EPA's Survey of In-Use Driving Patterns: Implications for Mobile Source Emission Inventories

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ABSTRACT

Preliminary data on in-use driving behavior and vehicle emissions are presented in this review of the Federal Test Procedure (FTP) Review Project. The driving surveys suggest that certain in-use driving modes, such as high speeds and high accelerations, are not represented by the FTP. Also, in-use start driving behavior, trip length, and the distribution of soak times all differ from their FTP representation. Through a limited vehicle emission test program, EPA evaluated the emission impact of the above factors, as well as the emission impact of road grade and air conditioning. In looking at the emission inventory implications of the test results, several pieces stand out. Emissions for HC, CO, and NOx were all higher for in-use driving relative to the FTP; the largest increase was in CO emissions. Start driving and soak effects impacted NOx and HC emissions. The use of air-conditioning had a large impact on NOx emissions, while road grade significantly elevated CO emissions.

INTRODUCTION

This paper presents EPA's preliminary findings on in-use driving behavior and vehicle emissions. The data were collected as part of EPA's Federal Test Procedure (FTP) Review Project. EPA contracted for several large-scale studies of in-use driving patterns in order to assess the adequacy of the driving cycle used in the current FTP. While the principal focus of the Congressionally mandated project was to evaluate the need for regulatory revisions, the data and analyses are equally relevant to the understanding of motor vehicle emission inventories. The driving behavior characteristics covered here are: soak time, start driving, and speed and acceleration not represented the current FTP. Two additional factors, air conditioning and road grade, are examined for their potential emission impact.

Following this introduction, the paper is divided into five sections. A brief review of the in-use driving surveys along with the key findings are presented first. This is followed by a discussion of EPA's cycle development efforts. The third section discusses the vehicle emission testing program and the forth section presents an emission assessment based on the results of this test program. The last section summarizes the preliminary implications for current emission inventories.

DRIVING SURVEYS

With support from the American Automobile Manufacturers Association (AAMA) and the Association of International Automobile Manufacturers (AIAM), EPA conducted surveys of driving behavior in Baltimore, MD, and Spokane, WA. Two methods of data collection were employed. In an instrumented vehicle study, 113 Baltimore and 102 Spokane vehicles were equipped with "3-parameter" datalogger packages that recorded second-by-second speed and two other variables during 7-10 days of vehicle operation. As part of the same surveys, the manufacturers recruited 79 vehicles for study using "6-parameter" instruments designed to measure additional variables. A separate chase car study collected similar speed data in the two cities using a laser device mounted on a patrol car that tracked in-use target vehicles. Compared to the instrumented vehicle approach, the chase car approach produced relatively short sequences of data, but on a much larger sample of vehicles.

The Baltimore and Spokane surveys were supplemented by data collected in two other cities. EPA's Office of Research and Development sponsored an instrumented vehicle study in Atlanta, GA.

Also, the California Air Resources Board (CARB) sponsored a chase car study in Los Angeles similar to the chase car studies in Spokane and Baltimore.

In May of this year, EPA published the "Federal Test Procedure Review Project: Preliminary Technical Report[1]." This report presented a detailed discussion of the development of the driving survey methods, data collection, and preliminary analyses of the driving survey data. For reasons relating to representativeness, availability, and precision of the survey data, most of the discussion in the report and all discussion in this paper are confined to driving observed in the Baltimore 3-parameter instrumented vehicle study. The key findings are discussed below.

Speed and Acceleration

Speeds were much higher in Baltimore than are represented on the FTP. The average speed in Baltimore was 24.5 mph (median speed was 23.7). The speeds observed ranged to almost 95 mph; 6.4% were above 60 mph and 2.6% above 65 mph. By comparison, the FTP has an average speed of 19.6 mph with a maximum of 56.7 mph. About 8.5% of all speeds in Baltimore exceeded the FTP maximum.

Acceleration rates in Baltimore were also significantly higher than those on the FTP. The acceleration rates observed ranged up to 15 mph/sec, with a standard deviation of 1.5. The FTP has a maximum acceleration rate of 3.3 mph/sec and a standard deviation of 1.4. About 2.5% of all driving in Baltimore exceeded 3.3 mph/sec.

Power-related measures also indicate that the observed driving behavior was more aggressive than the FTP. Specific power[a] for the Baltimore sample ranged up to 558 mph^2/sec and averaged 46.0, with a median of 34.7. The FTP has a maximum power of 192, average of 38.6, and median of 21.6. An analysis was also done of the scatter of speed-acceleration points occurring in the Baltimore sample outside the FTP envelope of speed and accelerations. These points represent about 18% of total Baltimore driving time.

Vehicle Age. Newer vehicles (1983 and later) had higher average speeds than older vehicles (25.1 mph v. 21.2 mph), were driven somewhat longer and farther per day, and averaged fewer trips and slightly fewer stops per mile. The data indicate that newer vehicles spend more time at high speeds and are used for longer trips than older vehicles. However, analyses of the aggressiveness of the driving behavior, as measured by acceleration and power distributions, indicate very little difference between older and newer vehicles.

Vehicle Type. Speed distributions were fairly similar for each of the three categories analyzed; trucks, sedans, and high performance vehicles. However, high performance vehicles demonstrated more aggressive driving behavior than the other classes, with over twice as much operation at power levels above 200 mph^2/sec.

Trip Patterns

Average in-use trip lengths are much shorter than the FTP, which represents a 7.5 mile trip. The average observed trip[b] covered 4.9 miles. The median value of trip distance indicates that "typical" trips are even shorter, only 2.5 miles. One of the in-use impacts of shorter trips is that a much

[a]The power needed from an engine to accelerate a vehicle is proportional to both the vehicle speed and the acceleration rate. Thus, neither variable, by itself, is a good measure of the load placed on the engine during acceleration. The joint distribution of speed and acceleration is the best measure, but it must be examined in three dimensions, which is difficult to visualize and comprehend. While not as good as the joint distribution of speed and acceleration, the best two-dimensional measure is "specific power," which is roughly equivalent to (2 * speed * acceleration). This measure has the units mph^2/sec.

[b]For this analysis, a trip has been defined as beginning when the engine is turned on and ending when the engine is shut off (although engine off times of less than 18 seconds are ignored).

higher proportion of overall driving is done within 0.67 mile of vehicle starts (12.0% v. 8.9% on the FTP), prior to engines and catalysts reaching normal operating temperatures. The frequency of stops on the FTP is also uncharacteristic of in-use trips; the average distance between stops on the FTP is only 0.41 miles compared to 0.87 in Baltimore. Despite these differences, the FTP and Baltimore trips disagree only slightly in the proportion of time spent in the four operating modes: idle, cruise, acceleration, and deceleration.

Vehicle Soaks

The in-use data contains a large proportion of intermediate soak periods (that is, the time between the end of a previous trip and the beginning of the next one) that are not reflected on the FTP. The FTP contains soak periods of 10 minutes and 12-36 hours; almost 40% of all soak periods in Baltimore were between 10 minutes and 2 hours. As catalysts cool off much faster than engines and most are almost completely cold in about 45-60 minutes, this is a potential emission concern. Analyses indicate that only about 30% of all in-use starts occur with catalysts hot enough to be immediately effective; the FTP implicitly assumes that 57% of all starts occur with hot catalysts. On the other hand, the FTP implicitly assumes that 43% of all starts occur with cold engines, while less than 25% of in-use starts occur with cold engines.

Trip Start Driving Activity

While the FTP has lower speeds and is less aggressive than in-use driving behavior, overall, the reverse occurs for the first few minutes after a vehicle start. The average observed speed during the first 80 seconds of all trips (the initial idle period was not included in this period) was only 14.4 mph, compared to 23.1 mph for the first micro-trip on the FTP. The average in-use speed 81-240 seconds into the trip was 22.8 mph, compared to 29.8 for a comparable period on the FTP. The aggressiveness of the FTP was also off substantially, with the first micro-trip on the FTP substantially less aggressive than in-use driving and the second FTP micro-trip much more aggressive.

CYCLE DEVELOPMENT

The next step after the analysis of the driving patterns data was to assess the exhaust emissions during such driving. This required reduction and synthesis of the driving data into "representative" driving cycles for use in vehicle testing. EPA's approach to cycle development involved the selection of actual segments of in-use driving which best matched the joint in-use distribution of speed and acceleration. The data set used in developing the in-use cycles was the driving survey data from Baltimore (discussed above) and the Los Angeles chase car data. EPA felt cycles targeted at different types of driving were necessary to capture the full range of in-use driving, given the nonlinearity of emissions associated with certain driving behavior. In particular, a separate non-FTP cycle was needed to properly characterize infrequent, high load events which occur in-use.

Cycle Methodology

Under contract with EPA, Sierra Research developed a number of driving cycles intended to represent the range of in-use vehicle operation. In generating a cycle, entire micro-trips (idle-to-idle) were the basic building blocks used to match the "target surface" of the joint distribution of speed and acceleration.

The cycle generation software developed for this task uses an iterative technique to find the combination of microtrips which best match the target surface. The first step involves the random selection of a specified number of microtrips. Their speed-acceleration surface is computed and compared to the target surface. The software then searches for the microtrip which provides the best incremental fit to the target surface. This micro-trip is then added to the cycle and the process is repeated until the desired cycle length is reached. In this manner, a large number of cycles can be generated (several thousand) for the selection of the "best" cycle. Final selection of the "best" cycle is made by examining the differences between the speed-acceleration surface of each of the candidate cycles and the target surface.

Start cycle. The start cycle (see figure 1, seconds 1-257) represents driving which occurs during the first four minutes after the start of the vehicle (excluding the initial idle). The driving characteristics of start portion are important because of their potential impact on engine and catalyst warm-up, and thus, emissions. The cycle was developed by matching the in-use data set's joint speed and acceleration distribution for 3 successive 80-second segments of driving after vehicle start.

Non-FTP cycle. This cycle is intended to represent the distribution of speeds and accelerations which are outside the boundary of the FTP. However, using entire micro-trips as the building blocks makes it impossible to create a cycle which is exclusively non-FTP driving. About 30% of the non-FTP cycle (figure 1) is actually FTP-like driving. In analyzing the emissions from this cycle, the cycle was divided into a high speed portion (seconds 1-1182) and a high acceleration portion (seconds 1183-1386)

Remnant cycle. The remnant cycle was developed in order to have a set of cycles which represent the full-range of in-use driving (see figure 1, seconds 258-1494). As the name suggests, this cycle represents that portion of in-use driving which is not represented by the non-FTP cycle or the start cycle. As a result, much of the cycle is FTP-like driving, although there are segments of non-FTP driving (low speed, high acceleration) which were not represented by the non-FTP cycle.

VEHICLE EMISSION TEST PROGRAM

The objective of EPA's FTP Test Program was to assess the emissions from well-maintained, current technology vehicles over the in-use cycles. Nine vehicles representing a range of vehicle and engine types were selected for a limited test program. Table 1 describes the eight vehicles which completed the program (one vehicle was lost due to malfunctions). EPA's testing was done in coordination with test programs sponsored by AAMA/AIAM and the California Air Resources Board. Both test programs are in progress; the results from these programs will greatly enhance EPA's limited testing.

Driving Behavior Testing

Baseline FTP tests were run on each vehicle to make sure it complied with current emission standards. All of the in-use testing was designed to test the vehicle in a hot, stabilized condition; the effect of cold start emissions was explicitly excluded for this portion of the test program. In addition to the in-use cycles, bag 1(505) and bag 2 of the FTP driving cycle were tested in a hot, stabilized condition for comparison purposes. Bag emission data were collected, as well as one-second engine parameters and catalyst temperatures. A replicate test was run for each cycle.

Vehicle Soak and Trip Start Driving Behavior Testing

Unlike the other components of the testing program, this part specifically examined the impact of soak periods and start driving behavior on vehicle emissions. A subset of 4 vehicles (the Crown Victoria, Chevy Sonoma pickup, Dodge Intrepid, and Saturn) were tested using the new start cycle after a series of different soak times: 10 minutes, 20 minutes, 30 minutes, 45 minutes, 60 minutes, 90 minutes, 2 hours, and overnight. For comparison, complete FTPs were conducted to establish 10 minute and overnight soak emissions using the FTP driving cycle. Also, to assess the potential emission reductions from an intermediate soak emission standard, the above soak tests were repeated on each vehicle after insulating its catalyst. Bag emission data were collected, as well as once-per-second engine and catalyst temperatures. A replicate test was run for each cycle.

Air Conditioning and Road Grade Testing

The objective of both the air conditioning and road grade testing was to get a rough estimate of the magnitude of their emission impact. EPA lacked activity data on both factors, so we were compelled to use "reasonable" simulations. In the case of road grade, the dynamometer load was adjusted to simulate a constant 2% road grade throughout the entire test cycle. The air conditioning approach was simple and direct; the air conditioning was turned on to maximum with maximum fan setting. The testing was done on the in-use cycles for a subset of vehicles: the Crown Victoria, Saturn SL, and Honda Accord.

EMISSION ASSESSMENT

Driving Behavior

Figure 2 presents a summary of the emission results for the 8 vehicles in the FTP test program. The data are expressed in both grams per mile and grams per minute for comparison purposes. As previously mentioned, all tests were run with the vehicle in a hot stabilized condition including the FTP driving cycles (505 and bag 2) . The highest grams per mile emissions were found on the high acceleration portion of the non-FTP cycle. The high speed portion of the non-FTP cycle produced high emissions on a grams per minute basis; however, due to the high average speed, the grams per mile numbers were much lower. This is an excellent example of the sensitivity of grams per mile estimates to average speed.

In order to assess the significance of the non-FTP emissions, proper weighting factors need to be applied. The in-use and FTP cycles have explicit weights associated with their representation of in-use vehicle operation. The weights are shown in table 2.

As shown in figure 3, the weighted "in-use" emissions are significantly higher than the weighted FTP emissions. HC increased by 0.05 grams/mile, CO jumped by 2.6 grams/mile, and NOx rose by 0.06 grams/mile. The comparable grams per minute results showed slightly larger percentage increases for all 3 pollutants, a reflection of the relatively high grams per minute emissions on the high speed portion of the non-FTP cycle. (Note, the remainder of this paper will be limited to reporting gram/mile results, as is conventional; the reader is encouraged to consider the alternative grams per minute approach.)

Figure 4 presents the in-use/ FTP comparison for each of the 8 vehicles tested. While one shouldn't draw conclusions from a single vehicle's behavior, two points can be inferred from the bar charts. First, the overall in-use increase in HC and CO emissions are fairly consistent for all the vehicles tested. However, the average NOx increase of .06 grams per mile can be attributed almost exclusively to two vehicles: the Ford Crown Victoria and Dodge Intrepid. This high and variable NOx emission response is not fully understood and requires further investigation.

The increase in in-use emissions relative to the FTP cannot be credited to a single driving mode or condition. In evaluating the relative significance of the in-use components, their contribution to the increase was calculated as:

(In-use component - FTP) * in-use component weighing factor

The total difference between in-use and FTP emissions is the sum of the weighted differences.

Figure 5 shows each in-use component's contribution as a percent of the total increase. The results suggest that while "non-FTP" driving accounts for a large fraction of the increase (28% to 61%), the other in-use driving modes also make significant contributions, especially for HC and NOx. Some of the observed emission increases were unexpected. For example, substantial emission increases for all three pollutants were observed on the Remnant cycle; such increases were not predicted given the Remnant cycle's similarity to the FTP in speed and acceleration. One possible explanation is that the emission increases are associated with the greater degree of speed variation found on the in-use cycles compared to the relatively "smooth" FTP cycle. An analysis of jerk, the second derivative of speed, should help to quantify this concept of speed variation. EPA also plans to examine the second-by-second emission data which are being collected in the auto manufacturers' test program.

Vehicle Soaks and Trip Start Driving Behavior

In order to calculate the in-use impact of soak periods, the frequency distribution of soak times was used from the Baltimore data set. In addition, the first 1.4 miles of driving on the new start cycle was weighted by the in-use proportion of start driving, which is about 25% higher than the implicit weighting of the first 1.4 miles on the FTP. Figure 6 compares the in-use weighted emissions over the first 3.6 miles of driving to the weighted bag 1/bag 3 results from the FTP. (The test results are for only three of the four vehicles tested, as the Sonoma pickup behaved erratically during the test program).

This comparison of in-use start emissions to FTP start emissions is impacted by four different factors:

1) *Proportion of start driving.* As used here, this is the proportion of overall driving that occurs within 1.4 miles of the vehicle start, which is 25% higher in-use than on the FTP.
2) *Soak distributions.* There is a high proportion of "intermediate" soak periods (i.e. between 10 minutes and 2 hours) in-use that are not represented on the FTP, with the result that the FTP overestimates "cold" engine starts and underestimates "cold" catalyst starts. While these tend to be offsetting factors, they could become significant under specific in-use conditions.
3) *Start driving impact.* Compared to the FTP, the start driving cycle has lower speeds, is slightly more aggressive, and has substantially more minor speed variations. This results in higher emissions, overall, but the effect appears to be small and is hard to separate from the larger impacts due to vehicle soaks.
4) *Effect of start driving behavior on engine and catalyst warm up.* The data indicates slightly larger increases in emissions on the new start cycle compared to the FTP after an overnight soak than after a 10 minute soak. This means that the new start cycle may impact how the engine and catalyst warm up, causing slightly increased emissions during the warm up period. However, the effect appears to be small and is hard to separate from the large impact of overnight soaks on vehicle emissions.

Of these four factors, the proportion of start driving was clearly the most important on the three vehicles tested. EPA plans to conduct further soak/start testing to better quantify the different factors involved.

Intermediate Soak Emission Reduction. The current FTP incorporates only a 10 minute and an overnight soak period. Thus, manufacturers have had no incentive to reduce emissions during starts after intermediate soak periods (i.e. 10 minutes to 2 hours). As engines stay reasonably hot for several hours after they are shut off but catalysts cool off relatively quickly, regulating vehicle emissions after an intermediate soak period may prove to be feasible and cost-effective. One possible method to improve emissions would be to slow the rate of catalyst cooldown. To investigate the potential emission benefits from such a strategy, EPA repeated the series of tests over different soak periods after insulating the catalyst. The results on the three cars are presented in Figure 7. The average emission reductions on these three vehicles (two of which included close-coupled catalysts), weighted over all in-use driving, were 0.040 grams per mile HC, 0.2 CO, and 0.028 NOx. While these reductions have no application to existing emission inventories, they may apply to future emission inventories should EPA establish intermediate soak standards.

Air Conditioning and Road Grade

The emission assessment for road grade and air conditioning(A/C) was based on the emissions from the start, non-FTP, and remnant cycles weighted together. As for driving behavior analyses, all emissions are for a fully warmed up vehicle. For the three vehicles tested, figure 8 compares baseline emissions (no A/C or road grade) to the results from the A/C and road grade simulations. The effect of road grade was greatest for CO, with an average increase of 3.2 grams/mile. Nox emissions also increased by 0.11 grams/mile; however, most of the incre•se can be attributed to the sharp increase for the Crown Victoria. The increase in HC was quite small for all vehicles..

The results for air conditioning tests were less clear. The impact on HC and CO was very small for the Crown Victoria and the Accord; on the other hand, the Saturn's CO emissions increased by 5.7 grams/mile. Of greater concern is the large increase in NOx emissions exhibited by all three vehicles with the A/C turned on. The average NOx emissions increased by 0.21 grams/mile. Like road grade, the impact of A/C should be directly related to the increased load placed on the engine. The A/C results suggest that additional factors are involved which result in NOx emissions being particularity sensitive to the use of air conditioning. EPA plans to conduct additional testing in order to better understand the causes of the emission increases with air conditioning.

INVENTORY IMPLICATIONS

Test Result Implications

The primary purpose of the driving surveys and emission testing described above was to evaluate the need for regulatory revisions. Much of the work, however, has clear implications for mobile source emission inventories. The test results suggest that emission estimates for in-use driving behavior are likely to be understated. Current approaches to estimating start emissions are also likely to underestimate in-use emission levels. Air conditioning and road grade both appear to result in substantial emission increases. Air-conditioning had the greatest impact on NOx; for ozone non-attainment areas this may be of great concern since air conditioning usage is likely to be greatest during periods of peak ozone formation. Road grade seems to be primarily a CO issue, which is likely to be important to CO nonattainment areas which feature significant grades.

Table 3 presents our preliminary estimate of the in-use impacts for these four components. A rough adjustment (test results were cut in half) was made to the upper end of the road grade estimate range in recognition that vehicles spend as much time going down as going up a grade. In the case of air conditioning, the test results were reduced by 40 percent in an attempt to account for air conditioning usage (in addition, the CO result is listed as a range starting from zero in recognition that most areas do not have summertime CO exceedences). Both adjustments are admittedly crude and future work is needed in developing activity factors. Included at the bottom of the table is the potential impact on future emission inventories associated with the assumed adoption of intermediate soak standards; such standards would actually cause a decrease in future inventories compared to current inventory assessments.

Other Inventory Implications

As the principal focus of this project is to evaluate the need for regulatory revisions to the FTP, only modern technology, properly operating vehicles that are representative of future vehicle production have been tested. In addition, because of work being done in other areas to improve the evaporative emission test procedures, no evaporative emission testing was conducted. Thus, there are several in-use factors that were not included in EPA's test program that may also significantly impact emission inventories.

Current Vehicle Fleet. The emission impact on older vehicles in the current in-use vehicle fleet is likely to be different than the test results presented from modern, properly operating vehicles. Carburetors and, to a lessor extent, single-point injection systems offer less precise fuel control than the multi-point injection systems on all but two of the eight test vehicles. It is likely that these older fuel systems will have larger gram/mile increases during the higher speed, higher load, and more variable cycles representative of in-use driving behavior. On the other hand, these older vehicles also have higher emissions during normal operation and vehicle starts and tend to have a higher incident of malfunctions; all of which raise the baseline emissions compared to modem, multi-point fuel injected vehicles. Thus, the emission impact on a percentage increase basis may be smaller for older vehicles, even though the grams/mile increase is likely to be larger.

Evaporative Emissions. One of the most significant findings of the instrumented vehicle driving surveys is that in-use trip lengths are much shorter and there are more trips per day than previously thought. This is likely due to stops taken for errands and short hops between stores. These factors may have a very large impact on hot soak evaporative emissions. The larger number of trips results in more hot soak evaporative events that the canister must absorb, and the short trips suggests that the vehicle does not have as much time to purge the canister between events. This combination may cause in-use hot soak emissions to be much higher than is currently modelled (as an aside, it should be noted that this may also increase the cost and/or reduce the effectiveness of catalyst preheaters). The high proportion of intermediate soaks, instead of long soaks, and high number of trips per day may also impact diurnal evaporative emissions and the relative distribution of hot soak and diurnal emissions.

In conclusion, results from of the FTP Review Project suggest a number of in-use driving modes or factors which are not adequately accounted for in current emission inventories. Further work, focused exclusively on emission inventories, is needed to build on these early findings.

Positions and opinions advanced in this paper are those of the authors and not necessarily those of the Environmental Protection Agency.

References

1. *Federal Test Procedure Review Project: Preliminary Technical Report*, EPA 420-R-93-007; U.S. Environmental Protection Agency, May 1993.

Table 1. Description of vehicles in FTP Test Program

Vehicle	Displacement (Liters)	Weight/Power (ETW/Net HP)	Fuel System
1992 Ford Crown Victoria	4.6	21.05	MFI
1991 Honda Accord	2.2	27.00	MFI
1992 Dodge Dakota	5.2	17.39	MFI
1991 GMC Sonoma	2.8	27.00	TBI
1993 Dodge Intrepid	3.3	24.21	MFI
1993 Mercedes 400SEL	4.2	16.67	MFI
1992 VW Golf	1.8	27.50	MFI
1993 Saturn SL	1.9	32.35	TBI

MFI=multi-point fuel injection
TBI=throttle body injection

Table 2. In-use weighting factors for hot, stabilized driving

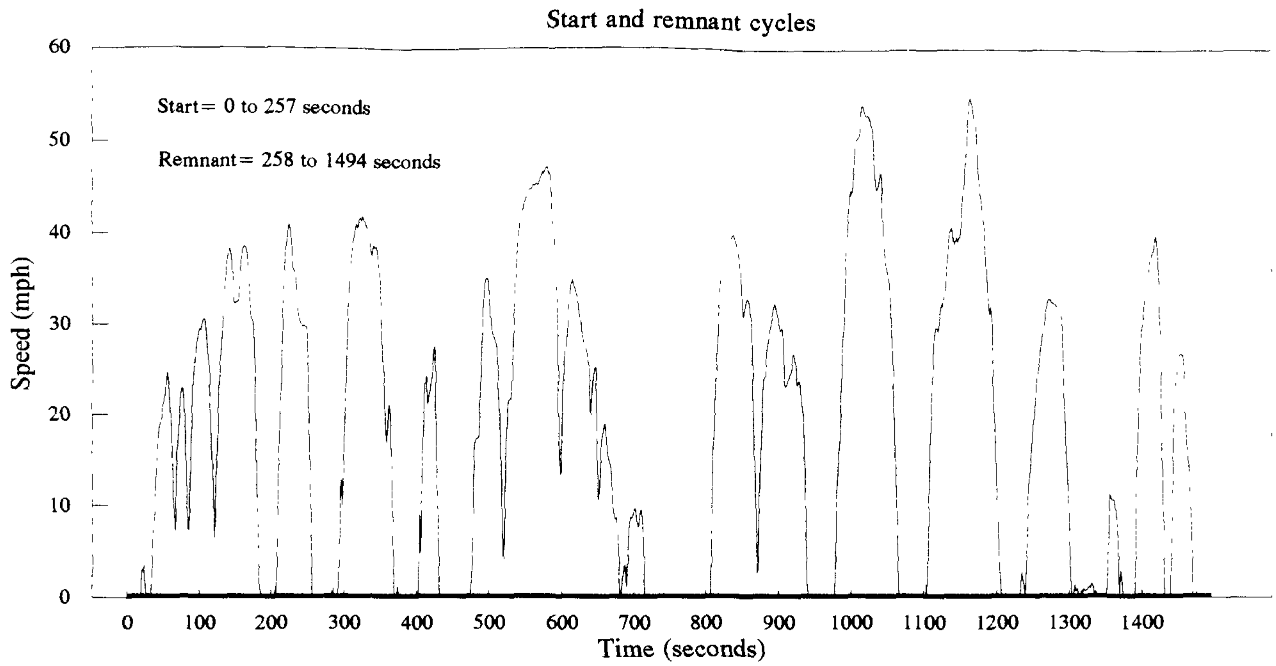
	Fraction of total distance (grams/mile)	Fraction of total time (grams/minute)
FTP		
Bag 1	0.48	0.368
Bag 2	0.52	0.632
In-use		
Start	0.24	0.296
Remnant	0.48	0.581
Non-FTP high speed	0.264	0.105
Non-FTP high accel	0.016	0.018

Table 3. Preliminary estimates of emission inventory impact (grams/mile)

	HC	CO	NOx
In-use driving	0.05	2.6	0.06
Soak/start effects	0.05	0.4	0.10
A/C operation	0.02	0 - 1.4	0.12
Road grade	0 - 0.02	0 - 1.6	0 - 0.06
Total	0.12 - 0.14	3.0 - 6.0	0.28 - 0.34
Intermediate soak standards*	(0.04)	(0.2)	(0.03)

*Potential reduction in future emission inventories associated with assumed adoption of intermediate soak standards.

Figure 1. In-use driving cycles



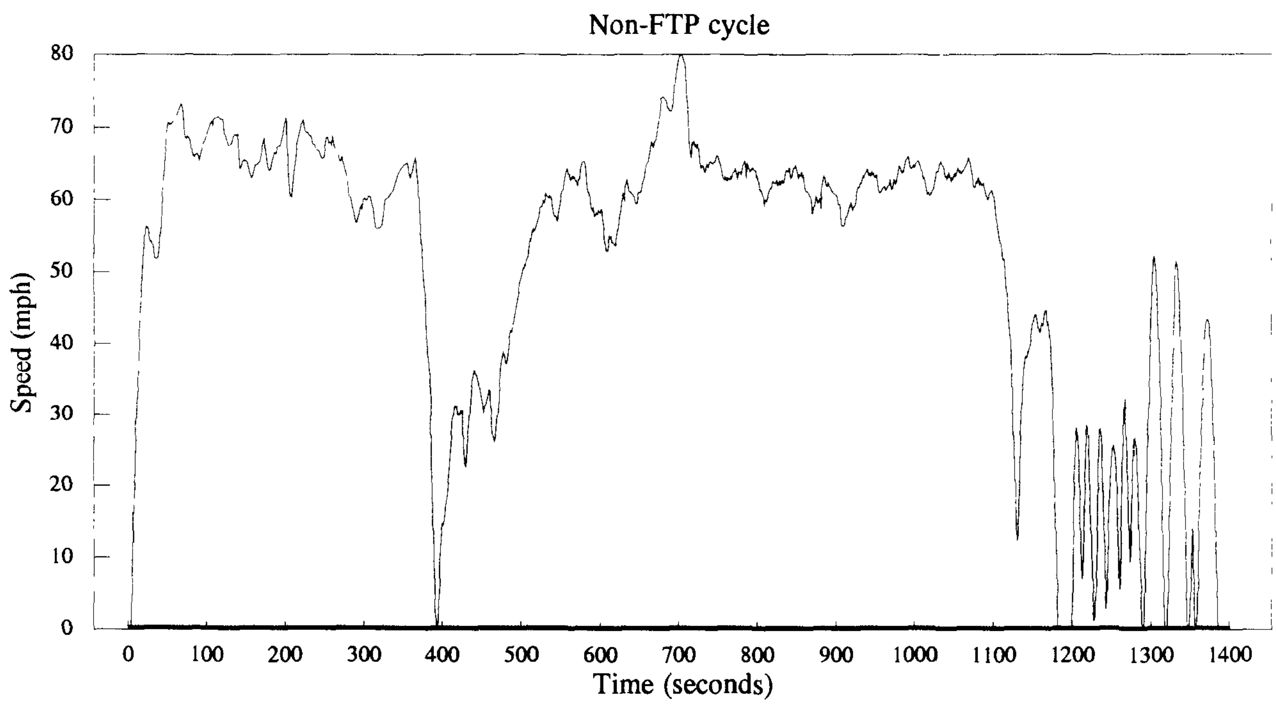


Figure 2. Comparison of unweighted emissions from individual in-use and FTP driving cycles (hot stabilized)

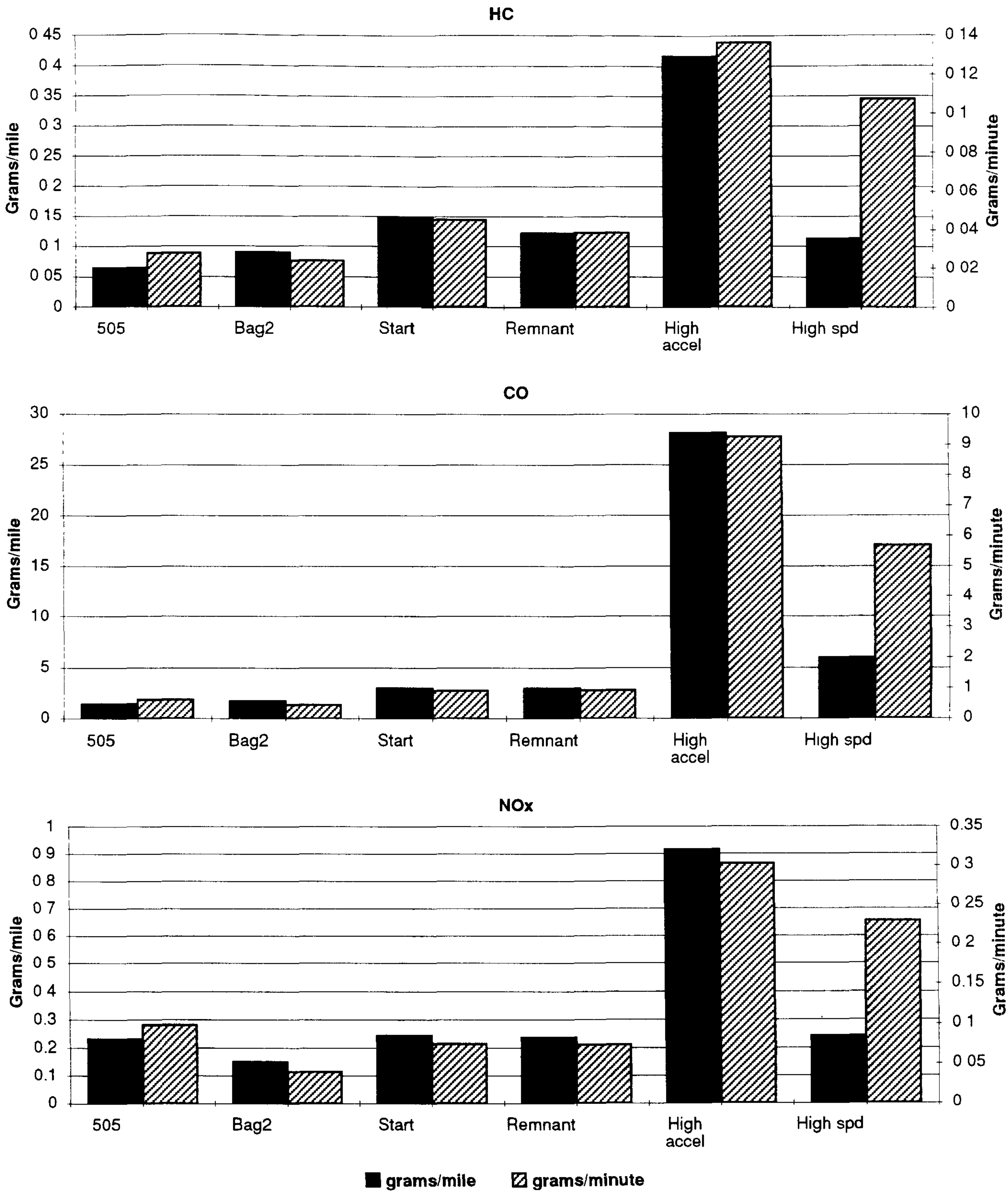


Figure 3. Comparison of weighted emissions for in-use and FTP driving cycles (hot stabilized)

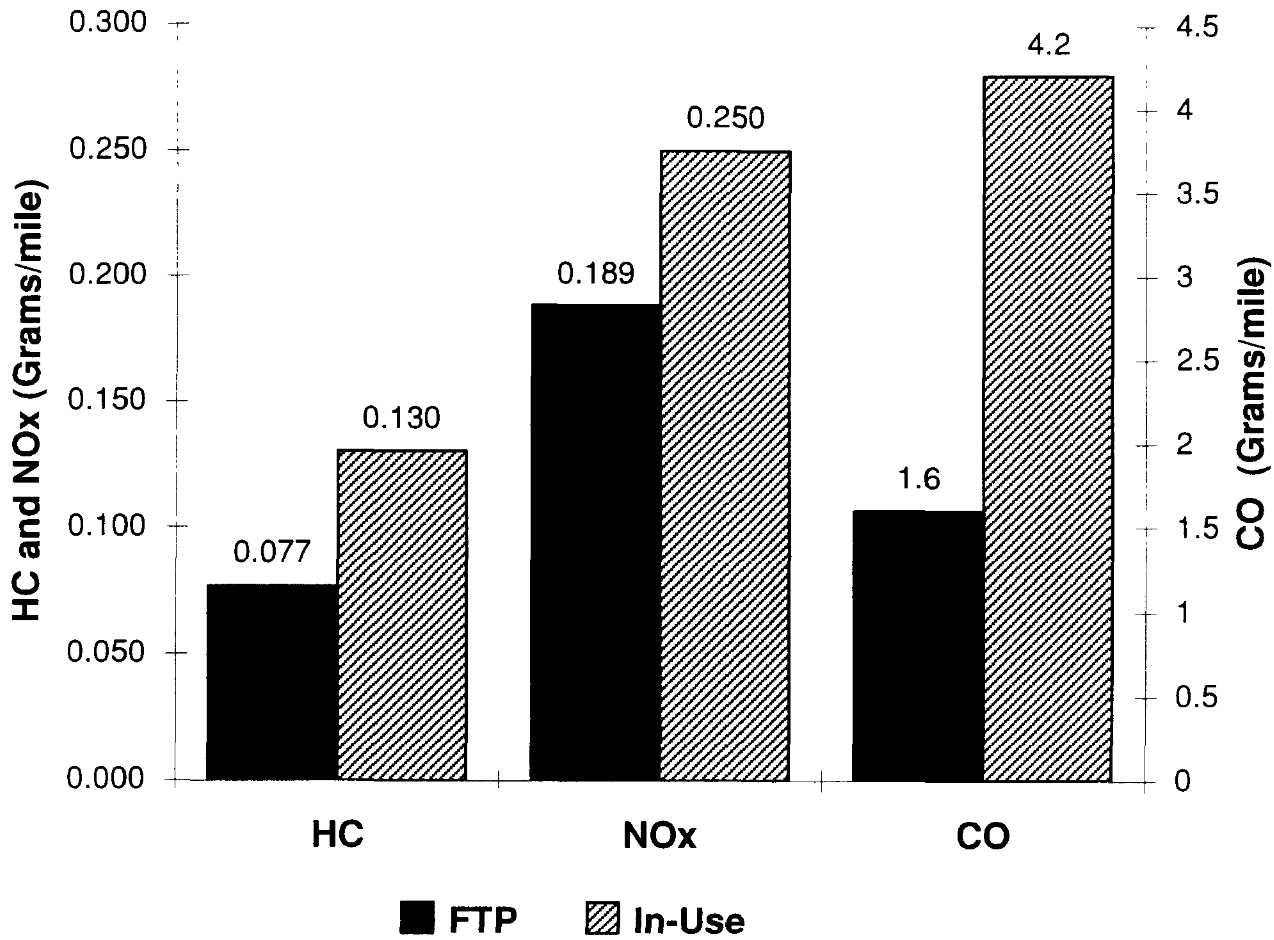


Figure 4. Comparison of weighted emissions for In-use and FTP driving cycles by vehicle (hot stabilized)

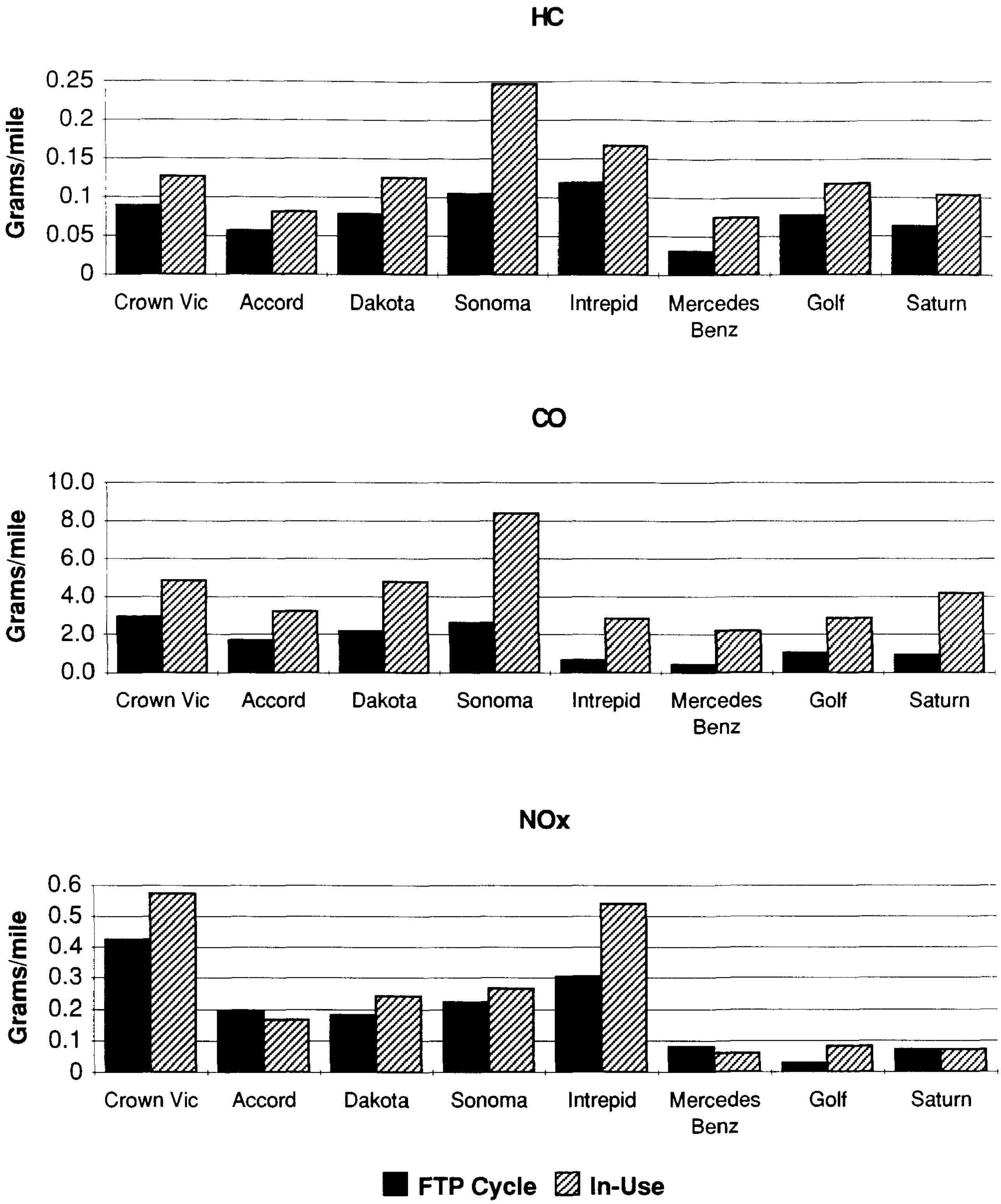


Figure 5. In-use driving modes contribution to emission increase (percent of total increase)

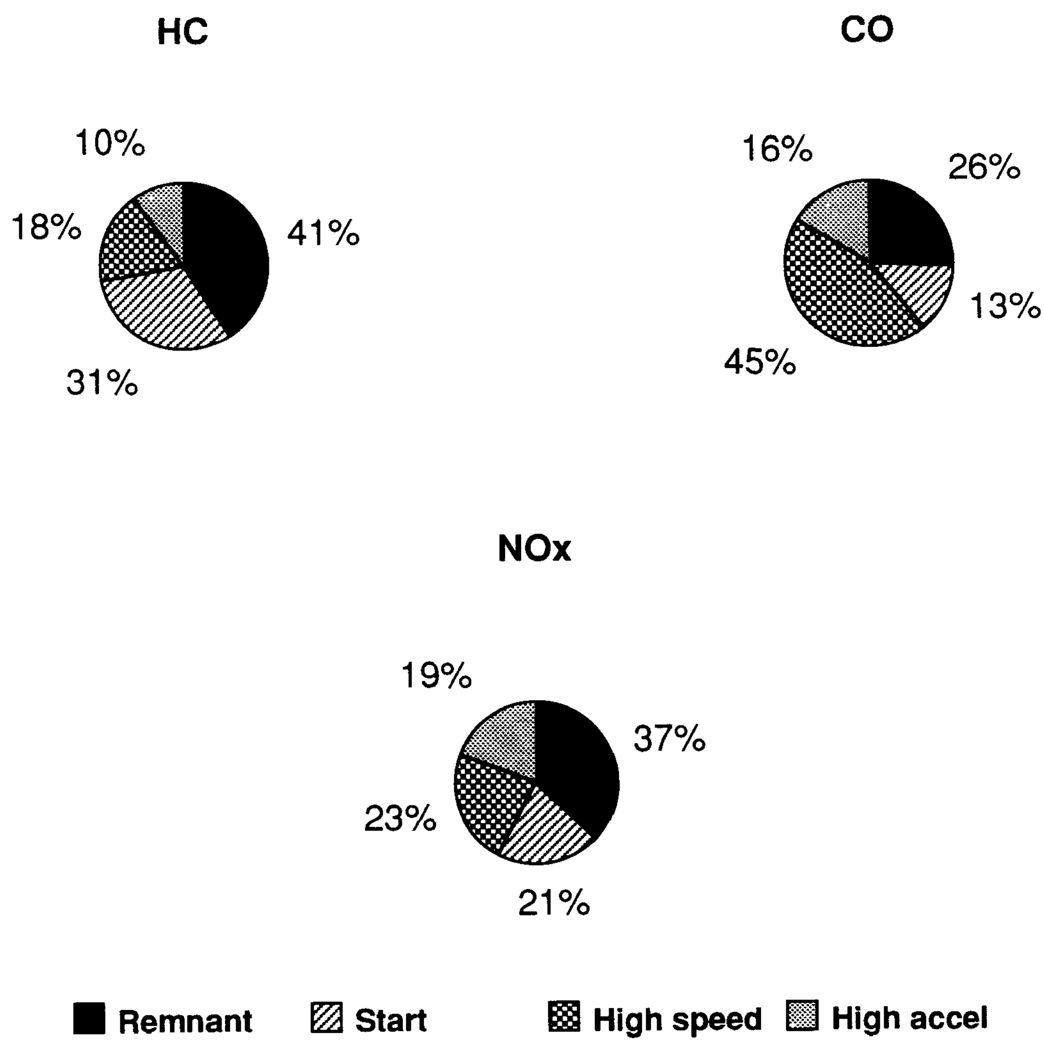
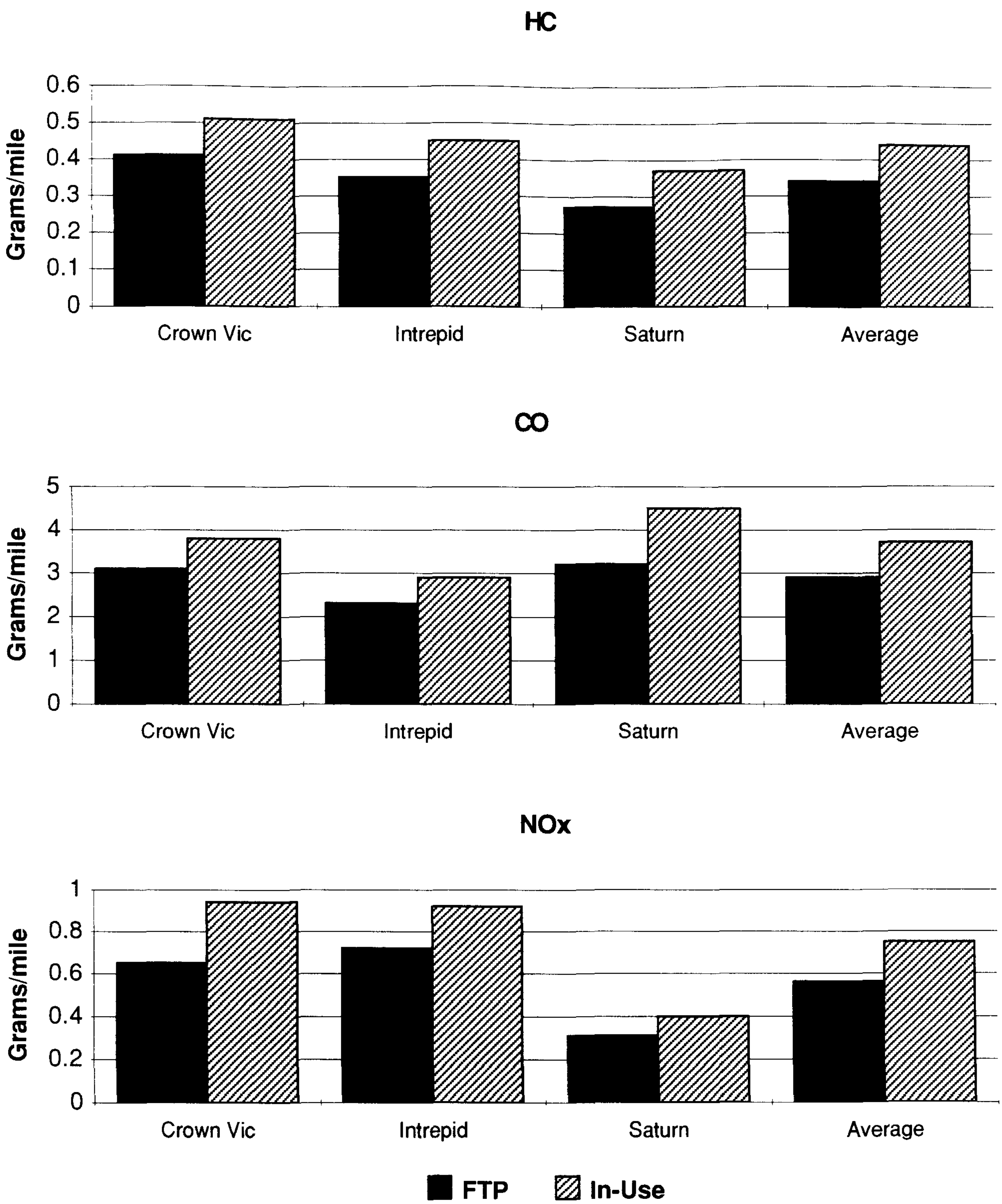
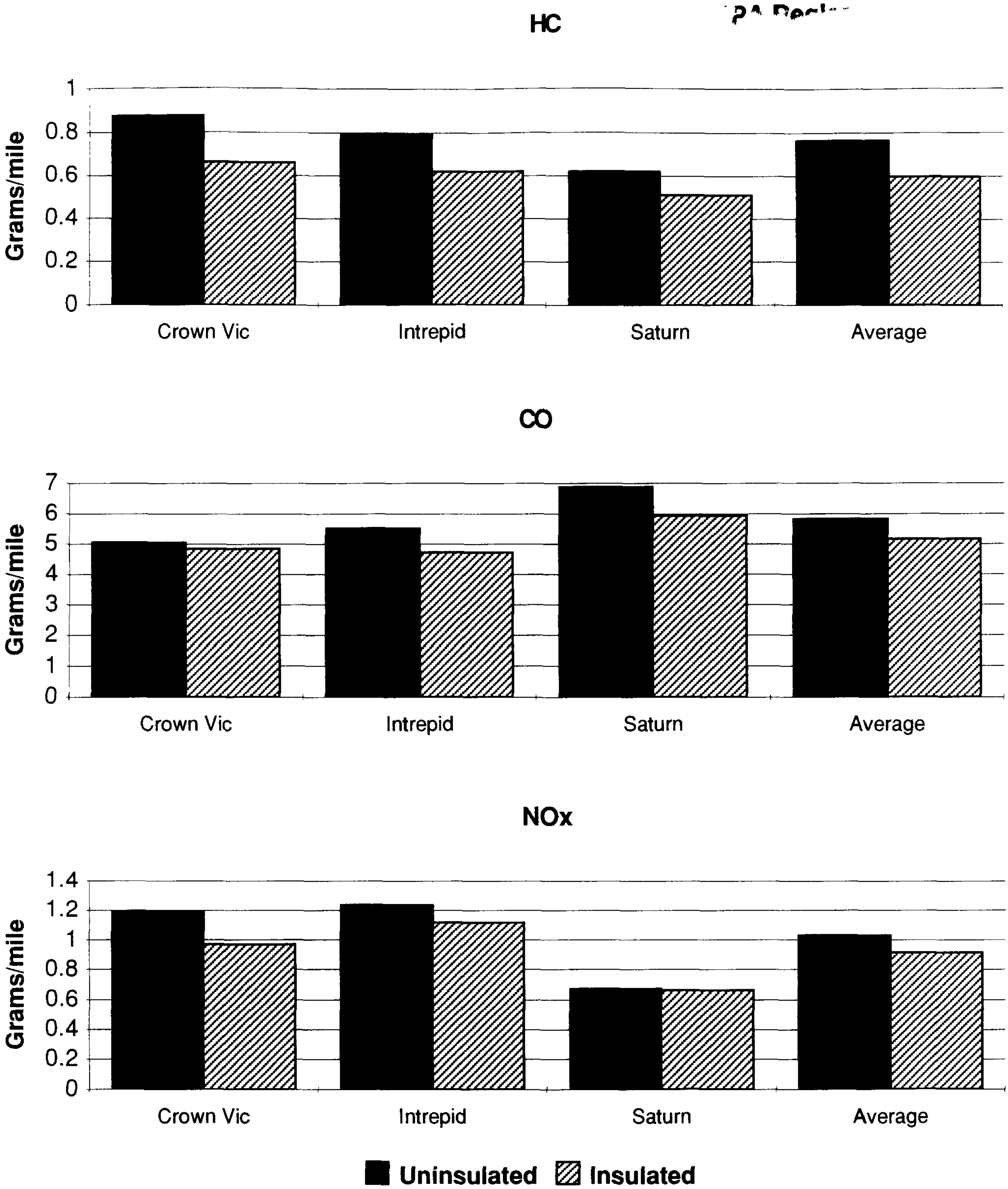


Figure 6. Comparison of soak and start emissions from FTP and in-use operation.



Note: Emissions are for the first 3.6 miles only (48% of all driving)

Figure 7. Comparison of soak and start emissions for insulated and uninsulated catalysts (in-use start cycle)



Note: Emissions are for the first 1.4 miles (24% of all driving)

Figure 8. Summary of road grade and air conditioning emission impact (in-use driving cycles)