions are tested after heating the fuel tank to simulate heating by the sun (the diurnal test) and again after the car has been driven and parked with a hot engine (the hot soak test). Exhaust emissions are measured by driving the vehicle (placed on a dynamometer) on a simulated urban driving trip under two conditions: with a cold start designed to represent a morning startup after a long soak (a period of non-use) and then following a hot start that takes place after the cold start test while the engine is still hot. The FTP also encompasses all factors relevant to vehicle testing, such as fuel, vehicle preconditioning, ambient temperature and humidity, aerodynamic loss, and vehicle inertia simulations. In addition to evaporative and exhaust emissions, the FTP is also used in evaluating fuel economy.

This status report addresses the progress EPA has made to date in complying with the CAA provision and the status of future research efforts. The first section, "Areas of Potential Concern," discusses the four general areas of concern with the FTP noted in §206(h), the basis for each concern, and the remedies that have been or are being implemented by EPA to date. The remainder of this report discusses the research program being

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For a detailed discussion of the development of this cycle, see: Kruse, Ronald E., and Thomas A. Huls, SAE Paper #730553 "Development of the Federal Urban Driving Schedule," 1973. A speed-time trace of this cycle is contained in 40 CFR Part 86, Appendix I.

conducted by the Agency regarding in-use driving behavior.

Areas of Potential Concern

It is a basic premise that motor vehicle emission levels determined through the FTP should adequately reflect in-use vehicle emissions. If in-use driving modes exist that generate significant amounts of emissions that are not reflected on the FTP, then the anticipated benefits from motor vehicle standards are not being fully achieved.

It is also basic that no test procedure can reasonably duplicate all in-use conditions. The overall goal of the Agency's review of the FTP is to aid in determining whether or not the FTP should be modified to reflect in-use conditions not currently found in the test and, if so, what modifications should be made. To meet this goal it is not enough to simply examine factors such as ambient temperature ranges, in-use fuel characteristics, or driving patterns. For example, qualitative evidence has existed for years that certain types of actual driving behavior are not represented on the FTP, such as high acceleration rates. However, it would be counterproductive to modify the FTP unless two conditions are met. First, the driving behavior or other condition not represented properly by the FTP should contribute a significant amount to motor vehicle emissions. If it does not, then modifying the FTP would incur substantial costs and disruption with little or no air quality benefit. Second, any modification to the FTP should be expected to promote design improvements to vehicles and thereby create real improvements in controlling in-use emissions. If the current FTP is already effective in reducing emissions during the non-FTP driving or other conditions, then modifying the FTP would again incur substantial costs with little or no air quality benefit. Even if off-cycle emissions exist that are not properly controlled by the FTP, it is critical to ensure that FTP modifications will actually promote the proper design improvements. The Agency believes this approach is a reasonable way to implement Section 206(h)'s requirements.

Section 206(h) of the Act specifically requires that EPA consider four potential areas of concern: fuel, temperature, acceleration, and altitude. The Agency has identified several other potential areas of concern relating to driving behavior: speed, cold starts (frequency and driving behavior), trip length, time between trips, and road grade.

Fuel

I. Gasoline.

The composition of the gasoline used for the FTP (commonly referred to as indolene) was established by regulation over 20 years ago.[3] While it was representative of in-use fuel at the time, commercial or in-use fuel properties have changed significantly since then, in some cases having a major impact on vehicle emissions, both tailpipe and evaporative.[4] Studies conducted during the 1980's indicated that vehicles tended to emit higher emissions using commercial gasoline than indolene, particularly through evaporative losses. To address this

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40 CFR Part 86 Section 86.113-94.

Evaporative emissions include diurnal, hot soak, refueling, and running losses.

concern, EPA established volatility limits for gasoline and alcohol blends. These regulations capped the allowable Reid vapor pressure for commercial gasoline during the summer months. The second phase of these controls became effective in the summer of 1992.[5] As a result of these actions, the emissions of a vehicle fueled with indolene are more representative of the in-use emissions results of a vehicle fueled with commercial gasoline.

II. Diesel fuel.

The Agency has also taken steps to reduce the sulfur content of in-use diesel fuel. Regulations were published on May 7, 1992 to reduce sulfur content in diesel fuel, to take effect on October 1, 1993.[6]

III. Alcohol and other fuels.

The Agency promulgated regulations in 1989 which established emission standards and test procedures for vehicles fueled with methanol and proposed similar regulations in 1992 for vehicles fueled with compressed natural gas and liquefied petroleum gases. At this early stage of alternative fuel development, it is impossible to know what the real-world fuel compositions will be for any of these fuels when used in automotive applications. In each of these rulemakings, EPA has avoided adoption of narrow fuel specifications, specifying instead that test fuels be representative of typical in-use fuels.

These recent requirements established for in-use fuel appear in general to satisfy §206(h)'s requirements regarding fuel use

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5 55 FR 23658 (June 11, 1990).

6 57 FR 19535 (May 7, 1992).

in the FTP. In addition, the Agency is also addressing the use of representative fuels in the Certification Short Test rulemaking, for which a proposed rule is expected to be published in January.

Temperature

The FTP is conducted between 68 and 86 degrees Fahrenheit, and includes a cold start in its driving cycle.[7] Vehicle emissions after a cold start increase at colder temperatures as a richer mixture is employed to ensure sufficient fuel vapor for combustion to occur. In addition, colder temperatures lead to longer warm-up times. This is not a major concern for ozone, which is primarily a summertime phenomenon, but it is for CO. Most CO exceedances occur from December to March and over half occur at temperatures below 45 degrees Fahrenheit.

To reduce the emissions generated from motor vehicles during cold temperature operation, EPA recently issued 20●F CO emission standards and test procedure. These regulations were issued on July 17, 1992 and are phased in beginning with the 1994 model year.[8] The regulations also established interim temperature defeat device criteria to maintain proportional CO emission control between the 20 degree standard and the warm temperature standards. These regulations insure that the Agency's test procedures properly reflect the impact of temperature on CO emissions. As the cold CO rules will prevent emission step-functions just below 68 degrees that could also impact hydrocarbon (HC) emissions, they will also insure that the FTP is

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An engine start is considered to be a "cold" start if it is preceded by a long uninterrupted soak, such as those starts that occur after an overnight soak.

57 FR 31888 (July 17, 1992).

representative of HC emissions at colder temperatures.

At warmer temperatures the primary emission concern is increased fuel evaporation. The Agency is in the process of revising its evaporative test procedures to address a number of concerns, including temperature. The final regulations are expected to specify ambient test temperatures of 95●F. These new test requirements should insure that vehicles can control evaporative emissions for most in-use events.

The Agency believes that the above FTP changes appear in general to satisfy §206(h)'s requirements regarding temperature conditions in the FTP.

Altitude

It has long been recognized that at high altitude locations, if there is no compensation for the lower air density, engines tend to run rich more frequently and emit more HC and CO emissions. Virtually all light-duty vehicles have been required to meet emission standards at both low and high altitude without adjustment or modification since the 1984 model year. Light-duty trucks and light-duty vehicles have had separate high altitude standards since the 1982 model year. Regulations published on June 5, 1991 will require light-duty trucks to meet emission standards at both low and high altitude without adjustment or modification beginning with the 1997 model year.[9] The cold temperature CO regulations require that both light-duty vehicles and light-duty trucks meet the standard at both low and high altitude without modification. The FTP does not specify an altitude range in which the test must be conducted. In effect, the regulations allow the FTP to be conducted at any altitude and

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56 FR 25724 (June 5, 1991).

this, in fact, occurs.

As with fuel and temperature parameters for the FTP, EPA believes that the above requirements appear in general to satisfy §206(h)'s requirements regarding altitude conditions in the FTP.

Driving Behavior (including acceleration)

Current technology vehicles have achieved impressive reductions in emissions during normal operation, primarily due to catalyst technology development. Catalyst conversion efficiencies (i.e. the rate at which HC and CO are oxidized into carbon dioxide (CO_2) and water vapor, or oxides of nitrogen (NO_x) are reduced to nitrogen and oxygen) in a modern, properly operating, warmed-up vehicle can simultaneously exceed 98% for HC, 99% for CO and 90% for NO_x. This includes typical transient urban traffic operation, such as that represented by the FTP. However, these simultaneous catalyst conversion efficiencies are only achievable with a three-way catalyst in a very narrow range of fuel/air ratios around the minimum theoretical air requirement for complete combustion (called stoichiometry). Thus, modern, properly operating vehicles are designed to operate at stoichiometry as much as possible during the FTP.

There are two types of operation that make it difficult to operate an engine at stoichiometry. The first type of operation is cold starts. Fuel must be vaporized with air to combust properly. When the engine is cold there is not enough heat to properly vaporize the fuel and additional fuel must be added for proper operation. Cold start emissions are also increased due to the lack of conversion activity in the catalyst until it heats up (little catalyst activity occurs below about 600 degrees Fahrenheit). Thus, emission rates during cold starts can be 20-100 times the emission rates during stoichiometric operation. In fact, the vast majority of emissions from modern, properly operating vehicles on the FTP occur during the first 10% of the test, before the engine and catalyst have warmed up. Thus an important question is whether the cold start portion of the FTP properly reflects the proportion of time vehicles actually spend in the warm-up mode.

The second type of operation that makes it difficult to operate an engine at stoichiometry is high engine loads. High loads on an engine running at stoichiometry can dramatically increase engine and catalyst temperatures. These elevated temperatures greatly increase NOx emissions and can cause engine knocking and/or damage to the catalyst. The performance and driveability of an engine under high load can be improved by running with a richer mixture of fuel. Thus, to prevent overtemperature damage to the catalyst and insure the best possible driveability and performance, manufacturers often design their vehicles to run rich at high loads. While this reduces NOx emissions, it increases HC and CO by almost the same 20-100 times factor as cold start operation. An important question then is whether a significant amount of high load operation occurs in-use that is not reflected on the FTP. Due to the nonlinear nature of the emission rates, this amount of driving could actually be fairly small and still have a significant emission impact.

There are a wide variety of in-use factors that impact the amount of time vehicles spend in either a warm-up or high-load mode. Warm-up factors include distributions of trip length, time between trips (referred to as "soak time"), ambient air temperature, initial idle time, and driving behavior. Factors that can cause high loads on a vehicle include high acceleration rates, high speeds, road grades, air conditioning operation, or some combination of factors (such as moderate acceleration up a moderate road grade). Complicating the assessment is the fact that different vehicles have very different calibration strategies. Thus, the impact on emissions of the exact same driving behavior may vary widely from vehicle to vehicle.

To properly address the emission impact of driving behavior, very detailed and statistically valid data are needed for both actual driving conditions and the impact of this driving on emissions from a wide variety of vehicles. When the CAA was amended in 1990, very little information was available on any of the driving behaviors or conditions discussed in this section, or on their emission impacts. It was therefore necessary for EPA to conduct a research program on actual driving behavior and the emissions impact of such driving.

Research on Driving Behavior

Past qualitative assessments have concluded that the FTP effectively represents in-use emission reductions from vehicle emission standards (i.e. any off-cycle emissions did not occur with enough frequency to have a significant impact). However, the larger the baseline emissions, the smaller the impact from off-cycle emissions. Other CAA mandates such as Tier I emission standards and longer useful life will all serve to reduce the baseline emissions measured by the FTP. If adopted, Tier II emission standards would have a like effect. Thus, any off-cycle emissions will become relatively more important in the future. The research program undertaken by the Agency is designed both to quantify any emission impacts from off-cycle driving behavior and to provide information needed to determine whether or not EPA should make regulatory changes to the FTP.

The program developed by the Agency to evaluate driving behavior contains three basic components. First, to determine how vehicles are actually driven, an extensive amount of vehicle monitoring was conducted. This is described in the next section, "In-Use Assessment of Driving Behavior." Second, the data from the vehicle monitoring is being analyzed to determine cycle and trip information and the impacts of different factors on driving behavior and to develop driving cycles that represent the complete range of actual driving behavior. This part of the program is described in the section, "Analysis of Driving Behavior Data." The third part of the program involves assessing the emission impact of the driving behavior. This is being pursued both by development of a computer simulation model and by vehicle testing, as described in the section, "Emission Assessment of In-Use Driving Behavior."

These three sections are designed to describe the entire research program from start to finish. The final section of this report, "Status and Plans," identifies which portions of the work have already been completed, which are currently in progress, and which are still to be done. It outlines the status of the tasks discussed in the sections on the research program and sets up a general schedule for work that has not yet been completed.

In-Use Assessment of Driving Behavior

Outreach

From the start of the FTP study, EPA has made a concerted effort to inform all interested parties of our plans to evaluate in-use driving behavior and to solicit input and participation. The first public meeting was held at the EPA National Vehicle and Fuel Emissions Laboratory on December 20, 1990 to discuss EPA's plans for the FTP study. This meeting was well attended and generated considerable interest among motor vehicle manufacturers. A second meeting was requested by auto representatives to allow them to respond to several issues discussed at the initial meeting. In these subsequent meetings, the auto manufacturers demonstrated a willingness to work with EPA to ensure a thorough and successful study. As a result of these meetings, an Ad Hoc Panel on the FTP was formed by the Motor Vehicle Manufacturers Association (MVMA) and the Association of International Automobile Manufacturers (AIAM).

As part of the outreach effort for the FTP Study, EPA held discussions with the State and Territorial Air Pollution Program Administrators (STAPPA) and the Association of Local Air Pollution Control Officials (ALAPCO) members during the first part of 1991. These talks led to the establishment of a Cooperative Agreement with New York State's Albany Emission Laboratory (AEL). The agreement called for AEL to conduct vehicle testing to examine engine and catalyst cool-down temperatures and their relationship to motor vehicle emissions.

Driving Behavior Data Acquisition

A centerpiece of EPA's approach to the FTP Study is the examination of how vehicles are operated in the real world. Early on, EPA reviewed existing data sources on current driving behavior and found them deficient for our task. To truly understand driving behavior EPA felt that it was critical to collect real-time driving data on a representative sample of drivers. The MVMA/AIAM Ad Hoc Panel on the FTP supported this approach and talks were held to discuss a cooperative research effort.

A meeting was held in Atlanta, Georgia in June of 1991 to discuss options for conducting surveys of in-use driving patterns. The meeting included experts from industry, government, and academia. Two EPA contractors gave presentations on alternative driving survey approaches. As a result of the meeting, EPA concluded that two complementary approaches were necessary; data were to be collected using both a chase car approach and an instrumented vehicle approach. Each approach is described below.

The next step was the selection of cities to survey. Resource constraints limited the surveys to two cities. In addition, the two driving survey methodologies restricted the choices for possible cities. For example, to minimize potential bias in the selection of drivers and vehicles, the instrumented vehicle study required recruiting drivers from centralized Inspection and Maintenance (I/M) stations. The chase car approach dictated that a city possess an up-to-date transportation network model. These requirements limited the choices to a handful of prospective cities. The Agency selected Baltimore, Maryland and Spokane, Washington. Baltimore represents a major urban ozone non-attainment area and is within the Northeast corridor. In contrast, Spokane is characteristic of a smaller, cold CO non-attainment area.

Additional information on in-use driving behavior has been collected in Los Angeles, California and Atlanta, Georgia. The California Air Resources Board (CARB) has utilized the chase car approach to collect data in Los Angeles. The Agency and CARB have coordinated activities from the start of the FTP Study; the CARB chase car study closely paralleled EPA's chase car efforts and was conducted by the same contractor.

The Atlanta work was done in coordination with EPA's Air and Energy Engineering Research Laboratory (AEERL) of the Office of

Research and Development (ORD). AEERL is conducting research in Atlanta as part of a long-term project to improve mobile source emissions inventories and emissions modeling. With financial support from AEERL, an instrumented vehicle survey was conducted in Atlanta during the summer of 1992 using the 3-parameter dataloggers developed for the FTP study. This study, along with the Los Angeles study, will improve the regional representation of the original in-use driving surveys.

Instrumented Vehicle Study

The instrumented vehicle study consists of placing instruments in individuals' privately-owned vehicles. Datalogging devices are mounted inconspicuously under the vehicle's hood and data are collected for about one week. To minimize potential sampling bias, drivers are recruited randomly from centralized I/M stations using a formal recruitment/replacement protocol.

To date, a major accomplishment of the FTP study is the cooperation and support of both MVMA and AIAM. The instrumented vehicle component of the FTP study in Baltimore and Spokane was a joint effort with MVMA and AIAM. After EPA designed the basic program and established a contract with Radian Corporation to conduct the testing, the MVMA/AIAM Ad Hoc Panel on the FTP contributed funds and specialized instrumentation to the contractor to augment our base program. The MVMA/AIAM Ad Hoc Panel also agreed to allow EPA to manage the entire data collection effort. The joint goal was to instrument 144 vehicles in each city, for a total of 288 vehicles, as described below:

100	EPA sponsored 3-parameter vehicles
98	MVMA/AIAM sponsored 3-parameter vehicles

90	MVMA/AIAM sponsored 6-parameter vehicles

288	Total

The 3-parameter instrumentation measures vehicle speed, engine speed in revolutions per minute (rpm), and manifold absolute pressure. The 6-parameter instrumentation also collects information on coolant temperature, throttle position, and the air/fuel ratio. The latter instrumentation packages were custom-designed by each manufacturer. The 3-parameter instrumentation was developed by Radian Corporation. At the conclusion of the program, the 55 3-parameter dataloggers were turned over to EPA for future use.

A pilot study was conducted in Spokane on January 6-10, 1992. Alternative solicitation and incentive strategies were evaluated and 4 vehicles were instrumented. Data collection for the full study in Spokane began February 3 and was completed the first week of March. The Baltimore study followed, with data collection completed in early April, 1992.

Chase Car Study

The traditional chase car approach typically involves driving an instrumented vehicle in a manner that simulates the driving behavior of the vehicle being "chased." The methodology used by the Agency in this project is an enhanced version of this traditional approach. The new chase approach uses a chase car which is instrumented with a grill-mounted laser rangefinder. With the laser rangefinder, it is possible to accurately calculate the speed of a target vehicle without the chase car having to emulate the target car's driving behavior. The chase car is driven over representative road routes, which are generated using a transportation network model. The strengths of this approach are its ability to collect driving patterns data for a large sample of vehicles and the virtual elimination of the bias introduced by the drivers knowing that their driving behavior is being monitored.

The laser rangefinder was a modification of a new technology; a hand-held laser gun used by police for identifying speeders. Pilot tests of the laser-equipped chase car were conducted in the summer and fall of 1991. Data collection for Baltimore study began in November of 1991; the contractor, Sierra Research, drove a total of 248 routes finishing December 20. Following enhancements to the laser and other on-board electronic equipment, Sierra Research carried out the CARB-sponsored Los Angeles chase car study in the Spring of 1992. The Spokane chase car study was completed by the end of July, 1992.

AEL Research

The current FTP implicitly assumes that all starts are either "hot" starts (represented by an engine off time of 10 minutes before restart) or "cold" starts (represented by an overnight soak before restart). However, almost half of all restarts in-use occur after a soak period of 10 minutes to 4 hours, for which the engine and catalyst may be in intermediate temperature conditions. The New York State Automotive Emission Laboratory, under a grant from EPA, conducted testing to study the effect of soak time and ambient conditions on engine and catalyst temperatures. To date, AEL has drafted 4 progress reports which presented results of the testing. This information will provide insight into the condition of the engine and catalyst during starts that fall into these intermediate temperature conditions.

Analysis of Driving Behavior Data

Data Summary

The instrumented vehicle and chase car studies have produced very large data sets that must be synthesized to permit useful study. Both surveys collected second-by-second measurements of several variables, resulting in millions of individual data points. Following data collection, EPA's contractors edited these data in order to validate their accuracy and adjust for known limitations of the measurement equipment. Data suspected as being significantly flawed were withheld from subsequent analyses pending more detailed examination.

In the first phase of this data synthesis, EPA constructed lists of summary statistics for the two sets of survey data based on a review of past driving studies and on an assessment of the current project's requirements. These lists were provided to the individual survey contractors, who developed computer programs to generate the requested values. These outputs were furnished to the agency in the form of paper hardcopy as well as electronic data files. The data summary phase offers an initial overview of the survey outcomes and provides inputs to further, more in-depth analyses. In this way, a number of questions can be addressed using a greatly reduced data set and considerably fewer computer resources.

The data summary was designed to comprehensively describe recorded driving behavior and to anticipate the study of emissions impacts. The basic description centers on three aspects of driving: overall speed and acceleration patterns, instrumented vehicle trip or chase car route characteristics, and variation in individual vehicle/driver behavior. Factors suspected to have a disproportionate impact on emissions are given special emphasis. These include the quantity of high acceleration driving and the proportion and type of driving that occurs under cold engine conditions (discussed below).

A number of measures are contained within the basic descriptive categories. In addition to speed and acceleration, a measure known variously as specific power or positive kinetic energy (pke) was compiled. As a composite of the first two values, this measure has been suggested as a useful predictor of high emission episodes, a claim supported by preliminary analysis of emission test data collected as part of this study.

For the instrumented vehicle survey, trip characteristics identified as needing further analysis include:

- time and distance of a trip,
- soak time between trips,
- time in idle versus moving, and
- average speed and specific power.

Vehicle/driver measures needing analysis consist of:

- average daily driving time,
- driving distance,
- number of trips day,
- average stops per hour,
- fractions of time spent at high levels of speed, and acceleration and specific power.

In the chase car study, route measures are similar to the trip measures given above. In addition, statistics are calculated on the portion of survey time during which the laser was locked on a target vehicle.

Several types of summary measures were requested from EPA's contractors. Measures of location and dispersion (mean and standard deviation), minimum, and maximum capture the essential features of a particular sample. Greater detail is found in frequency distributions and their associated graphical display. Because of the concern with the emissions impact of non-FTP high speed, acceleration, and power, the upper percentiles of these distributions are computed explicitly to support more detailed study of these "extremes" of driving behavior. Finally, the combined distribution of speed and acceleration will be tabulated to enable more detailed study of engine load patterns.

The driving behavior surveys collected or identified different factors that could influence driving behavior, such as type of vehicle, location, and road congestion. The summarized data described above will also be broken down by these factors. Analysis of these breakdowns enables the assessment of potential bias as well as the relative influence of measured factors on driving. For the instrumented vehicle study, criteria needing examination for impact on driving behavior include:

- vehicle age,
- vehicle performance,
- transmission type,
- time of day and week,
- driver age,
- recruitment site, and
- observation phase (first day or later).

Criteria collected by the chase car study needing study include:

- road type,
- road grade,
- road congestion level, and

target vehicle performance type.

Survey Bias

In order to judge possible bias induced by the data acquisition methodologies, the study includes several types of comparisons. For the instrumented vehicles, the breakdown by observation phase is used to examine: (1) whether survey participant driving behavior is influenced by the presence of the datalogger; and (2) if any such influence diminishes over time. Another potential concern with the instrumented vehicle data involves driver refusal to participate. Drivers of high-performance or luxury vehicles were less likely to agree to have their vehicles instrumented. If these drivers and vehicles have different operating characteristics than the population at large, it could have a significant impact on the results of the study due to the disproportionate impact of brief periods of high acceleration on emissions. While vehicle solicitation was designed to replace drivers who refused to participate with drivers and vehicles with similar characteristics, the data will also be analyzed to try to determine if bias occurred and, if so, how to analytically correct for the bias.

There are three primary concerns with potential bias from the chase car study. The first is the representativeness of driving behavior on the selected routes to overall driving behavior. The second is the accuracy of the laser rangefinder; i.e., does it properly reflect the speed and acceleration of the target vehicles. The third is whether aggressive drivers are properly represented in the data base. While the methodology used to select vehicles to follow was carefully constructed to ensure the proper selection of all types of drivers/vehicles, the chase car is more likely to lose aggressive drivers prematurely.

Analysis of whether or not this occurred, and determination of analytical methods to correct for this if it did, are in progress.

Another potential source of bias is the locations selected for the driving surveys. Study of the surveys' representativeness to other areas and analyses of the differences in driving behavior for the surveyed areas will permit adjustment of estimates to reflect target populations. With the instrumented vehicle survey, detailed vehicle information can be accessed to enable weighing of summary statistics on vehicle characteristics. For the chase car data, it is possible to compare route features with those of the population. The driver aspect of this analysis is restricted due to the limited collection of driver demographics.

Cold Start Analysis

Because it is known that driving under cold engine conditions contributes much higher emissions than after warm-up, special attention is being given to analyzing cold start driving. The basic issue concerns differences in driving behavior under cold and warm engine conditions, including the initial idle time. This poses a number of problems in estimating the portions of the survey driving that occurred in the cold state. Warm-up time varies with the vehicle, pre-start soak time, initial idle time, and type of driving, making it difficult to classify engine and catalyst temperature. Data from the six-parameter instrumented vehicles include coolant temperature which will be studied for insights into the problem. The work done by the New York State Auto Emissions Laboratory will also help classify starts into cold, warm, and hot categories.

Cycle Development

To assess the impact of non-FTP driving, it is necessary to estimate the difference between emissions predicted by the FTP cycle and emissions that occur in actual driving. Using either computer models or dynamometer testing, this assessment requires the development of one or more driving cycles that are representative of the real world. The driving survey data discussed above will serve as the primary input to this component of the project.

Several approaches to cycle development currently are under review. These vary considerably in level of subjectivity. One approach, used in developing the current FTP, is to splice together segments of real speed patterns that are selected from the survey data. A final cycle is obtained by matching summary features of the resulting speed-time trace with those of the full sample. A virtue of this and related approaches is their basis in real driving experience that can be reproduced in dynamometer testing. The choice of segments and matching criteria are potential difficulties.

A more directly quantitative approach to cycle development is to generate a vehicle speed-time trace using Monte Carlo simulation. Simulated second-by-second values are chosen according to statistical criteria derived from the survey data. Cycles are subjected to matching criteria in order to screen out unsatisfactory candidates. This is likely to be a more efficient method of producing different cycles, but these cycles are wholly "unreal" in comparison to the splicing approach described above.

Emission Assessment of In Use Driving

Approach

In analyzing data from the in-use driving surveys it is essential to consider the emissions impact of the real-world driving patterns that are not represented by the current FTP driving cycle. As discussed, above, this requires assessment of a wide range of driving behavior, factors influencing emissions, and manufacturer calibration strategies. In order to perform these large scale assessments, EPA is developing a computer model which simulates vehicle emissions over any desired driving cycle. EPA is using the modeling approach because it affords flexibility in analyzing the emission impact of the driving survey data and could allow us to conduct a smaller vehicle testing program. A simulation model will allow the emission assessment of a number of unedited and/or composite driving cycles over a large number of vehicles with relative ease. Conversely, a strict vehicle testing-based approach for an initial assessment of the emission impact of in-use driving behavior would limit the assessment to a small number of composite cycles over a relatively small sample of vehicles, and would not allow the needed flexibility for the type of large-scale assessment desired by EPA. Vehicle testing will be used during the course of the emission assessment effort in order to validate the results of the computer simulation model. Contingency testing plans to gather basic emission impact information are also being prepared in case the model proves to be too inaccurate for qualitative analysis.

Emission Simulation Model

The simulation model computes instantaneous fuel and emission rates based on instantaneous vehicle speed. This model is currently being developed as two components, known as VEHSIM and VEMISS.

The VEHSIM component was originally developed by GM and later revised by the Department of Transportation. The VEHSIM model takes instantaneous (generally second-by-second) vehicle speed inputs and calculates instantaneous engine speed and load. These calculations of engine speed and load are performed utilizing vehicle information regarding vehicle aerodynamics, drivetrain, transmission, and engine accessories stored in a database known as a part library.

The second component of the model, VEMISS, was developed by EPA to provide fuel and emission rate calculations based on the engine speed and load inputs produced by VEHSIM. VEMISS uses a series of lookup tables, known as engine maps, to simulate the fuel and emission rates for a particular vehicle. An engine map contains fuel and emission rates over a matrix of engine speed and load. VEMISS implements an interpolation method with the engine map in order to calculate fuel and emission rates for an instantaneous engine speed and load.

Upon completion of VEHSIM and VEMISS, these components will be linked to produce a fully functioning model capable of simulating instantaneous fuel and emission rates based on an inputted speed/time trace.

Engine Map Development

EPA's goal is to determine the emission impact of actual driving behavior on technology that is available today and will likely be available in the next few years. To this end, EPA tested a fleet of 29 late model, current technology, low mileage vehicles which cover a broad range of vehicle types (both car and light truck). The objective is to enable EPA to match the driving characteristics of any vehicle in the driving survey sample with a representative vehicle from the 29 vehicle fleet.

The Agency has completed the testing and development of engine maps for each of the 29 vehicles. Currently, EPA is working to compile the part libraries for these vehicles so that the VEHSIM/VEMISS model will be able to simulate fuel and emission rates using any speed/time trace input for each vehicle in the fleet.

Warm Model Validation

Before the model can be used to confidently assess the emission impact of in-use driving, a validation of the model must be performed. This validation effort is in progress and currently focuses on the component of the model which simulates emissions under warm operating conditions. The purpose of the first phase validation is to assess the accuracy of the warm model and highlight the refinements necessary to improve the accuracy of the model. This is being done by comparing the model output to actual data over a series of test cycles, including the FTP and a high acceleration cycle. Future validations will include comparisons of model results to test results run using new test cycles on a single large-roll electric dynamometer (which should much more accurately reflect in-use emissions). Refinements may include improvements to the engine maps, part libraries, and the model itself. Validation will continue in an iterative fashion for each vehicle as improvements are made.

Cold Model Development

Cold start emission simulations also need to be developed to estimate the impact of cold start driving behavior and soak time. As the cold start simulation will calculate emissions using the warm engine-out emission maps as the starting point, development of the cold start module is being sequenced behind the warm component of the model. Once the warm component is satisfactorily validated, the cold operation component will be developed based on existing test data on the 29 vehicles, integrated into the model, and validated. Upon completion, the model will be able to simulate fuel rate and emissions for an entire vehicle trip.

NPRM Development

The Agency will use the analyses described above in determining whether or not the driving cycle or other aspects of the FTP should be revised to properly represent vehicle emissions during actual driving conditions. However, in any proposal to revise the FTP, EPA would also need to consider various other issues, including:

- Technology assessment
- Type of revision needed
- Lead time
- Cost and cost effectiveness analyses

The technology assessment includes determining the changes needed for manufacturers to reduce emissions during the identified off-cycle condition, the level of reduction achievable with different technologies and/or calibration strategies, and the feasibility of making the technology changes. Closely related issues are cost and lead time, as greater levels of technology change or added component requirements will increase the cost of the regulation and, possibly, increase the lead time needed for manufacturers to implement the changes.

The type of revision to the FTP would also have to be considered. For example, revisions to the existing cycle would impact the usefulness of the vast array of historical data and would require assessments of the impact on CAFE and on the stringency of the emission standards. It may be much more cost effective, instead, to establish a new cycle and standard (much as was done for cold temperature CO emissions, where a new 20 degree cycle was established with a separate standard). If the emission benefits prove to be relatively minor, or if it appears that emissions could be effectively reduced without standards, it might be desirable to simply promulgate stronger defeat device requirements. The basic strategy to improve the FTP would have to be evaluated, as well as the impacts on costs and emission benefits.

Evaluation of this wide array of control strategies, technology requirements, standard stringency, costs, and benefits is a complex task. The level of complexity will be significantly impacted by the results of the study in regards to the level of off-cycle emissions and the type of driving generating the emissions.

Status and Plans

The above sections describe the programs being implemented by EPA to assess the emissions impact of driving behavior. This section outlines the tasks completed to date, work in progress, and plans to complete the study. In order to keep this outline reasonably simple and understandable, only very brief statements are made to describe each item. The purpose of this section is simply to show how all the pieces come together to complete the study. Detailed descriptions of each piece have already been presented in the previous sections of this report.

1. Tasks Completed to Date

A. Driving Behavior Assessment

Vehicles instrumented:
- Spokane - 102 3-parameter
  - 42 6-parameter
- Baltimore - 113 3-parameter
  - 37 6-parameter
- Atl. (ORD) - 110 3-parameter

Chase car:
- Spokane - 249 routes
- Baltimore - 248 routes
- L.A. (ARB) - 202 routes

Data processed (Baltimore and Spokane)

Summary statistics defined

1st draft data summaries:
- Spokane instrumented veh
- Baltimore instrumented veh
- Baltimore chase car

Cool-down study (N.Y. AEL):
- 6 vehicles tested
  - 4 progress reports

B. Emission Assessment

29 vehicles mapped:
- 1990-92, MPI
- 40-55 steady state points
- 7 cold start steady state
- FTP
- Calif. accel cycle

Data downloaded to PC

Engine torque calculated

Warm emission module written
  (VEMISS)

1st cut evaluation of maps

2. Work in Progress

A. Driving Behavior Assessment

Trip definition
Bias analyses/correction
Recovery of suspect vehicles
Process Atlanta data
Phase I warm speed/accel
   analysis (inst. veh.)

B. Emission Assessment

Test programs:
   Torque verification
   Soak time emission impact
Compile parts library
Develop databases
Validate warm modeling/maps
   (2 vehicles)
Summarize test data - all veh.

3. By January, 1993

A. Driving Behavior Assessment

Complete cooldown analysis (AEL)
Analyze:
   Trip length and soak time
   Cold start driving behavior
   Warm driving behavior

B. Emission Assessment

Begin cold start model development
Enhance part library data
Validate VEHSIM/part library methodology
Compare modal data to VEMISS predictions
Assess modeling effectiveness, inc. testing validation
Develop contingency test plan

4. By March, 1993

A. Driving Behavior Assessment

Develop warm driving cycles

Analyze effects of driving behavior influences on:

trips and soak time

cold driving

warm driving

Compile draft of driving behavior study for review
Hold public workshop on analysis of driving behavior study

B. Emission Assessment

Compile cold start database
1st cut warm speed/accel emission evaluation
Compile/validate part libraries - all vehicles

5. By May, 1993

A. Driving Behavior Assessment

Publish preliminary technical report; request public comment

B. Emission Assessment

Validate warm VEMISS/maps on rest of vehicles

6. By September, 1993

A. Emission Assessment

Complete enhancements to model
Complete cold start module
Validate model with test data
Assess emission impact of all driving behavior

7. By November, 1993

Final study report, including recommendations, ready for internal Agency review; begin development of an NPRM to revise the FTP or a notice of intent to not revise the FTP.