DETERMINATION OF THE EFFECTS OF SPEED, TEMPERATURE, AND FUEL FACTORS ON EXHAUST EMISSIONS

Final Report
Contract Number 92-323

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1995

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GLOSSARY OF TERMS, ABBREVIATIONS AND SYMBOLS

AFR	Air-to-fuel ratio
AQMP	Air Quality Management Plan
ASCII	American Standard Code for Information Interchange
CAA	Federal Clean Air Act
CAT	Catalyst
CARB	California Air Resources Board
CCAA	California Clean Air Act
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO2	Carbon Dioxide
CV	Conventional Vehicles
EMFAC	Emission Factor Model
FTP	Federal Test Procedure
FIP	Federal Implementation Plan
HC	Hydrocarbon
HFET	Highway Fuel Economy Test
HDT	Heavy Duty Truck
HDV	Heavy Duty Vehicle
Hz	Hertz
I/M	Inspection and Maintenance Program
Lambda	Measured Air/Fuel Ratio divided by the Stoichiometric Air/Fuel Ratio
LDA	Light Duty Automobile
LDT	Light Duty Truck
LEV	Low Emission Vehicle
MCY	Motorcycle
MDT	Medium Duty Truck

MOBILE	US EPA Mobile Source Emissions Model
DMV	Department of Motor Vehicles
MPH	Miles Per Hour
MPG	Miles Per Gallon (fuel economy)
NAAQS	National Ambient Air Quality Standards
NCAT	Non-Catalyst
NO	Nitric Oxide
NO2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
PM_{10}	Particulate Matter, 10 μm or less
psi	Pounds per Square Inch
ROG	Reactive Organic Gases
SCAQMD	South Coast Air Quality Management District
SCAQS	South Coast Air Quality Study
SIP	State Implementation Plan
SoCAB	South Coast Air Basin
TLEV	Transitional Low Emission Vehicle
UBD	Urban Bus - Diesel Powered
ULEV	Ultra-Low Emission Vehicle
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
ZEV	Zero Emission Vehicle

ABSTRACT ABSTRACT

This study provided a comprehensive approach to examining the relative significance and possible synergistic effects of speed, temperature, and fuel on mobile source emissions modeling. Tests were conducted on each vehicle with a random combination of three fuel types (Phase 1, Phase 2, and Indolene), three temperatures (50 F, 75 F, and 100 F), and ten speed cycles. It was found interaction terms among fuel, speed, and temperature were statistically insignificant. Individually, the temperature and fuel factor played a minor role in exhaust emission modeling. Speed and vehicle type were the two dominant factors determining exhaust emissions. These results confirmed the assumption in EMFAC that speed, temperature, and fuel factors are independent from each other. Staff recommends that more resources should be allocated to cycle related research in future.

EXECUTIVE SUMMARYEXECUTIVE SUMMARY

In the current EMFAC model, speed, temperature, and fuel correction factors are applied to the basic emission rates for adjustment to various conditions. Those correction factors were assumed to be independent of each other; nevertheless, such assumption was never confirmed. Modeling of the independent effects of these correction factors may ignore their synergistic effects that could lead to the underestimation of exhaust emissions under specific operating conditions. This study intends to confirm the above assumption by examining the relative significance and possible synergistic effects of speed, temperature, and fuel correction factors applied in EMFAC.

Eleven passenger vehicles from three fuel delivery system control groups were tested, namely, three from carburetor (CARBU), three from throttle body injection (TBI), and five from multi-port fuel injection (MPFI) group. A minimum of 90 tests were conducted on each vehicle with a random combination of three fuel types (Phase 1, Phase 2, and Indolene), three temperatures (50 F, 75 F, and 100 F), and ten speed cycles. Each vehicle was repeated for all ten speed cycles at 75 F with Indolene. The data were analyzed using the analysis of variance (ANOVA) and Student-t tests of paired samples.

In general, exhaust emissions descended in the order of fuel delivery system, namely, carburetor (CARBU), throttle-body injection (TBI), and multi-port fuel injection (MPFI). All vehicles in the CARBU group contained a "dead" catalyst, which probably explained why vehicles in CARBU were "high emitters."

Results from the paired t-test indicated that the difference in exhaust emissions between Phase 1 and Phase 2 fuels for all vehicles was significant. The net exhaust emissions reduction of Phase 2 over Phase 1 fuel for HC, CO, and NOx was 17%, 13%, and 11%, respectively; which was in good agreements with the CARB emissions reduction based on 1996 calendar year when Phase 2 fuel was introduced.

Temperature had minimal effects on exhaust emissions especially the test cycles

were in hot-stabilized mode. Nevertheless, exhaust emissions from cold-start mode were higher than hot-start mode because the catalyst had not reached to optimal operating temperature during the cold-start mode.

The relative contributions of speed, temperature, and fuel to exhaust emissions were determined using ANOVA and it was found interaction terms among fuel, speed, and temperature were statistically insignificant. Individually, the temperature and fuel factor played a minor role in exhaust emission modeling. Speed and vehicle type were the two dominant factors determining exhaust emissions. These results suggested that the correction factors applied in EMFAC were independent of each other. Because of the relative importance of speed cycle on exhaust emission, staff recommends more resources should be allocated to cycle related research in future.

CHAPTER 1

INTRODUCTION

1.1 Background

Accelerated technological progress, coupled with rapid global population growth since the industrial revolution, has imposed an enormous burden on the planet's biosphere. Adverse environmental factors affect not only the earth's fragile ecosystem, but also pose a direct health threat to humans. Physical boundaries generally exist for pollutants in solid or solution form, however, similar physical restrictions do not exist for air pollutants. While it is possible to avoid pollutants in solid or solution form, air pollutants once released are transported over great distances, thereby exerting a more far-reaching health impact than other pollutants in solid or solution form.

One of the most urgent environmental problems in Southern California is its air pollution. Southern California's Mediterranean-like climate and its unique topography are ideal for the photochemical formation of smog. In the last few decades, an expanding population has created major air pollution problems in many regions of the State. Air pollution is not just a blemish on the horizon, but a threat to California's quality of life and its economic future. Studies conducted by the California Air Resources Board (1991) have documented that smog can cost California farmers up to 300 million dollars per year, affecting virtually every major crop. Furthermore, it is estimated that the residents in the South Coast Air Basin experience ozone-related symptoms on an average of up to 17 days a year and face an increased risk of death in any year by 1/10,000 due to PM_{10}. If applicable air pollution standards were attained,

1600 lives could be saved yearly (Hall et al., 1991).

The Bureau of Air Sanitation (BAS) was established in 1955 to identify air pollution levels that could pose a threat to public health. In 1959 the Motor Vehicle Pollution Control Board (MVPCB) was formed to address the issue of pollutants from vehicular emissions. In 1967, the BAS and MVPCB merged to create the California Air Resources Board (CARB). With this merger, the authority to define the health threat of air pollution and to regulate its causes was united into a single organization. Presently, CARB oversees the air quality programs of counties, air pollution control districts (APCDs), and regional air quality management districts (AQMDs).

In 1988, California's air quality program came of age. The most significant air quality legislation in the last few decades, the California Clean Air Act (CCAA), spells out California's air quality goals, planning mechanisms, regulatory mechanisms and standards of progress. Under CCAA, APCDs in violation are mandated to reduce emissions by an average of five percent per year until California's air quality standards are met. Best Available Control Technology (BACT) is promulgated to reduce emissions from stationary sources. Moreover, CARB is required to adopt the most effective mobile source emission control possible for on-road motor vehicles and off-road mobile sources, including marine vessels, locomotives, utility engines, and farm and construction equipment.

California has always been a pioneer in combating air pollution. For instance, California was the first state to require positive crankcase ventilation on automobile engines and to adopt emission standards for HC and CO. Table 1.1.1 illustrates a

Table 1.1.1 Chronology of vehicle emission control technology in California.

Year of Implementation	Control
1961	Positive Crankcase Ventilation
1971	Exhaust Gas Recirculation
1975	Oxidation Catalyst
1977	Three Way Catalyst
1982	Computer Based Fuel Control
1984	Inspection & Maintenance Program (Smog Check Program)
1988	On-Board Diagnostics I
1990	Enhanced Inspection & Maintenance Program
1994	On-Board Diagnostics II
1998	Zero-Emission Vehicle (Electric Vehicle)

brief chronology of vehicle emission control technology in California. Early emission control programs in the 1970's consisted of oxidation catalysts for control of CO and HC. Later, three-way catalysts were introduced to control HC, CO, and NOx to meet the lower emission standards. This is reflected in the trend of emission standards for different vehicle model years as indicated in Table 1.1.2.

To further reduce emissions from mobile sources, CARB recently embarked on a low-emission vehicle program with more stringent and technology-forcing emission standards. Under the low-emission vehicle program, car manufacturers will sell the new vehicles based on a flexible percentage mix of conventional vehicles (CV), transitional low-emission vehicles (TLEV), low-emission vehicles (LEV), ultra-low emission vehicles (ULEV), and zero-emission vehicles (ZEV) that will result in the emissions meeting a fleet average NMOG standard starting in 1994. In other words, the combined certified testing of CV, TLEV, LEV, ULEV, or ZEV will meet the fleet's average non-methane organic gas (NMOG) emission standards of that calendar year for each car manufacturer. Thus, this technology-forcing approach encourages car manufacturers to sell more "clean" vehicles in order to meet the fleet's average NMOG emission standard. While there is no fixed percentage mix for CV, TLEV, LEV, and ULEV, there is a mandatory percentage of ZEV to be sold in the market starting in 1998 (see Tables 1.1.3 and 1.1.4).

The primary goal for setting air quality standards is to protect the public's health. Table 1.1.5 provides both the national ambient air quality standards and the California air quality standards. Despite the severity of the South Coast Air Basin's

Table 1.1.2 California gasoline and diesel vehicle exhaust emission standards for conventional passenger vehicles at 50,000 miles (CARB, 1994). Units are in g/mi unless otherwise indicated.

Vehicle model year	HC	CO	NOx	Note
1966-69	275 ppm	1.50%	None	7 mode test
1970	2.2	23	None	7 mode test
1971	2.2	23	4	7 mode test
1972*	1.5	23	3	7 mode test
1972	3.2	39	3.2	CVS-72 test
1973	3.2	39	3	CVS-72 test
1974	3.2	39	2	CVS-72 test
1975-76**	0.9	9	2	CVS-75 test
1977-79	0.41	9	1.5	CVS-75 test

Vehicle model year	NMHC/HC	CO	NOx	
1980***	0.39/0.41	9	1	CVS-75 test
1981****	0.39/0.41	3.4/7.0	1.0/0.7	CVS-75 test
1982-92	0.39/0.41	7	0.4/0.7	CVS-75 test

Vehicle model year	NMOG	CO	NOx	
1993 and later	0.25	3.4	0.4	CVS-75 test

* Switch to CVS-72 from 7 mode test

** Switch to CVS-75 from CVS-72 test

***Non-methane standard first introduced

**** Options is for vehicles certified to 7-year/ 75,000 mile recall standard

Table 1.1.3 Low-emission vehicle standards (CARB, 1994).

Vehicle Class	NMOG (g/mi)	CO (g/mi)	NOx (g/mi)
Conventional Vehicle (CV)	0.25	3.4	0.4
Transitional Low-Emission Vehicle (TLEV)	0.125	3.4	0.4
Low-Emission Vehicle (LEV)	0.075	3.4	0.2
Ultra Low-Emission Vehicle (ULEV)	0.04	1.7	0.2

Table 1.1.4 Fleet average NMOG emission standards by calendar year (CARB, 1994).

Year	NMOG (g/mi)	Percentage of ZEV required
1994	0.250	n.a.
1995	0.231	n.a.
1996	0.225	n.a.
1997	0.202	n.a.
1998	0.157	2%
1999	0.113	2%
2000	0.073	2%
2001	0.070	5%
2002	0.068	5%
2003	0.062	10%

Table 1.1.5 Comparison of California and Federal ambient air quality standards (SCAQMD, 1994).

Air Pollutant	California standard	Federal standard
Ozone	0.09 ppm, 1 hr avg	0.12 ppm, 1 hr avg
Carbon Monoxide	9.0 ppm, 8 hr avg 20 ppm, 1 hr avg	9 ppm, 8 hr avg 35 ppm, 1 hr avg
Nitrogen Dioxide	0.25 ppm, 1 hr avg	0.053 ppm, annual avg
Sulfur Dioxide	0.04 ppm, 24 hr avg 0.25 ppm, 1 hr avg	0.03 ppm, annual avg 0.14 ppm, 24 hr avg
Suspended Particulate Matter (PM10)	30 ug/m3, annual geometric mean 50 ug/m3, 24 hour avg	50 ug/m3, annual arithemetic mean 150 ug/m3, 24 hour avg
Sulfates	24 ug/m3, 24 hr avg	
Lead	1.5 ug/m3, 30 day avg	1.5 ug/m3, calendar quarter
Visibility Reducing Particles	In sufficient amount to reduce the visual range to less than 10 miles at relative humidity less than 70%, 8 hour avg (9 am - 5 pm)	

present air pollution problem, it represents a substantial improvement over historical air quality. According to the South Coast Air Quality Management District (SCAQMD, 1994), the federal standard exceedances for O_3, NO_2, and CO decreased by 32%; 95%, and 82%, respectively between 1975-77 and 1991-93 as shown in Figure 1.1.1. Though California has made progress over the last two decades, it still outranks all 49 other states in air quality problems, and Los Angeles remains the city with the worst air quality in the nation (USEPA, 1993).

In California, motor vehicles are the major source of pollutants emitted each year. According to the recent South Coast Air Quality Management Plan (SCAQMD, 1994) in the South Coast Air Basin, 98% of the carbon monoxide, 84% of nitrogen oxides, and 62% of hydrocarbon emissions come directly from mobile sources (see Table 1.1.6). Therefore, to combat the air pollution problem effectively, it is imperative to further reduce mobile source emissions. However, to develop a mobile source emissions control policy, it is essential to have as accurate an inventory of pollutant emissions as possible. As shown in Figure 1.1.2, the overall mobile source emissions control plan depends on many components. From vehicle testing to inventory models which shape the enforcement strategies and policy, each component is critical to other components. Nevertheless, the success of mobile source emission control strategies depends heavily on accurate inventory models derived from the research data. Hence, it is essential to continually conduct research and refine the current inventory models.

Both the CCAA and federal Clean Air Act (CAA) mandate compliance with

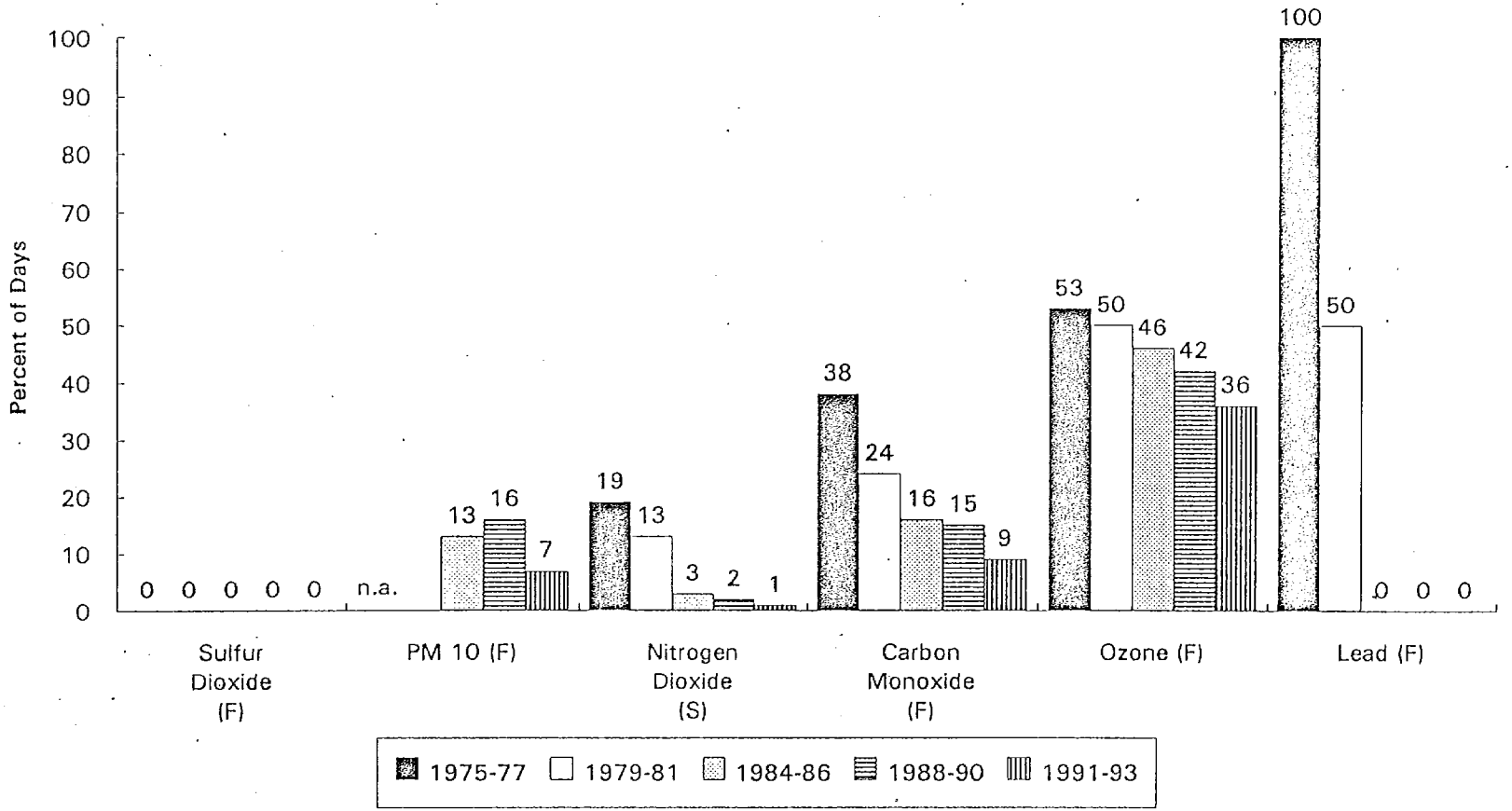

Figure 1.1.1 Percent of days exceeding state (S) / federal (F) standard from 1975-1993 in South Coast Air Basin (SCAQMD, 1994)

Table 1.1.6 Summary of emissions by major category in the South Coast Air Basin for 1990, average annual day (tons/day) (SCAQMD, 1994).

Source Category	VOC	NOx	CO	SOx	PM10
Stationary Sources	15	119	94	15	15
Fuel Combustion	1	2	5	0	1
Waste Burning	342	0	0	0	1
Solvent Use	97	1	4	2	3
Petroleum Process, Storage and Transfer	52	2	2	1	30
Industrial Processes	48	2	9	0	692
Reclaim Sources	n.a.	93	n.a.	20	n.a.
Total Stationary Source Emissions	660	219	114	38	742
Mobile Sources					
On-Road Vehicles	761	762	5342	31	70
Off-Road Mobile	135	351	1293	51	21
Total Mobile Source Emissions	896	1113	6635	82	91
TOTAL	1452	1332	6749	120	833

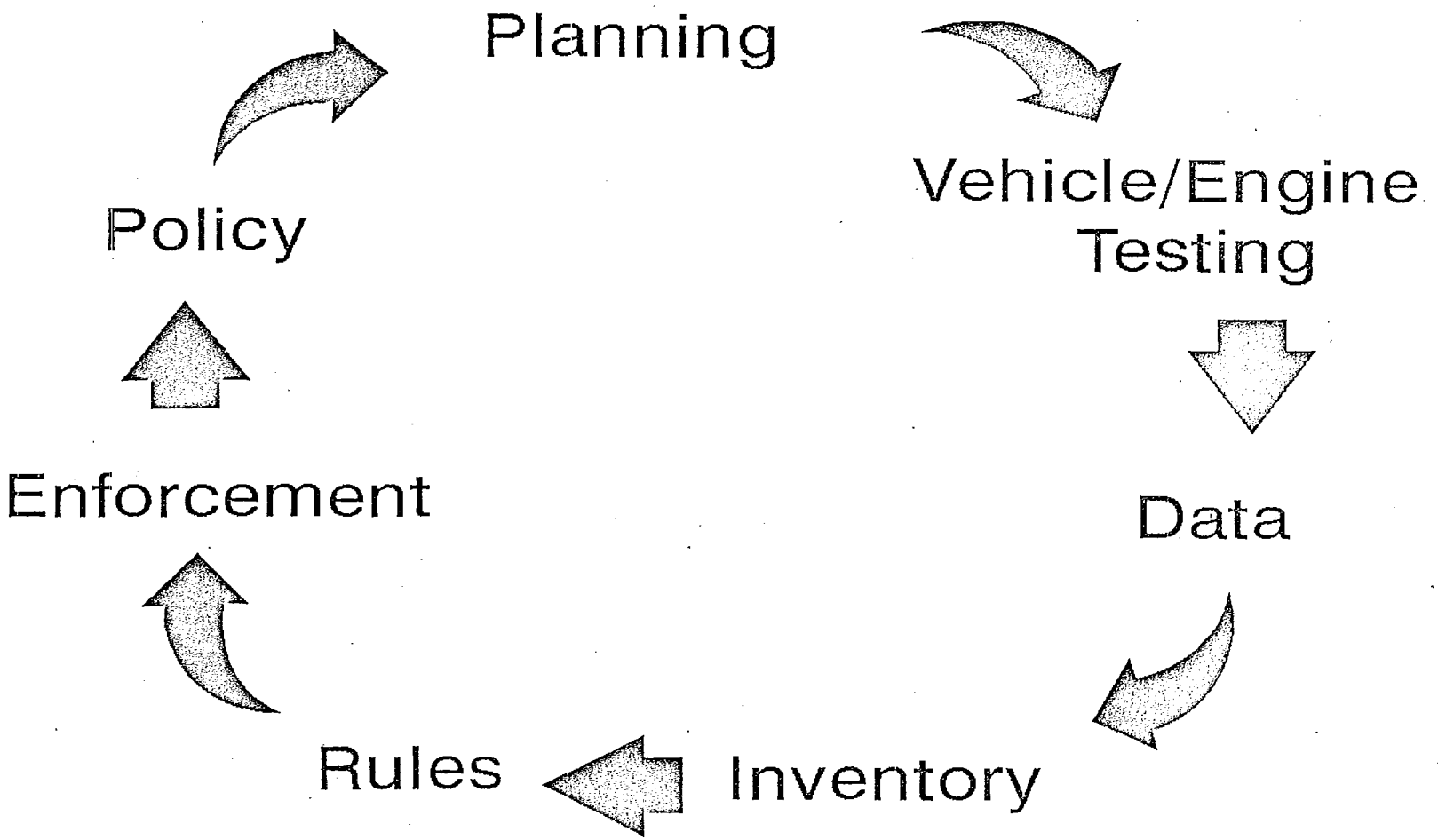

Figure 1.1.2 Schematic of in-use emissions control plan

ambient air quality standards and set requirements for controlling emissions of air pollutants. For those regions that don't meet the ambient air quality standards, the State must propose State Implementation Plans (SIP) to bring those regions into attainment by a specified date, varying with the severity of the air pollution problem. In the case of the federal Clean Air Act, areas failing to comply by that specific date may be subject to economic sanctions (1990 Clean Air Act Amendment).

Compliance with air quality standards is determined by direct ambient air measurements; however, forecasts of future air quality depend upon ambient air quality models and emission inventory projections. If the forecasts of air pollution for a particular area are higher than they should be, then the area will incorporate more costly emission control measures into its SIP than are necessary. On the other hand, if the forecasts for an area are lower than they should be, then the area does not attain the ambient air quality standards by its deadline and may face economic sanctions. Since there are undesirable repercussions from either overestimating or underestimating an emission inventory, it is crucial to have an inventory that is as accurate as possible. For these reasons, a tremendous amount of effort has been devoted to develop and refine inventory models.

1.2 Discrepancies in Emission Inventories

The primary purpose of promulgating emission limits is to achieve a desired concentration of an atmospheric pollutant. Such an approach is solely based on the understanding of the quantitative relationship between atmospheric emissions and ambient air quality. For the last several decades there has been major progress in the understanding of the chemistry leading to the formation of photochemical air pollution. In particular, the chemical relationships between ozone formation and precursor (NOx and VOC) emissions, as well as the kinetic aspects of night-time and day-time chemical transformations of pollutants, have been well documented (Finlayson-Pitts and Pitts, 1986; Atkinson, 1988; Seinfeld, 1986, 1989; National Research Council, 1991).

At the same time, there have been significant advances in the development of airshed models which assist in the formation of both mobile and stationary emission control strategies to combat air pollution. For instance, the SCAQMD, the local authority responsible for the regional air pollution control, uses models such as the Urban Airshed Model (UAM) to study air pollution control strategies in order to fulfil, via the State Implementation Plan (SIP), the requirements of the federal Clean Air Act (CAA) and the California Clean Air Act (CCAA).

While the air pollutants from stationary sources can be monitored and quantified, the pollutants from mobile sources are less well characterized both from a real-time emission and real-time ambient monitoring perspective. Thus, it remains a challenge to develop reasonable mobile source emissions models to estimate the

mobile source inventory. Though important groundwork has been laid in developing the mobile emissions model, additional research is needed. The following two sections briefly describe some of the major discrepancies between the mobile source emissions model and that of atmospheric measurements.

1.2.1 Top-down Studies

"Top-down" studies attempt to reconcile the estimated emissions of air pollutants with actual measured concentrations of the pollutants in the ambient air. During the last several years, a number of independent investigators have published studies suggesting that today's emission inventories may be underestimating emissions of non-methane organic gas (NMOG) and CO by substantial amounts. In the 1987 Southern California Air Quality Study, researchers found that the ambient CO/NOx and NMOG/NOx ratios were about 1.5 and 2 to 2.5 times higher, respectively, than the corresponding inventory ratios. This suggested the on-road motor vehicle CO and NMOG emission inventories were significantly underestimated (Fujita et al., 1992a, 1992b).

In a tunnel study conducted in Van Nuys, California, Ingalls et al. (1989) found the emission rates of CO and volatile organic compound (VOC) were factors of 2.7 ± 0.7 and 3.8 ± 1.5 higher, respectively, than values predicted by the Motor Vehicle Emission Inventory model (MVEI). NOx emissions rates agreed reasonably well with model prediction. Emissions for the EMFAC model were calculated with the assumption that all vehicles in the tunnel reached a stable operating temperature. For

the tunnel study, however, the actual fraction of vehicles in the cold operating mode was unknown. Cold operating mode (which occurs when the catalyst has not reached a stable operating temperature) increases CO and VOC exhaust emissions and evaporative losses and thus would reduce the discrepancies between measured and predicted CO and VOC.

Pierson et al. (1990) reviewed the Van Nuys Tunnel study and concluded that even if 100% of the observed vehicles operated in the cold mode, major discrepancies still existed between the measured and predicted VOC and CO inventories. Moreover, he found that underprediction of CO/NOx and VOC/NOx was found in other previous tunnel studies and roadside tests as well. All the above studies consistently suggested the existence of a discrepancy between predicted and measured motor vehicle emissions of CO and VOC.

1.2.2 Bottom-up Studies

Another means to confirm discrepancies in the emission inventory is to examine the methodologies and assumptions for estimating emission and activity factors in the exiting inventory models. These studies of emission sources are called "Bottom-up" studies, since they deal with individual components of the inventory models, which if they are correct, should result in a total inventory that may be confirmed by "Top-down" analyses.

For instance, one possible source for underestimation of motor vehicle emissions is that the current MVEI model underestimates the contribution of "high-

emitters." Several studies have been conducted by private investigators using a remote-sensing device to measure CO emissions from vehicles (Bishop et al., 1989, Stedman et al., 1991a, 1991b; Lawson et al., 1990). These studies all indicated that about 10% of the vehicles were responsible for approximately 50% of the total CO emissions.

These findings have been confirmed by government sponsored studies as well. For instance, from the 1991 remote sensing study conducted by both CARB and USEPA in southern California, it was found that the highest 10% of CO-emitting vehicles accounted for 58% of total CO emissions, while the highest 10% of HC-emitting vehicles generated 65% of the total HC emissions from all sampled vehicles (Stephens, 1994).

In a 1989 roadside survey sponsored by CARB and the Bureau of Automotive Repair (BAR), where 4,479 vehicles were randomly inspected for emission control devices and tested at no-load 1000 rpm idle conditions, it was found that 10% of the vehicles were responsible for about 60% of the exhaust CO emissions, and 10% of the same fleet produced about 60% of the exhaust HC emissions. The results showed only a weak relationship between high CO emitters and high HC emitters (Ashbaugh, et al., 1990).

Another possible reason for underestimating motor vehicle emissions is that the current certified driving cycle, the Federal Test Procedure (FTP), does not cover high speed and acceleration domains, or high-load situations, such as entering freeways and climbing hills. Groblicki (1990) showed that HC and CO emissions from one "hard-

acceleration" accounted for half of the total emission during a typical urban trip in a late-model passenger car with proper emission controls. In another study by Groblicki (1993), it was demonstrated that during a brief enrichment event CO emissions were increased by a factor of 2500, and HC emissions by a factor of 40, over closed-loop stoichiometric operations. Note that this sudden increase in fuel-to-air ratio (enrichment) is designed to protect late model year vehicles against overheating of the engine and catalyst during conditions of high power demand.

Similarly, St. Denis et al. (1994) found that a 1990 vehicle might emit nearly as much CO during a hard acceleration onto a freeway as it does during the entire 11-mile trip of the FTP in the laboratory. Figure 1.2.2.1 illustrates the speed and acceleration operating envelope generated by St. Denis' study. It is found that both conservative and aggressive driving regimes have broader speed and acceleration domains than the FTP. Relatively high accelerations and speeds have not been included in the FTP because until recently, laboratory dynamometers were not designed to simulate such driving modes. Hence, it is critical to develop a new testing procedure that simulates on-road speed and acceleration domains.

1.3 Goals of On-Road Emissions Models

Emissions reported in the mobile source inventory represent the best available estimates of emission levels but do include some degree of uncertainty. A reasonable mobile source emission inventory model should at least cover these five main components: (1) Vehicle - such as vehicle's model year, vehicle weight, engine size,

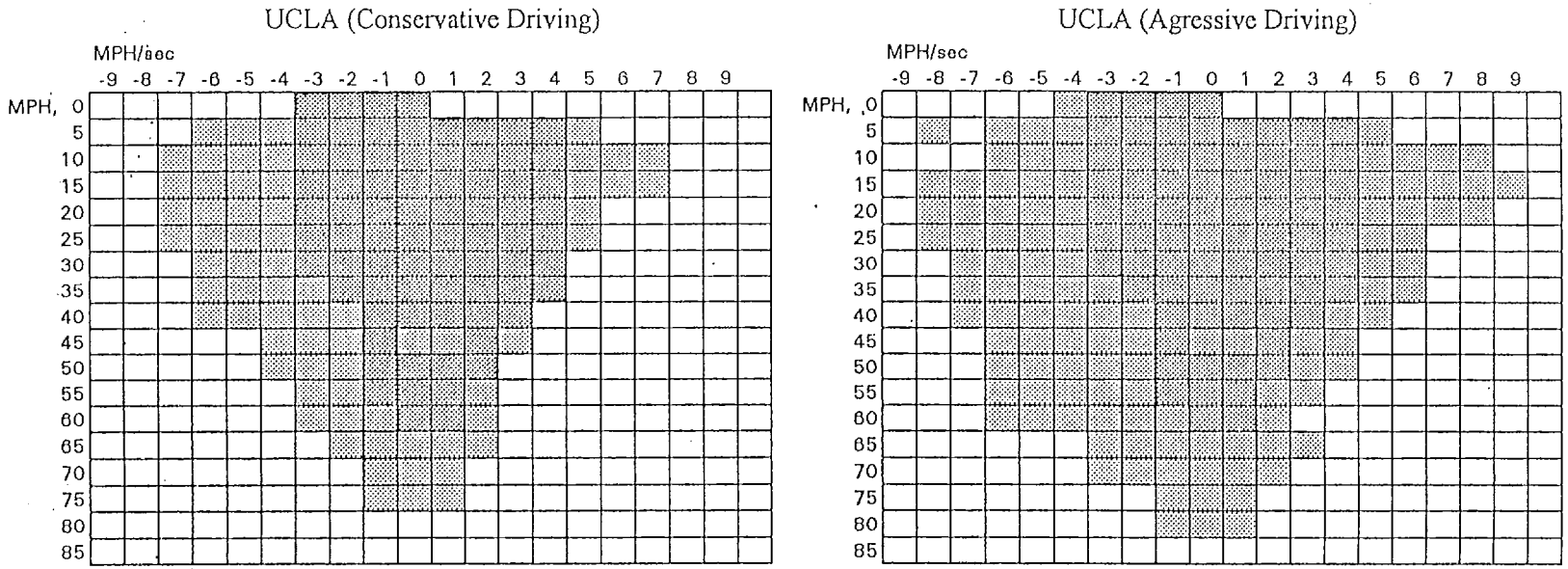

Figure 1.2.2.1 Comparison of speed-acceleration driving domain of FTP (darkly shaded portion) and the actual driving data collected by UCLA for SCAQMD (Cicero-Fernandez, 1993)

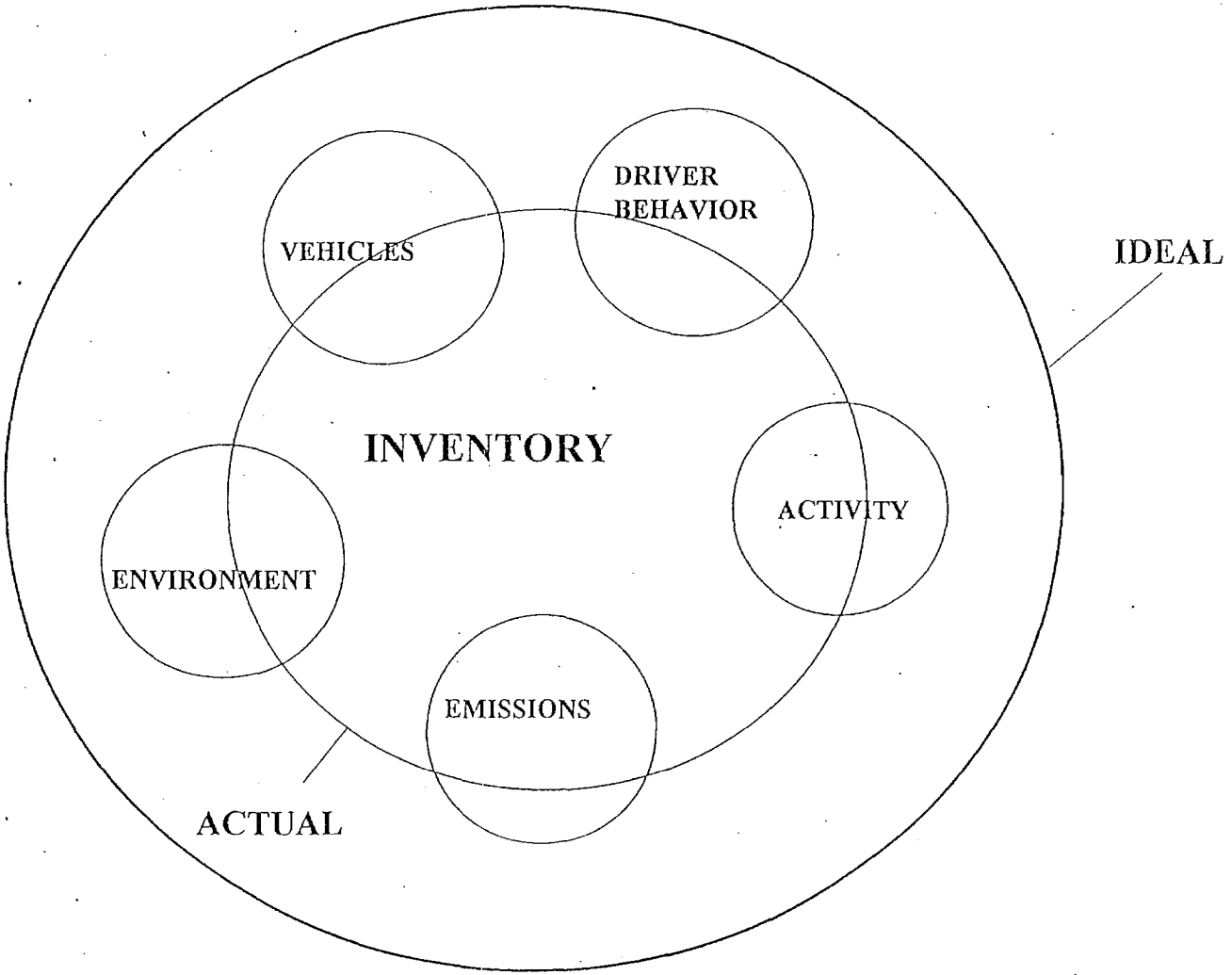

Figure 1.3.1 Schematic of inventory estimation goal

emission control technology, accumulated mileage, the effectiveness of smog-check program, the percent of high emitters in the vehicle population, and the effect of heavy-duty vehicles and out-of state vehicles. (2) Behavior - such as the frequency of hard acceleration on local streets and freeways, frequency of braking, and the frequency of cold and hot starts of vehicles. (3) Activity - such as the mileage accrual rates, vehicle age distribution, vehicle sales distribution, the average distance travelled per day, the frequency of stops or idling, and the number of trips per day. (4) Environment - the external factors such as ambient temperature, fuel, grade, wind speed, air conditioning, load conditions. (5) Emissions - the exhaust pollutants including HC, CO, NOx, CO_2, and particulate. In particular, HC from carburetor and fuel delivery system through evaporative emissions when the vehicle is resting or running must also be included. Furthermore, it is imperative to quantify the species of hydrocarbon as certain components in the HC exhaust pose health threats. For example, benzene, common in the exhaust emissions, is a well known carcinogen. Figure 1.3.1 illustrates the inventory estimation goal based on the above mentioned components (Carlock, 1992).

To construct a model, one must have adequate information about all the aforementioned components. Additional research is needed in order to obtain a better understanding on how each component relates to the overall estimation of the mobile source emission inventory.

The current MVEI model, while reflecting significant progress in the subject area, also recognizes that more work needs to be done. To improve the mobile source

inventory model, CARB is directing several studies to improve on-road emission estimates. These studies include: (1) assessment of number of daily vehicle trips, number of trips and trip length associated with older vehicles (Magbuhat, 1994); (2) the development of a new certified driving cycle, the Unified cycle, which covers a broader domains of speed and acceleration (Gammariello and Long, 1993); (3) the conceptual design of driving cycles pertaining to freeway and local traffic conditions (Effa and Larsen, 1992); (4) the study of air-conditioning effects on exhaust emissions (Parker, 1993); (5) the effects of grade and load on exhaust emissions (Cicero-Fernández and Long, 1994); and (6) the frequency distribution of high emitters (Carlock, 1993). The findings from these studies will likely be incorporated into the future MVEI model.

1.4 The Development of Motor Vehicle Emission Inventory Model (MVEI)

To estimate the emission inventory of all pollutants from mobile sources, CARB has developed four computer models, known as Motor Vehicle Emission Inventory models (MVEI): CALIMFAC, EMFAC, WEIGHT, and BURDEN (see Figure 1.4.1). Each model is a critical component in the overall estimation of emission inventory.

CALIMFAC (short for CALifornia I/M FACtor model) calculates Basic Emission Rates (BER) of passenger cars, light-duty trucks, and medium-duty trucks both with and without the assumed benefit of "Smog Check." The BERs or "baselines" are generated based on vehicle test data obtained from the Federal Test

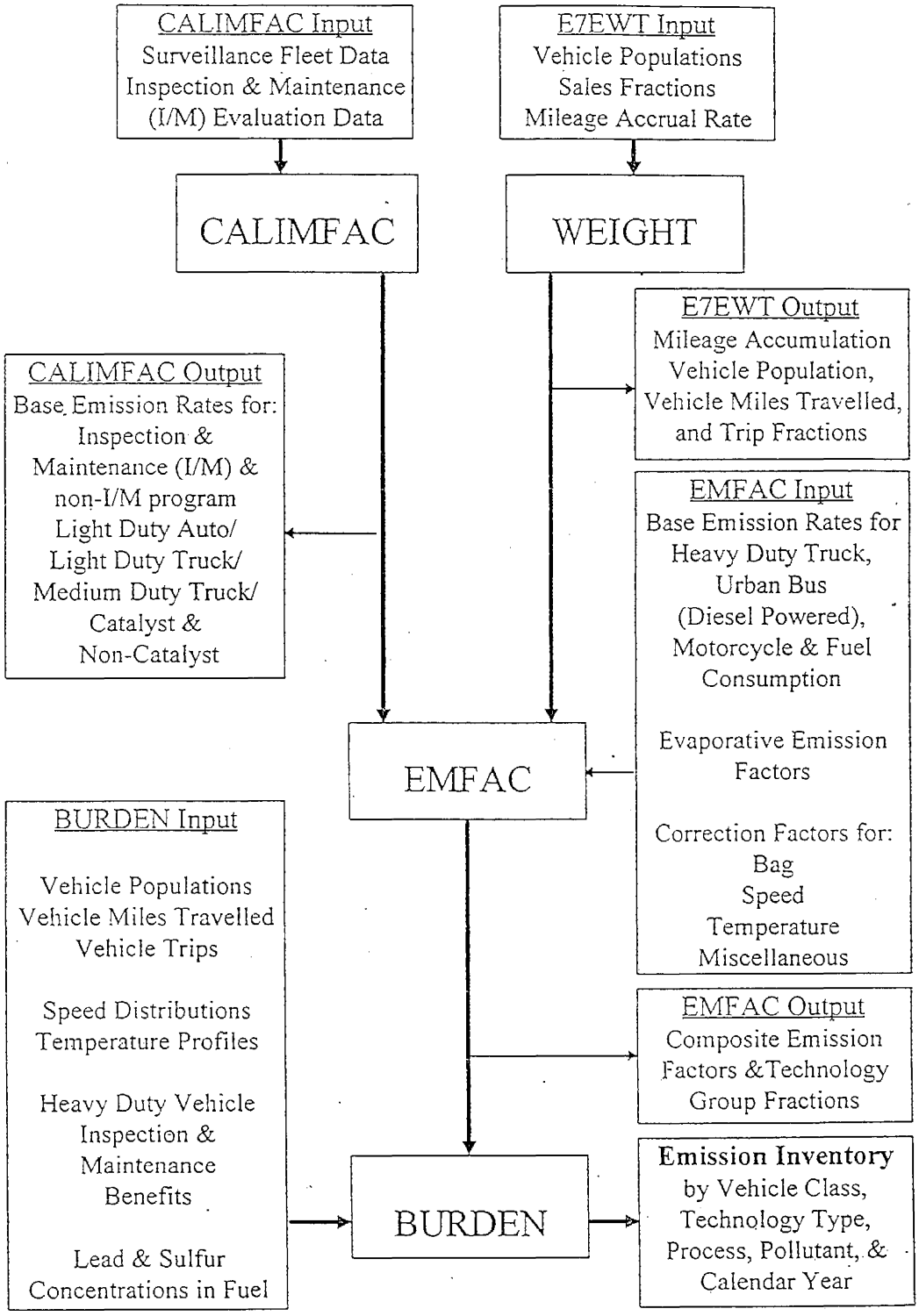

Figure 1.4.1 CARB's motor vehicle emission inventory process (CARB, 1992a)

Procedure (FTP).

Using the CALIMFAC generated BERs as input, the EMFAC model attempts to adjust the BER to non-FTP conditions of speed, temperature, fuel, and other parameters that the vehicles encounter during normal operation. Much of the EMFAC methodology is devoted to the handling of these correction factors. Testing is performed at these non-standardized (i.e., non-FTP) conditions, and correction factors of speed, temperature, fuel, and other parameters are generated to correct the BERs.

The WEIGHT program contains information on Department of Motor Vehicles (DMV) registration distribution, mileage, attrition rates and other information necessary to estimate the vehicle model year's specific contribution to the emission inventory for a particular calendar year.

The BURDEN program contains information necessary to convert emission rates from grams/mile to tons/day. This information includes vehicle population, total vehicle miles travelled (VMT), and trips per vehicle-day.

1.4.1 EMission FACtor (EMFAC) Model

The present dissertation intends to test the assumptions made regarding the correction factors in EMFAC. EMFAC can generate emission factors for various calendar years, for two seasons (summer and winter), and for a variety of combinations of pollutants, vehicle class/technologies, processes, speeds and temperatures. EMFAC7F, the latest version of EMFAC, generates emission factors for calendar years 1970 through 2020. Each calendar year includes a fleet of twenty-five

model years, except for passenger vehicles, which includes thirty-five model years. EMFAC also calculates both summertime and wintertime emission factors. The reason for seasonal emission factors is to reflect fuel vapor pressure (measured as Reid Vapor Pressure or RVP) and differences in fuel composition between summer and winter, which will affect exhaust pollutants.

EMFAC7F generates emission factors for the following pollutants:

- hydrocarbon (HC) from exhaust
- hydrocarbon (HC) from evaporation
- carbon monoxide (CO)
- nitrogen oxides (NOx)
- particulate matter from exhaust
- particulate matter from tire wear

EMFAC7F produces emission factors for the 13 different vehicle class/technology combinations listed below:

- light-duty automobile/non-catalyst gasoline
- light-duty automobile/catalyst gasoline
- light-duty automobile/diesel
- light-duty trucks/non-catalyst gasoline
- light-duty trucks/catalyst gasoline
- light-duty trucks/diesel

- medium-duty trucks/non-catalyst gasoline
- medium-duty trucks/catalyst gasoline
- heavy-duty trucks/non-catalyst gasoline
- heavy-duty trucks/catalyst gasoline
- heavy-duty trucks/diesel
- urban bases/diesel
- motorcycles/non-catalyst gasoline

In addition, EMFAC generates VOC emission factors for exhaust and evaporative categories. Because of different modes of driving and starts, correction factors are produced for three exhaust emission processes: cold starts, running exhaust, and hot starts. EMFAC produces emission factors for the evaporative processes: vaporization of fuel from the heat of the engine after it has been turned off (hot soak), vaporization of fuel from the fuel system while the engine is operating (running loss), vaporization of fuel within fuel system caused by the rise of daily ambient temperature (diurnal losses), and vaporization of fuel within fuel system caused by the fall of daily ambient temperature (resting losses).

Though many correction factors were developed in the EMFAC model, the focus of the present dissertation is to examine the fundamental concept that the baseline exhaust emissions can be corrected to different temperatures, fuels, and speeds through a set of "correction factors." According to EMFAC (CARB, 1993a & 1993b), the general emission factor equation for a given pollutant, vehicle class, technology group, and calendar year is given by equation 1:

$$EF = \sum_{my=1}^{35} [BER \times BCF \times TCF \times SCF \times FCF \times TP]_{my} \qquad \text{(Eq.1)}$$

where,

EF = emission factor

BER = basic emission rate

BCF = bag correction factor

TCF = temperature correction factor

SCF = speed correction factor

FCF = fuel correction factor

TP = travel fraction of the vehicle population

my = model year

In the following section, the principles in deriving TCF, SCF, FCF and BER will be explained briefly.

Basic Emission Rates (BER)

Basic emission rates are estimated through analyses of emission data collected in ARB's on-going vehicle testing programs. These programs include: In-Use Surveillance, High-Mileage Surveillance, and Inspection/Maintenance Evaluation. Currently, the emission factor database is comprised of test data for over 5,000 vehicles tested by the Federal Test Procedure (FTP). The FTP, developed in 1972, is a driving cycle of approximately 11 miles in length with an average speed of 19.6 mph. The cycle consists of three phases (or bags) including a cold start (Bag 1),

stabilized driving (Bag 2), and hot start (Bag 3). During the test the vehicle is exercised over a series of accelerations, decelerations, idles, and cruises designed to simulate a typical trip in a Los Angeles urban area. The mass emissions of HC, CO, and NOx are collected by phase and then weighted, thereby yielding a composite emission rate.

A statistical analysis is performed on the emission data to divide the fleet into technology groups which display unique emissions characteristics. The known or projected sales of vehicles utilizing each significant technology is then used to weight the data into model year specific, composite emission factors.

1.4.2 Derivation of Speed, Temperature, and Fuel Correction Factors

In this section, the speed, temperature, and fuel correction factors will be briefly described. In general, these correction factors are derived through regression analysis on the testing data from both USEPA and CARB.

Speed Correction Factor (SCF)

In EMFAC7F, the most recently released version of EMFAC, speed correction factors were updated for catalyst-equipped passenger cars, light duty trucks, and medium duty trucks. Speed correction factors are used to correct the running exhaust emissions at 16 mph (FTP-Bag2) to other speeds.

Data from tests conducted by USEPA and CARB of 746 vehicles over different speed cycles were used to develop the SCF for EMFAC7F. The average speeds range from 2.5 mph to 65 mph from these cycles. The SCF for a particular speed cycle at

its average speed (s) is defined as:

$$SCF(s)=\text{mean ER}(s)/\text{mean ER}(16\text{ mph}) \qquad \text{(Eq.2)}$$

where (s) is the evaluation speed and ER is the emission rate at either the evaluation speed or at 16 mph.

The analysis was performed by first calculating the mean emission level and the mean baseline emissions (at 16 mph) of vehicles tested at each speed. The ratio of the means was then calculated. Finally, for each technology group, a curve fit analysis was performed on the ratio of the means, weighted by the number of observations at each speed. A trial and error approach was utilized in selecting the general equations. For HC or CO, the equation developed is:

$$SCF(s)=EXP\{ A*(s-16) + B*(s-16)^2 + C*(s-16)^3 + D*(s-16)^4\} \qquad \text{(Eq.3)}$$

For NOx, the equation is:

$$SCF(s)=\{A*(s-16) + B*(s-16)^2 + C*(s-16)^3 + 1\}*16/s \qquad \text{(Eq.4)}$$

Where the A, B, C, and D are the regression coefficient from the above equations.

Temperature Correction Factor (TCF)

Temperature correction factors (TCFs) are used to adjust the basic emission

rates for conditions outside the FTP (75 F). The database was generated through various vehicle testing programs from USEPA and CARB. Approximately 2700 vehicles were tested over the FTP at 20 F, 50 F, 75 F, and 95 F and the baseline emissions are determined at each temperature level. Since the database is derived from different testing programs, the sample size is not evenly distributed for each temperature. For instance, about 2200 vehicles were tested at 75 F. The TCF at a particular temperature is defined by the following equation.

$$TCF\ (T) = \text{mean ER (T)} / \text{mean ER(75)} \qquad \text{(Eq.5)}$$

where T is the evaluation temperature and ER is the emission rate at either the evaluation or standard temperature. The significant technology groups were determined to be carbureted and fuel-injection vehicles. Similar to the SCF estimation, a curve fit analysis was performed on those ratio of means, weighted by the number of observations. The general equation for HC, CO, and NOx is as follows:

$$TCF\ (T) = A*(T-75) + B*(T-75)^2 + C*(T-75)^3 + 1 \qquad \text{(Eq.6)}$$

Fuel Correction Factor (FCF)

The BERs were determined using conventional gasoline prior to the introduction of reformulated gasoline in 1992. The fuel correction factors adjust the BERs to reflect the benefits of Phase 1 fuel (both summer and winter grade) for the

calendar year of 1992-95 and Phase 2 fuel for the calendar years 1996 and beyond. The database used to estimate the fuel correction factors, was derived from independent studies of the petroleum industries, as well as joint studies of ARB with the petroleum industries. These studies provided FTP emission test data for 66 vehicles fueled with Phase 1 and Phase 2 gasoline (Carlock, 1992).

The percent reductions were calculated for each vehicle and their means were calculated within each technology grouping (e.g., non-catalyst, catalyst with carburetor, or catalyst with fuel injection) for the respective fuel comparison. The general equation for FCF (in percent reduction) due to the reformulated fuel for HC, CO, and NOx emissions is defined as:

$$\text{Percent Reduction} = (\text{reformulated fuel/base fuel} - 1)*100 \qquad \text{(Eq.7)}$$

where a negative or positive value implies a decrease or increase, respectively, in emissions as a result of reformulated fuel. Since the use of reformulated fuel went into effect only after 1992, for pre-1992 calendar years the FCFs default to 1.00 since no emissions benefit is expected.

Two sets of FCFs were developed for HC, CO, and NOx based on the calendar year from which the emission inventory for that year calculated. The first set of FCFs is used to reflect the benefits of Phase 1 fuel for the calendar year 1992-95 while the second set of FCFs is used to reflect the benefit of Phase 2 fuel for the calendar years 1996 and beyond.

1.4.3 The Assumptions Used in EMFAC

In the state's current official version of the EMFAC7F model, BERs are determined through the FTP. To adjust for factors not included in the FTP conditions, such as vehicle type, fuel type, speed, etc. correction factors are applied to the BERs. Three of the most significant factors relative to achieving accurate FTP corrections are vehicle speed, temperature, and fuel. However, the use of these corrections are based on two critical assumptions:

1) There are neither synergistic nor antagonistic effects for any of the correction factors on non-FTP emission rates; and

2) The effects of the correction factors are independent of vehicle operation characteristics.

1.5 Objectives

A variety of studies sponsored by industry or government have investigated the effects of fuel, temperature and speed cycle separately on exhaust emissions. For instance, the Auto/Oil Air Quality Improvement Research Program, a cooperative program initiated by the three major auto companies and fourteen petroleum companies, is evaluating the effects of gasoline composition on emissions from current and older vehicles. This program, the largest and most comprehensive project of this nature ever attempted, has compiled data to assist industry finding fuel/vehicle system options that will help meet the nation's clean air goal (Society of Automotive Engineers, 1993). The USEPA has also investigated the effects of temperature and

fuel as related to exhaust emissions (Stump et al. 1989, 1990a, 1990b, 1990c, 1992a, 1992b, 1994), as well as the alternative fuels such as compressed natural gas and methanol (Gabele et al., 1990a, 1990b). Furthermore, in an attempt to improve the current speed correction methodologies, CARB has developed new speed cycles that reflect freeway and local traffic conditions (Effa and Larsen, 1993).

Though there have been numerous studies investigating the effects of fuel, temperature, and driving cycles on exhaust and evaporative emissions, their scopes have been limited. In fact, most of the fuel and temperature studies were based on the FTP with emphasis on exhaust hydrocarbon speciation.

While the speed, temperature and fuel correction factors were developed from different databases, the underlying assumptions for such an approach have never been scrutinized. There does not exist a comprehensive experimental approach to study the effects of speed, temperature, and fuel effects on exhaust emissions. It is the intent of this study to examine the approach of using correction factors to adjust the basic emission rates in the EMFAC model, and to test the assumptions in the EMFAC model concerning speed, temperature, and fuel correction factors.

The principal objective of this dissertation is the comprehensive examination of the effects of speed, temperature, and fuel on exhaust emissions, in particular, the interaction effects among speed, temperature, and fuel, if any. Other objectives include: (2) the identification of new factors which have the potential to affect emissions, (3) the comparison of Phase 1 and Phase 2 fuel on exhaust emissions, (4) the evaluation of temperature effects on the cold start of vehicles, and (5) the

comparison of relative contribution of speed, temperature, and fuel factors to exhaust emissions. The findings from this study could dictate future research strategies, and allocate resources to areas that require more in-depth research.

Eleven passenger vehicles were procured based on three fuel delivery systems, namely, three with carburetor, three with throttle body injection, and five with multi-port fuel injection. Ten speed cycles with average speeds ranging from 2.5 mph to 64.4 mph were selected. This wide range of speed cycles encompasses various on-road driving conditions, from congested local traffic to free-flow freeway conditions. In addition, three temperature profiles (50 F, 75 F, and 100 F) and three fuels (Phase 1, Phase 2, and Indolene) were selected. Thus, a minimum of 90 tests were conducted for each vehicle.

It is expected that this proposed research will lead to a better understanding of emission inventory methodologies, which will assist CARB in formulating balanced air pollution control strategies.

CHAPTER 2

EXPERIMENTAL

2.1 Facility Description

Automotive Testing and Development Services, Inc. (ATDS) was selected by the CARB as the sole contractor responsible for vehicle procurement, fuel procurement, vehicle testing, and data collection under close supervision from CARB. The ATDS testing facility located in Ontario, California consists of 25,000 square feet of laboratory, offices, and service space. ATDS has been in the vehicle testing business for over two decades and has vehicle testing experience from projects sponsored by major vehicle manufacturers, USEPA and CARB. ATDS also has the state-of-the-art vehicle emissions test system, namely the Horiba VETS 9200, that oversees the operation of dynamometer, constant volume sampler, exhaust gas analyzers, and data management. Figure 2.1.1 illustrates the test configuration for the present study. Each component will be described in the following sections.

2.1.1 Dynamometer Cells

There are two chassis dynamometer test cells with variable inertia flywheel systems ranging from 1750 lbs to 9625 lbs in 125 lb increments. In addition, each dynamometer is equipped with a road load power control. The purpose of the flywheels and load braking system is to provide a realistic simulation of load conditions on the road. The flywheels and brakes are set in accordance with the type of vehicle to be tested. A video monitor that displays the speed profile for the driver

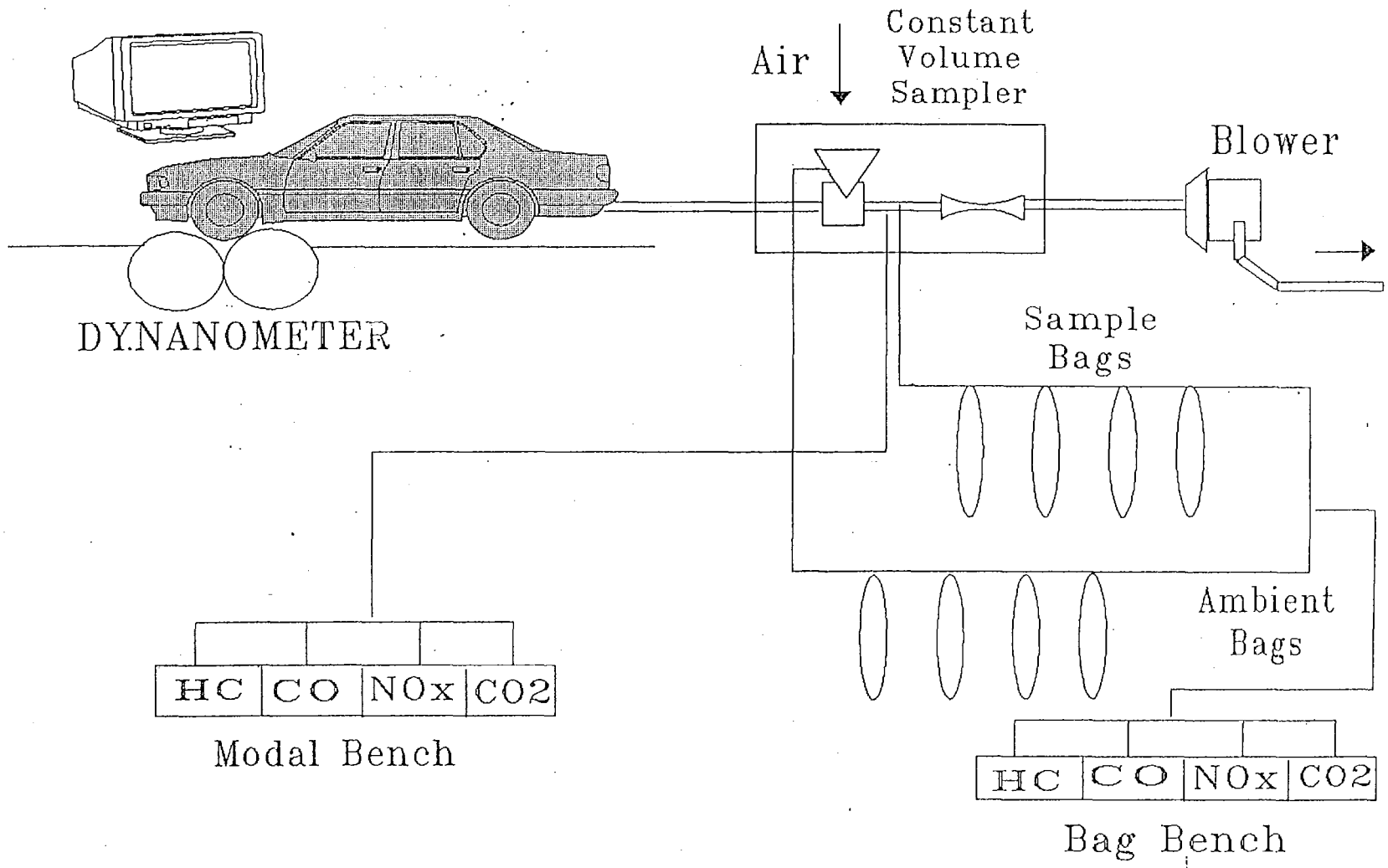

Figure 2.1.1 Testing configuration

to follow is adjacent to the chassis dynamometer. Because of the absence of air movement across the vehicle during test driving on the dynamometer, a powerful fan is used to blow air at the front end of the vehicle, simulating the cooling effect of the wind through the radiator while driving. The position of the chassis dynamometer is such that both front and rear wheel drive vehicles fit well in the cell. In this study, only test cell No.1 was used, which houses a Clayton EC 50 dynamometer.

The cell temperature control is achieved by two air conditioning systems. The first one is a conventional system with both heating and cooling functions, and is used primarily for heating up the cell. The second unit contains only an air conditioning system capable of cooling to temperatures below freezing. In general, the temperature in the cell is kept between 40 F to 120 F. There is also a humidity control in the test cell.

2.1.2 Vehicle Soak Area

In order to simulate the cold start and hot start testing modes, it is first necessary to "soak" the vehicle at the specified test temperature for at least 12 hours prior to testing. The soak temperature is controlled by five individual air conditioning units and is typically set between 70 F and 74 F. Soak temperatures outside this range are accomplished by special refrigerated and heated shipping containers. The ATDS maintains four of these containers and each is capable of soaking a vehicle from -5 F to 120 F. The soak area in ATDS is about 8,000 square feet.

2.1.3 Constant Volume Sampler (CVS)

The CVS is a Horiba model CVS-48/RS. This unit includes three user selectable volumetric flow ranges, a remote mixing tee, and a dilution air flow measurement system to calculate the exhaust volume for modal analysis. Moreover, it contains a 10 HP blower, and a 350 cfm Venturi module with Teflon bag sampling components, and a three stage background air filter is used to preserve the quality of the intake air. Exhaust emissions from the tailpipe are mixed and diluted with intake ambient air in the mixing chamber of the CVS and the flow rate exiting the CVS unit is kept at 350 cfm. A portion of the diluted emissions is collected with the Teflon bags, with the other stream of diluted emissions going directly to the on-line gas analyzers. Stainless steel is used throughout the sampling system. All the CVS functions are controlled by the Horiba VETS 9200 hardware.

2.1.4 Bag and Modal Data Sampling

The exhaust analytical system used for this project is a Horiba series 200 gas analysis console. This system is capable of measuring total HC, non-methane organic gases (NMOG), CO, CO_2, NOx, both at low and high ranges as well as recording data from the gas analyzers.

Under the modal (second-by-second) sampling mode, exhaust gases are continuously pumped to the analyzers from the CVS. Before the test begins, the computer zero/spans all ranges of the analyzers to ensure accurate readings during the tests. During the test, the system automatically switches the analyzer range in order to

obtain the most accurate readings possible.

While modal data are being collected during the test, bag data are collected at the end of the test. During each test the system fills one pair of bags, i.e., one bag with dilute exhaust and the other with ambient air. After the test is completed, the pair of bag samples is analyzed immediately. The system begins the analysis sequences by evaluating a small portion of the collected exhaust sample. Based on the results of this "sniff," the computer selects one range of each analyzer to be used in analyzing the full sample.

Analyzer response to gas concentrations changes gradually or "drifts" over time. This analytical system mathematically corrects for drift by measuring analyzer response to zero-grade gas and then span gas (at or near full scale), comparing the response to similar measurements taken when the analyzer was calibrated, and calculating factors of offset and gain. The zero/span calibration is included in every test that involves the analyzer to ensure the analyzer is fully operational.

2.1.5 Computer Control

The VETS 9200 test control software which utilizes a Hewlett Packard 9000-series model 425S computer workstation, is the central control system. It controls equipment in the cell, regulates the sequence of events in the test, displays the graphic driving schedule, relays instructions to the driver, collects the data, calculates and reports emissions levels and other test results. The system acquires data from two types of sources: input signals from the sampling and analysis devices (e.g.

dynamometer, analyzer, CVS) and cell parameter tables stored on the system disk.

The system software includes calibration programs for the analyzers, various analog devices, and CVS. Results from the calibration are stored in several cell parameter tables. For instance, the Analyzer and Signal Calibration Program assists in calibrating gas analyzers and system analog signals, such as CVS temperature and inlet pressure, and auxiliary signals. The system records the calibration results in the cell parameter tables. In addition, the CVS calibration program collects the data needed to calculate flow rate from temperature and pressure readings at the critical flow venturi in the CVS. Furthermore, whenever the span bottle for an analyzer range is changed, a new span concentration must be entered in the cell parameter table describing that analyzer range.

2.1.6 Quality Control of the Instrument

All calibration and test data are checked by a quality auditor to ensure that the procedures have been correctly followed and the data are recorded and transcribed correctly. Routine periodic calibrations are performed as required by the Code of Federal Regulations. Calibrations or calibration checks are performed daily, weekly, and monthly depending of the type of the instruments.

All analytical instruments are calibrated with gases traceable to the National Bureau of Standards. Traceability is certified by Scott Environmental Technology, Inc. All the analytical instruments are calibrated at 7 points (including zero) across each range using a precision gas divider. Calibration tolerance is ± 2% of each point

from the least square regression line.

ATDS regularly participates in correlation testing including the Calibration Gas Reference Service provided by Scott Environmental Technology, Inc., and periodic correlation vehicle tests which provide cross checks between major manufacturers, USEPA's Ann Arbor laboratory, and CARB. More importantly, CARB periodically sends technicians to inspect and cross-check the testing system at ATDS, from the dynamometer test cell to the analytical instrument streams, to ensure the quality of the data.

2.2 Test Vehicle Procurement

One of the major challenges in this study was the selection of the "representative" vehicles that could reflect the vehicle fleet under the constraints of small sample size where n=11. Obviously, the greater the sample size the more representative it is of the vehicle fleet. In general, to choose a representative fleet of vehicles, the following parameters should be considered (Thu Vo, 1992):

1. Emission control system type
2. Emission technology level
3. Vehicle registration (quantity)
4. Engine type, size and sales weighted volume
5. Vehicle manufacturer

All the above factors could directly or indirectly affect the quality of the experiment design. For instance, older vehicles tend to have higher emissions due to the wearing out of parts. The EMFAC7F model has adopted three technology groupings as the basis for the emission correction factor analysis (CARB, 1992) and this is the basis on which the selection of the eleven vehicles was made in the present study.

In this study, the vehicles were representative of the following categories:

Fuel Delivery System	Number of Vehicles
Multi-Port Fuel Injection (MPFI)	5
Throttle Body Injection (TBI)	3
Carburetor (CARBU)	3

Other guidelines were also adopted to ensure that the selected vehicles were representative of the general fleet. In particular, the baseline FTP emissions should be no greater than four times the applicable vehicle emission standards. In addition, each vehicle selected reflected typical mileage accrual rates (between 8,000 to 12,000 miles per year). Based on the above criteria, eleven vehicles were selected and are presented in Table 2.2.1.

Finally, prior to the final procurement of the vehicles, each vehicle was inspected thoroughly to ensure that it was in good operating condition for testing. Items that may destabilize the performance of the vehicle testing, such as cracked hoses, excessive oil consumption, fluid leakage, and other destabilizing factors, were

Table 2.2.1 Description of test vehicles

Multi-port Fuel Injection					
Make/ Style	Lincoln Town Car	Oldsmobile	Toyota Paseo	Mercury Topaz	Ford Taurus
Year	90	92	92	89	92
Mileage	42360	16667	22209	39737	37887
No. of cylinders	8	6	4	4	6
Displacement (l)	5	3.8	1.5	2.3	3
Fuel delivery system	MPFI	MPFI	MPFI	MPFI	MPFI
Catalyst	TWC/OX	TWC	TWC	TWC	TWC
Inertia weight	4250	3750	2375	3000	3500
Road horse power	9.9	6	5.2	7.3	6.8
Adaptive learning	Yes	Yes	Yes	Yes	Yes

Throttle Body Injection Group			
Make/ Style	Continental MRKVII	Cadillac Sedan	Dodge Daytona
Year	85	86	88
Mileage	80990	104741	36088
No. of cylinders	8	8	4
Displacement (l)	5	4.1	2.5
Fuel delivery system	TBI	TBI	TBI
Catalyst	TWC	TWC / OX	TWC / OX
Inertia weight	4000	4500	3000
Road horse power	9.1	8	6.3
Adaptive learning	Yes	Yes	Yes

Carburetor Group			
Make/ Style	Chevrolet Impala	Buick Regal	Honda Accord
Year	79	82	83
Mileage	114265	85274	107014
No. of cylinders	8	6	4
Displacement (l)	5.7	3.8	1.8
Fuel delivery system	CONV. CARB	ELEC. CARB	CONV. CARB
Catalyst	OX	TWC	OX
Inertia weight	4000	3625	2750
Road horse power	13.3	10.3	7
Adaptive learning	No	Yes	Yes

MPFI - Multiple Point Fuel Injection
TBI - Throttle Body Injection
CONV. CARB - Conventional Carburetor
ELEC. CARB - Electrical Carburetor
TWC - Three Way Catalyst
OX - Oxidation Catalyst

checked and corrected prior to the testing.

2.3 Test Cycles

Ten speed cycles were chosen for this study. The average speed of these cycles ranges from 2.5 mph to 64.4 mph. In general, the speed cycles such as Low 1, Low 3, New York City Cycle (NYCC), and Speed Correction Cycle-12 mph (SCC-12), with average speeds ranging from 2.5 to 12 mph, depict driving conditions in a congested traffic environment on local streets, where vehicles tend to stop and idle more frequently. Table 2.3.1 lists the characteristics of each speed cycle. The speed time trace of each speed cycle is presented in Figures 2.3.1 to 2.3.10, respectively. Except for the Unified Cycle (UC), also known as LA92, all other speed cycles were also used in the development of speed correction factors.

Speed cycles such as the Highway Fuel Economy Cycle (HHWY), U Highway Cycle (UHWY), W Highway Cycle (WHWY), and X Highway Cycle (XHWY), with average speeds ranging from 45 mph to 64.4 mph, represent typical freeway driving conditions. In fact, the UHWY, WHWY, and XHWY cycles were derived from a segment of HHWY and have the same speed-trace pattern as the HHWY but with different average speeds.

The FTP and the UC are the only two cycles that consist of 3 bags. In both cycles, there are three operating modes, namely, cold start (Bag 1), hot running (bag 2), and hot start (bag 3). The UC, also known as LA92, was derived from the results of instrumented vehicle chase-car studies in Los Angeles in 1992, and utilizes 833

Table 2.3.1 Description of test cycles

Cycle	Cold Start (yes/no)	Distance (miles)	Duration (seconds)	Average Velocity (mph)	Peak Velocity (mph)	Average Running Velocity (mph)	Average Accel (mph/s)	Average Decel (mph/s)	Idle (%)	Accel (%)	Decel (%)	Cruise (%)
LOW1	no	0.4	617	2.5	10	4.7	1	-0.8	45.4	18	21.6	15.1
LOW3	no	0.7	625	4	16	6.3	1.1	-1	34.1	26.1	28.8	11
NYCC	no	1.2	599	7.1	27.7	10.9	1.4	-1.4	32.1	32.6	33.4	2
SCC-12	no	1.2	343	12.3	29.1	16.6	1.2	-1.4	24.5	38.8	31.8	5
FTP	yes	7.5	1372	19.5	56.7	24.2	1.1	-1.3	19	39.7	34.3	8.1
UC	no	9.8	1435	24.6	67.2	29.4	1.5	-1.7	16	38	34	12
UHWY	no	5.9	474	45	53.3	45.6	0.5	-0.5	0.8	39.9	40.3	19
HHWY	no	10.3	765	48.3	59.9	48.6	0.4	-0.5	0.5	44.2	38.7	16.6
WHWY	no	7.8	486	57.8	67.4	58.4	0.5	-0.5	0.8	40.1	40.5	18.5
XHWY	no	8.8	492	64.4	74.9	65.1	0.6	-0.6	0.8	40.2	40.7	18.3

FTP - Federal Test Procedure
UC - Unified Cycle or LA92 Cycle
NYCC - New York City Cycle
SCC-12 - Speed Correction Cycle - 12 mph
HHWY - Highway Fuel Economy Test
UHWY - U Cycle
WHWY - W Cycle
XHWY - X Cycle
LOW1 - Low 1 Cycle
LOW3 - Low 3 Cycle

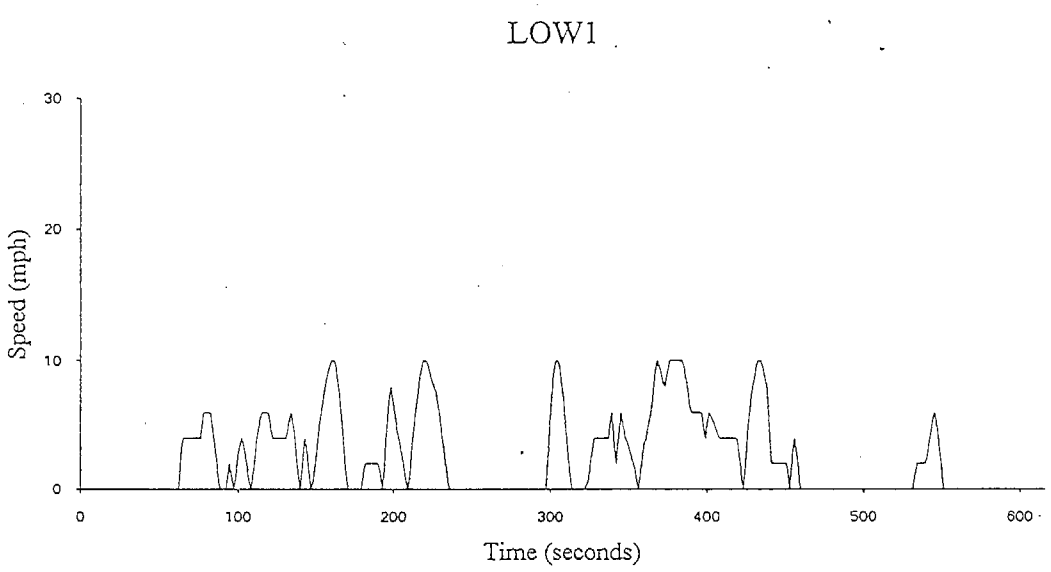

Figure 2.3.1 Speed trace of Low 1 Cycle (LOW1)

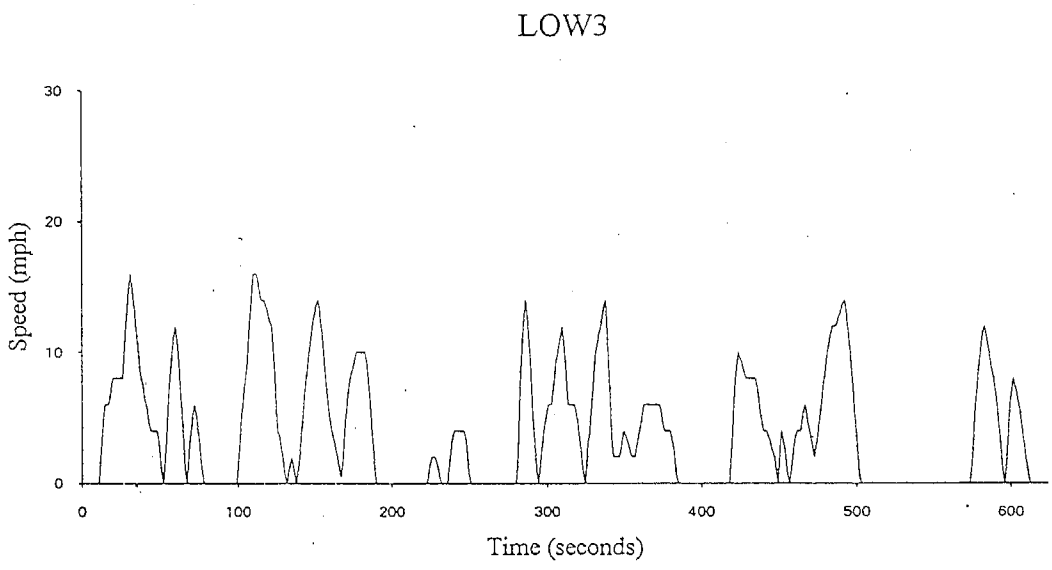

Figure 2.3.2 Speed trace of Low 3 Cycle (LOW3)

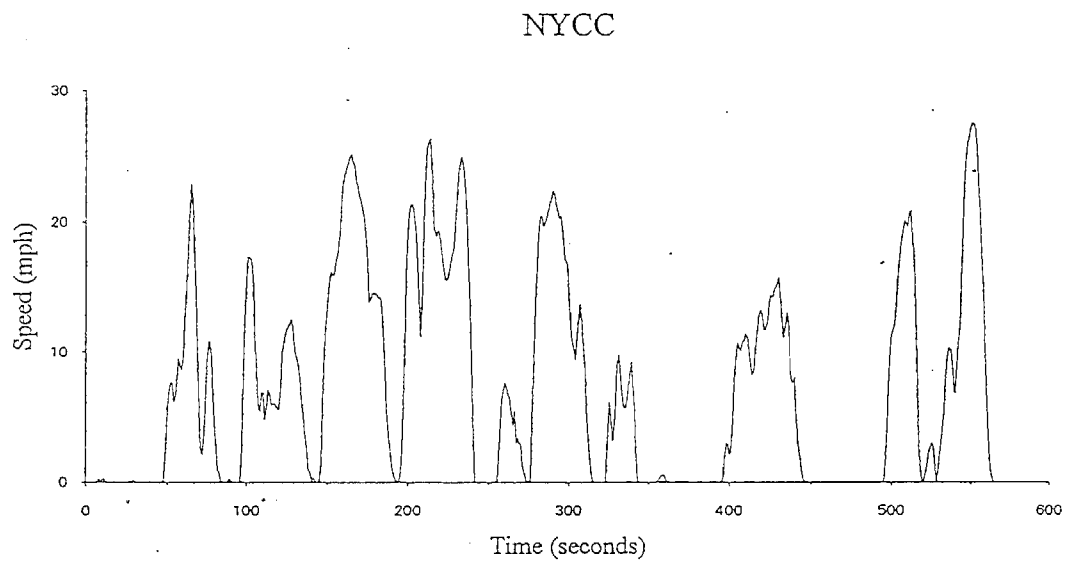

Figure 2.3.3 Speed trace of New York City Cycle (NYCC)

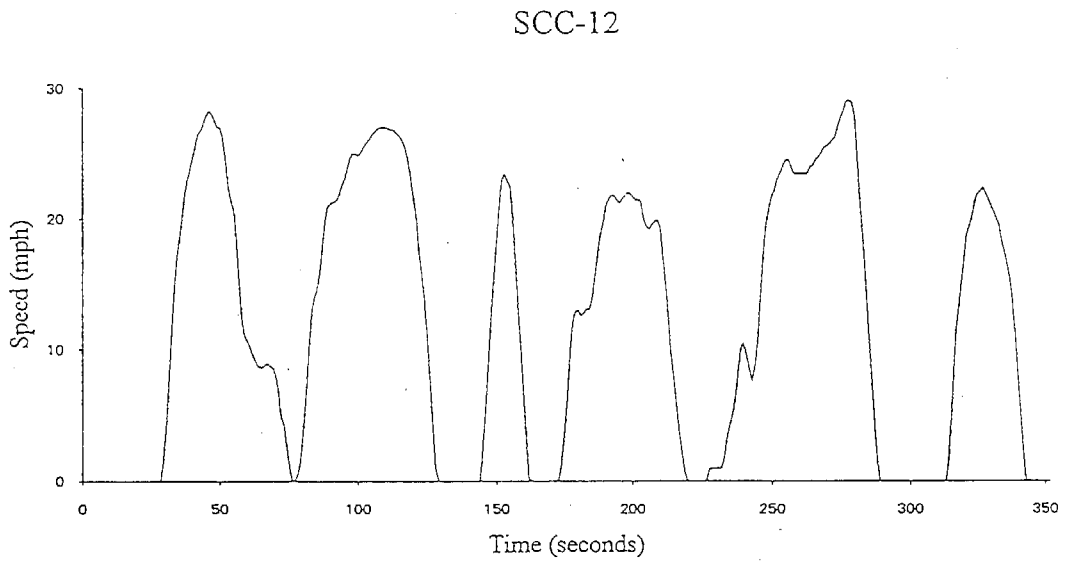

Figure 2.3.4 Speed trace of Speed Correction Cycle -12 mph (SCC-12)

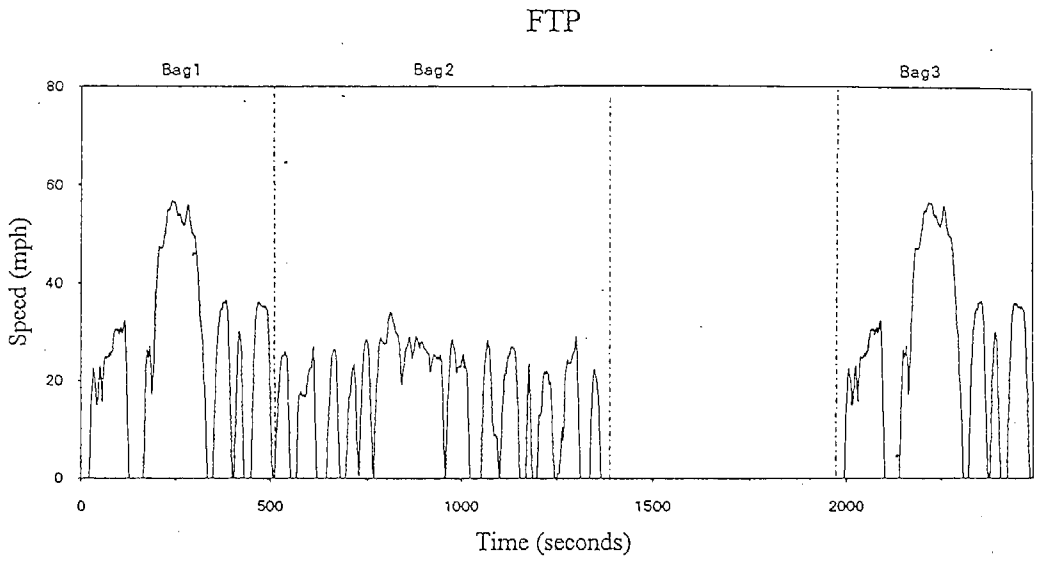

Figure 2.3.5 Speed trace of Federal Test Procedure (FTP)

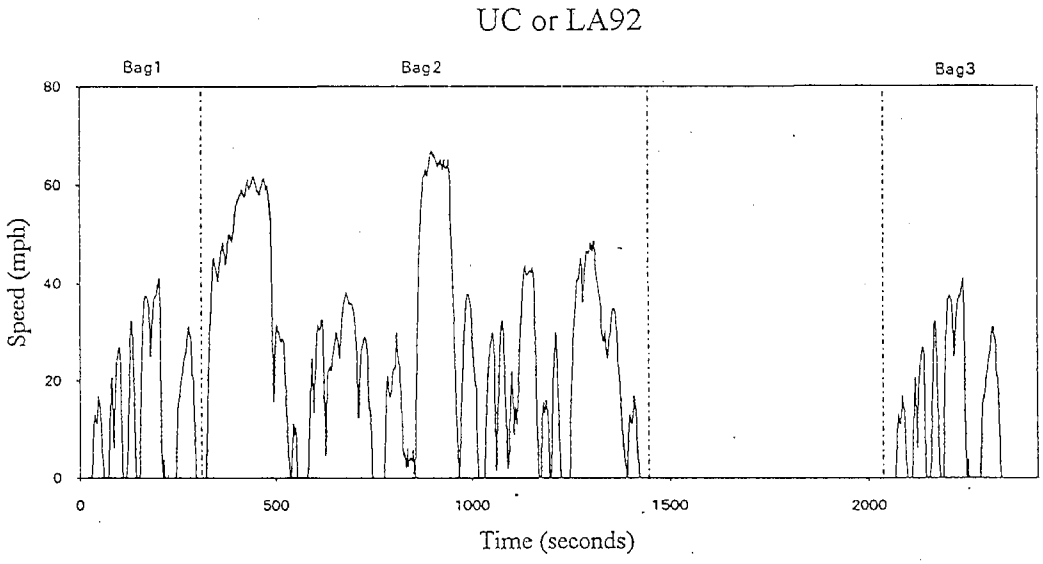

Figure 2.3.6 Speed trace of LA92 or Unified Cycle (UC)

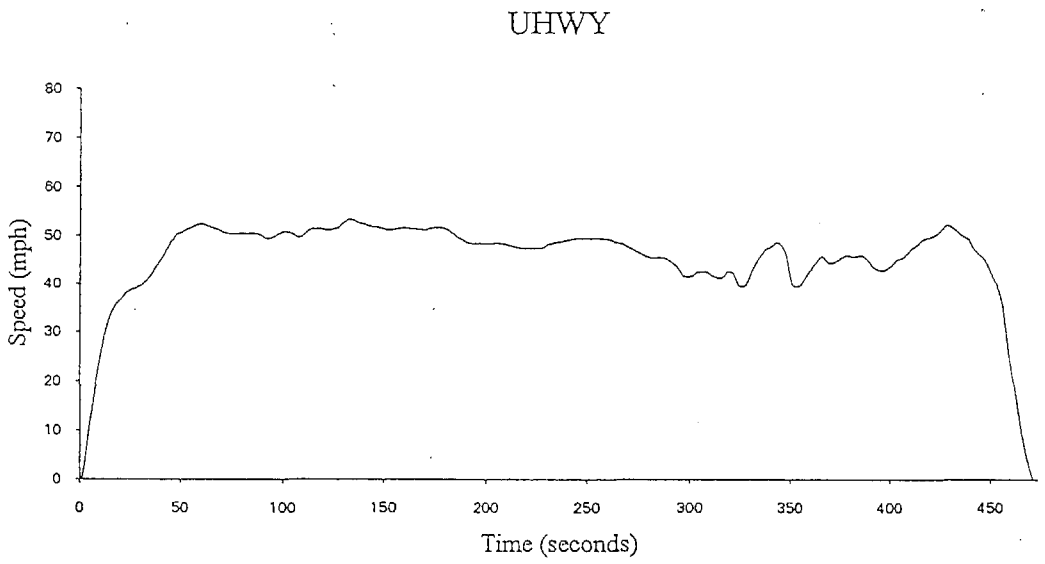

Figure 2.3.7 Speed trace of U Cycle (UHWY)

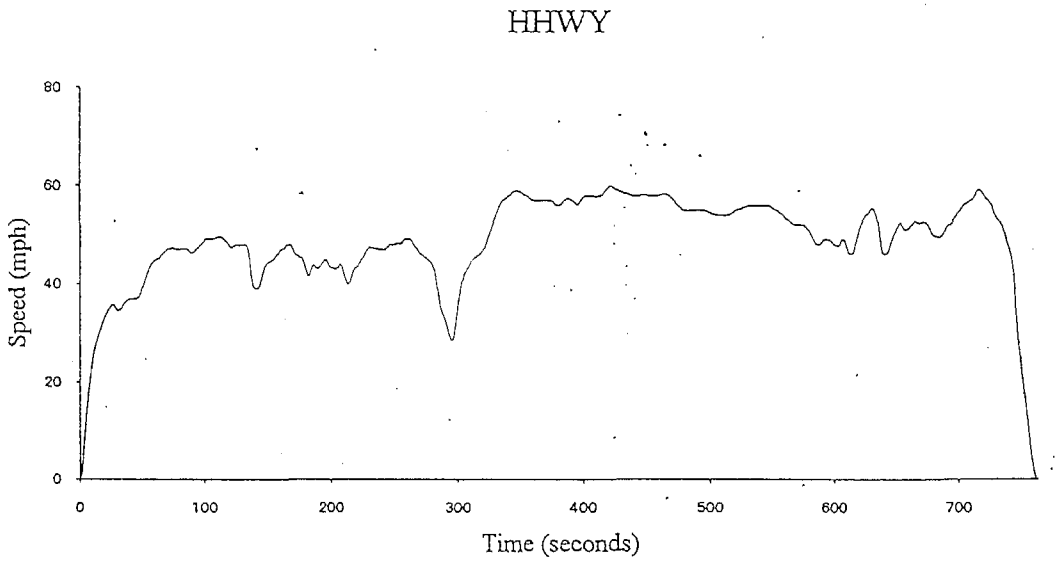

Figure 2.3.8 Speed trace of Highway Fuel Economy Cycle (HHWY)

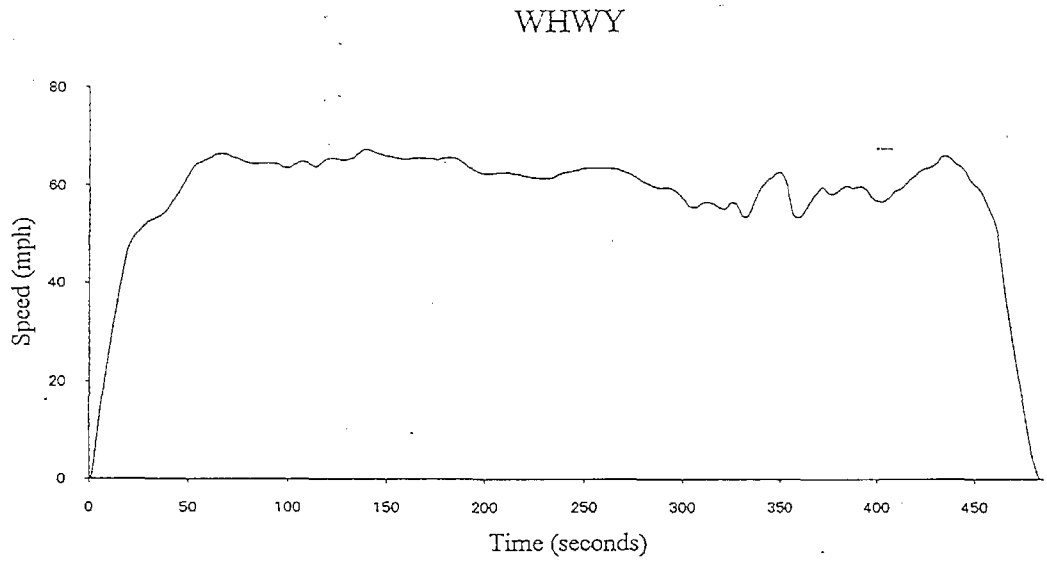

Figure 2.3.9 Speed trace of W Highway Cycle (WHWY)

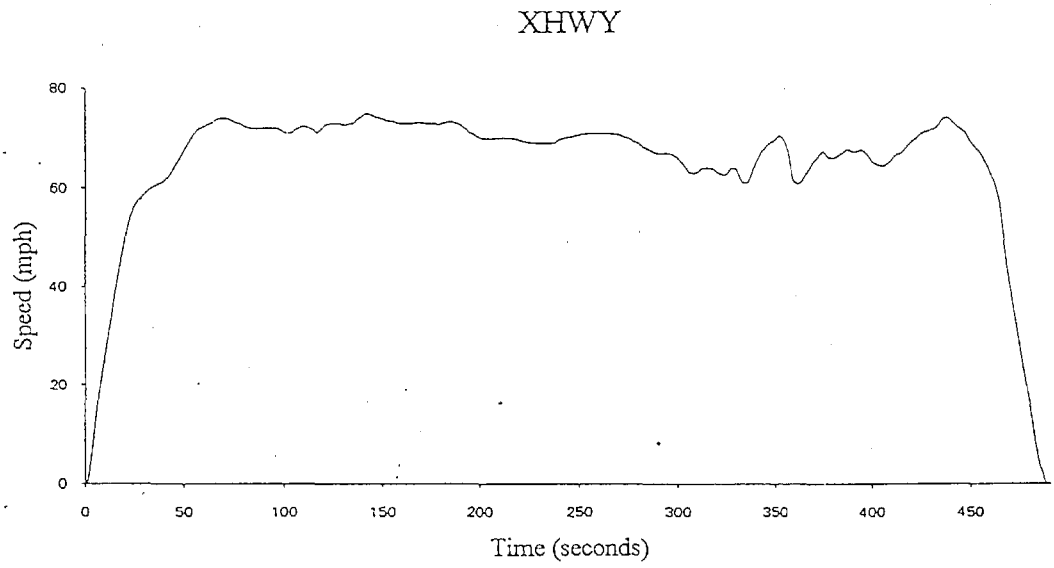

Figure 2.3.10 Speed trace of X Highway Cycle (XHWY)

"microtrips." The microtrips were joined together to represent a "typical" driving cycle (Austin, 1993). Compared to the FTP, the UC definitely covers a broader domain of speeds and accelerations. In the present study, only the FTP has a cold start mode while the UC has a hot start mode for both Bag 1 and bag 3.

2.4 Fuel Specifications

The fuels (Phase 1, Phase 2, and indolene) used in this study were supplied by Howell Hydrocarbons & Chemicals, Inc. Three-hundred and thirty gallons of each type of fuel was ordered. To confirm the fuel specifications as stated by the supplier, the fuels were analyzed by ARB's laboratory in El Monte. Moreover, before each drum was opened for use, a sample was collected from the drum and analyzed for RVP. Table 2.4.1 summarizes the fuel specifications of Indolene, Phase 1, and Phase 2 fuel.

Phase 1 fuel was implemented in California in 1992 and is available in summer grade (without oxygenates) and winter grade (with oxygenates). The purpose of adding oxygenates to the winter grade Phase 1 fuel is to reduce the carbon monoxide exhaust emissions. In addition, Phase 1 fuel includes the elimination of lead and the addition of deposit control additives. Note that the summer grade Phase 1 fuel was used in this study.

Phase 2 fuel, proposed by the CARB, will be available in 1996. It has more stringent requirements, such as further reduction of RVP, addition of oxygenates year round, reductions in sulfur, benzene, aromatic hydrocarbons, and olefin content, and

Table 2.4.1 Fuel specifications

Fuel Parameter	Units	Phase 1 *	Phase 2*	Indolene**
Reid Vapor Pressure	(psi)	7.45	6.65	9.2
Distillation Range	(F)			
Initial Boiling Point		92	99	87
10% point		130	138	127
50% point		222	202	217
90% point		312	296	313
end point		411	386	401
HC Composition	(Vol %)			
Olefins		9	3.6	3.5
Aromatics		33.3	24.2	30.5
Multi-Substituted Alkyl Aromatics		20.3	15.2	na
Benzene		1.8	1	na
MTBE (methyl tertiary butyl ether)		0	11.2	na
Ethanol		0	0	na
Lead, maximum	(gram/gal)	< 0.05	< 0.05	< 0.001
Sulfur	(ppmw)	132	31.0	50
Phosphorus	(gram/gal)	< 0.005	< 0.005	< 0.001
Oxygen Wt. Fraction	(%)	0	2.02	na

* Test results reported by ARB laboratory at El Monte

** Test results reported by Howell Hydrocarbons & Chemicals, Inc.

the reduction of distillation temperature. Phase 2 fuel is designed to achieve the maximum reductions in emissions of criteria pollutants and toxic air contaminants, such as benzene. More importantly, because of the lower RVP, evaporative hydrocarbon emissions will be significantly reduced. This could have major implications for reducing hydrocarbon emissions from vehicles, as it is estimated that approximate 30% of total motor vehicle hydrocarbon emissions is the result of evaporative emissions (CARB, 1993b).

In general, the specifications for Phase 1 and Phase 2 fuels contain only the "cap" limits which cannot be exceeded throughout the gasoline distribution system. The actual composition of Phase 1 fuel that is available in the market varies among the suppliers. Indolene is a standard industrial fuel and its fuel specification is well defined and standardized. Indolene is mainly used for certified testing of new or in-use vehicles to check whether they meet the emission standards.

The detailed speciation of each fuel is presented in the Appendix. The purpose of using these three fuels is to compare the fuel effects on exhaust emissions, in particular, and to examine the net benefit of Phase 1 and Phase 2 fuels as predicted by the EMFAC model.

2.5 Test Matrix and Test Procedures

Each of the eleven vehicle was tested with three fuels (Phase 1, Phase 2, and Indolene), at three temperatures (50 F, 75 F, and 100 F), and through ten speed cycles resulting in a total of 990 tests or 99 sequences (each sequence contains ten speed cycles) for the eleven vehicles. In other words, each vehicle had 9 sequences of tests. After the initial 990 tests were completed, each vehicle repeated one sequence at 75 F with indolene to evaluate the variability of the tests. During the repeated tests, the catalyst efficiency of each vehicle was also evaluated. Table 2.5.1 presents the test matrix including fuel, temperature, and vehicles.

The dynamometer cell at ATDS is capable of maintaining an ambient temperature between 50 F to 100 F. Prior to testing, each vehicle was visually inspected, including engine oil, radiator coolant, brakes, and tire pressure. Fuel was then added to 40% of the fuel tank capacity. The vehicle was then soaked for no less than 12 hours and no more than 36 hours at the testing temperature.

The FTP was always the first test in each sequence because Bag 1 is a cold start. The remainder of the 9 tests in each sequence were randomized. All subsequent nine tests were separated by a pre-conditioning cycle of five minutes. Each sequence generally took a few hours to complete. Depending on the daily testing schedule, up to two sequences could be completed each day. The drivers for this study were trained and required to follow the speed-trace shown in the monitor. Any test that had violations due to the mismatch of actual speed trace to the designated speed trace in the monitor was aborted. Note that the acceptable margin of error from the actual

Table 2.5.1 Test matrix

Fuel	Temp (F)	Vehicle	Speed Cycles	Fuel	Temp (F)	Vehicle	Speed Cycles	Fuel	Temp (F)	Vehicle	Speed Cycles
		H	10			G	10			B	10
		I	10			F	10			J	10
		F	10			A	10			G	10
		D	10			J	10			H	10
		G	10			B	10			I	10
Phase1	75	E	10	Phase2	50	E	10	Indolene	50	E	10
		K	10			C	10			D	10
		B	10			D	10			C	10
		C	10			I	10			A	10
		A	10			H	10			K	10
		J	10			K	10			F	10
		D	10			I	10			H	10
		G	10			K	10			E	10
		F	10			J	10			K	10
		A	10			B	10			C	10
		E	10			F	10			F	10
Phase1	100	C	10	Phase2	100	H	10	Indolene	75	A	10
		K	10			G	10			G	10
		I	10			C	10			I	10
		J	10			D	10			J	10
		H	10			E	10			B	10
		B	10			A	10			D	10
		B	10			E	10			E	10
		D	10			H	10			I	10
		I	10			D	10			F	10
		F	10			K	10			H	10
		A	10			J	10			A	10
Phase1	50	C	10	Phase2	75	B	10	Indolene	100	B	10
		G	10			C	10			C	10
		H	10			F	10			K	10
		J	10			G	10			G	10
		E	10			I	10			J	10
		K	10			A	10			D	10

Note that the temperature, vehicles and test cycles are randomized
(There are 10 cycles in each sequence)

speed trace is ± 2 mph.

Recent experiences at ATDS had suggested that some vehicles possessed "adaptive learning" capability, which allowed the vehicle to recalibrate itself during the changeover of fuel type. That is, vehicles will "learn" to compensate for the presence of an oxygenate in the fuel. This compensation usually results from the trimming of fuel delivery algorithms as a function of composite oxygen sensor activity. The time required to accomplish this "trimming" activity varies widely even within a single manufacturer's model and with model year. To eliminate this bias due to fuel exchange, each vehicle was turned off a few times in order to reset the algorithms after the fuel exchange. This was followed by twice running the FTP to eliminate any previous fuel residuals in the system, and to ensure the vehicle "adapted" to the new fuel.

2.6 Data Collection

The Horiba VETS 9200 system was also used for data storage. It contained a 500 Mb hard disk for data storage. There was also a laboratory datalogger system for backup. The standard sampling rate for the Horiba VETS 9200 was 5 Hz.

The Horiba VETS 9200 could accommodate a wide variety of signal types and sources. The range included most common types of signals, including analog to 100 V; digital event level to 1 MHz; frequency to 25 kHz; thermocouples (all types); and current in milliamps. For sampling outside these ranges, special signal conditioners could be used to adjust the ranges to acceptable limits.

The data collected in this study included a combination of analog, digital and thermocouple signals. The entire data file was stored as raw data in the Horiba VETS 9200 and could be retrieved as ASCII files. The raw data were downloaded onto 3.5" floptical disk with 21 megabytes storage capability.

Prior to the start of each single test, the analytical instruments were checked and tested for their reading range. Background readings including HC, CO, NOx, CO_2, wet bulb temperature, dry bulb temperature, and barometric reading were recorded.

After completing the required number of tests, second-by-second mass exhaust data as well as bag emissions data were collected. The modal emissions data included instantaneous vehicle speed, engine rpm, exhaust gas oxygen content, catalyst temperature, and concentrations of HC, NOx, CO, and CO_2. Each test data set included the test information of run number, speed cycle, start/end cell temperature, fuel type, and bag emission data for HC, NOx, CO and CO_2. Modal data of each test were adjusted for any time delays (such as exhaust gas transportation time and sensor response time) so that all values in each record were standardized to real time.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Data Analysis

This chapter presents the exhaust emissions data (gram/mile) from the test results of 11 vehicles. Each vehicle was tested over nine sequences (each sequence consisting of 10 test cycles) with a combination of three temperatures (50 F, 75 F, and 100 F) and 3 fuels (Phase 1, Phase 2, and Indolene). Upon completion of the initial nine sequences for each vehicle, data were evaluated before advancing to the 10th sequence or repeated sequence (75 F, Indolene). Thus, there was a brief idling period ranging from one to seven months between the 9th and 10th sequences, depending on the testing schedule of each vehicle. Note that "speed" in this chapter was defined as the average speed of each cycle, and could also refer to the specific cycle.

Due to the variation in experimental factors, such as speed, temperature, fuel, and vehicle, the emissions data spanned up to six orders of magnitude. Two-dimensional graphs were used to illustrate the relationships between any two particular factors. Since each distribution of HC, CO, and NOx exhaust emissions appeared skewed to the right and was not normally distributed, they were plotted using a logarithmic (base 10) scale. Most emissions data were presented as box plots since these provide the advantage of displaying the trend and shape of the distribution as well as the median, minimum, maximum, and lower and upper quartiles. To examine the effect of fuel delivery technology (i.e., MPFI, TBI, and CARBU), data were aggregated based on technology groups and all 11 vehicles combined.

Note that one sequence (100 F and Indolene) from the 1992 Oldsmobile was excluded from the data analysis due to malfunctioning of the oxygen sensor; Section 3.2 explains this problem in detail. While the FTP was the only test including cold start mode (vehicle was soaked at the testing temperature for at least twelve hours prior to testing), the remaining nine test cycles were conducted in the hot stabilized condition. In order to obtain meaningful data analysis, the conditions at which vehicles were tested should be similar, therefore, FTP Bag 2 (hot stabilized mode) was used for most of the data analyses.

Besides comparing emissions data through graphical representations, statistical methods were employed to analyze the data. One-way analysis of variance (ANOVA) was used to evaluate: (1) the temperature effects within each fuel type, (2) the fuel effects within each temperature, (3) the temperature effects within each cycle, and (4) the fuel effects within each cycle.

Student-t tests of paired samples was used to test: (1) the difference between exhaust emissions due to Phase 1 and Phase 2 fuel for all vehicles, (2) test repeatability of the sequence (75 F and Indolene) of each vehicle, and (3) the effect of Bag 1 and Bag 3 on FTP and UC, respectively. Moreover, principal component analysis (PCA) was used to explore the correlations between the dependent and independent variables. Finally, three-way ANOVA was used to investigate the interaction or synergistic effects between speed, temperature, and fuel type.

3.1.1 Comparison of Fuel and Temperature Effects

This section graphically presents the relationship of fuel and temperature effects on HC, CO, and NOx exhaust emissions while keeping other factors (vehicle and cycle) constant. That is, only the relationship of temperature and fuel was evaluated despite the possible effects from both the vehicle and cycle factors. For example, of the 270 data sets in CARBU (3 vehicles x 3 temperatures x 3 fuels x 10 cycles), the vehicle and cycle factors were held constant so that the fuel or temperature effects could be examined.

The effects of fuel and temperature were examined based on the three technology groups MPFI, TBI, CARBU and all 11 vehicles as a group. Figures 3.1.1.1 to 3.1.1.1.3 present the effects of fuel and temperature on HC, CO, and NOx exhaust emissions in the MPFI group. Since the data used for comparison encompassed ten cycles and five vehicles, there were 50 data per box plot. .The wide range of distribution in each box plot is due to vehicle-to-vehicle and cycle-to-cycle variation. In general, when examining fuel and temperature effects, it is difficult to discern a clear pattern of fuel or temperature effects. Nevertheless, it appears that HC, CO, and NOx exhaust emissions due to Phase 1 fuel are slightly higher than those due to Indolene and Phase 2 fuels based on the data distribution when temperature is held constant. The same relationship was not observed when examining the temperature effect while the fuel factor was held constant.

Figures 3.1.1.4 to 3.1.1.6 illustrate the distribution of HC, CO, and NOx exhaust emissions for various combinations of fuel and temperature in the TBI group.

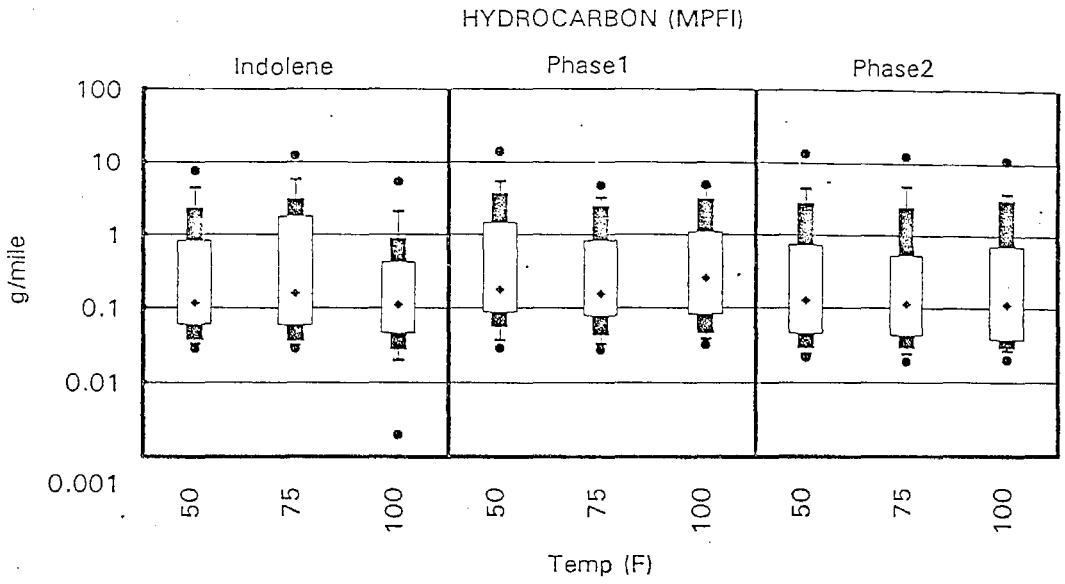

Figure 3.1.1.1 Box plots showing the effects of fuel and temperature on HC exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

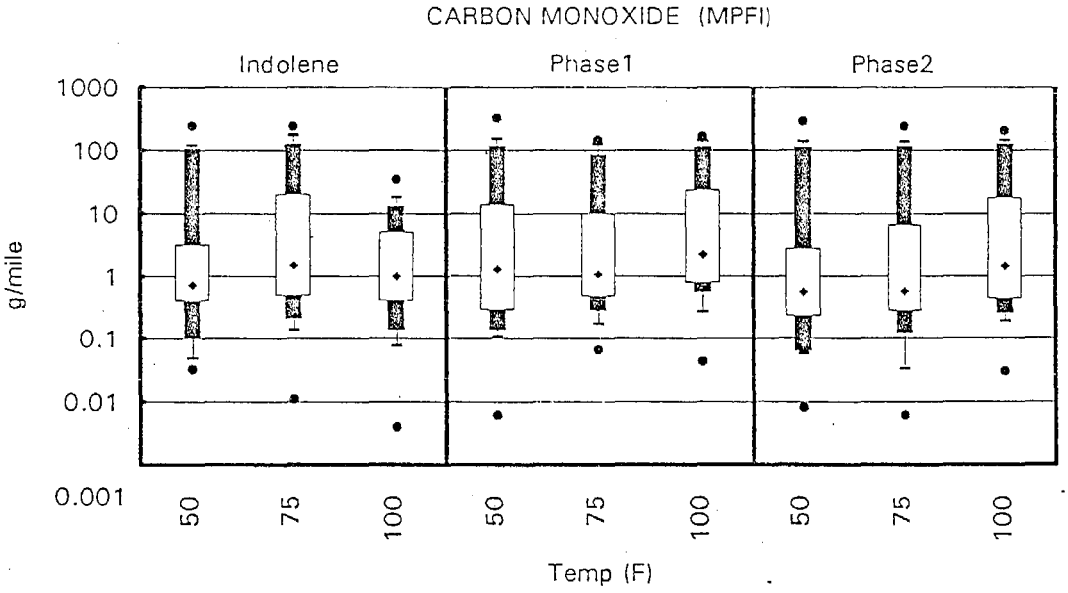

Figure 3.1.1.2 Box plots showing the effects of fuel and temperature on CO exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

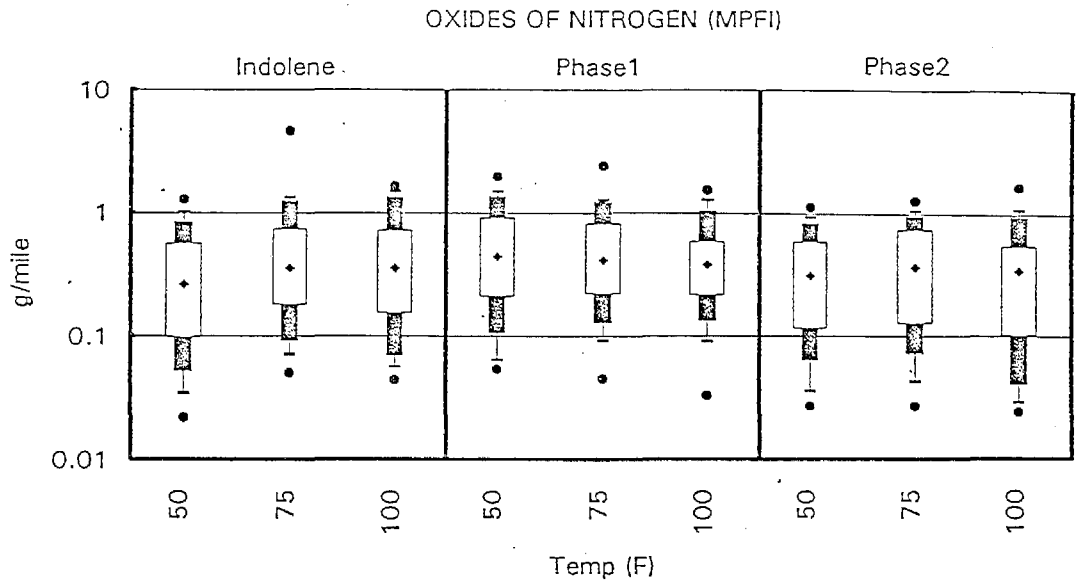

Figure 3.1.1.3 Box plots showing the effects of fuel and temperature on NOx exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

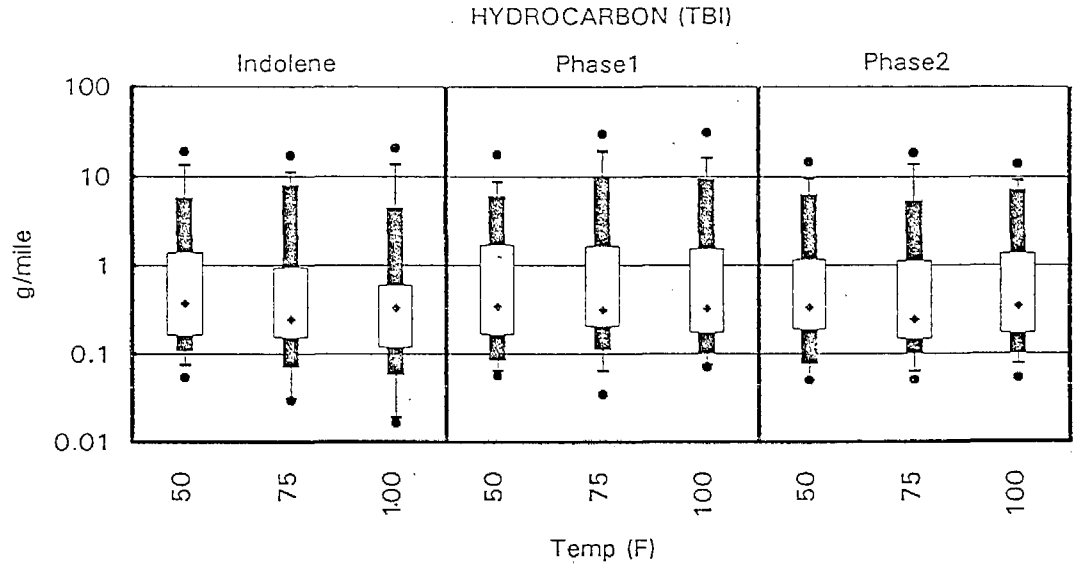

Figure 3.1.1.4 Box plots showing the effects of fuel and temperature on HC exhaust emissions (TBI). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

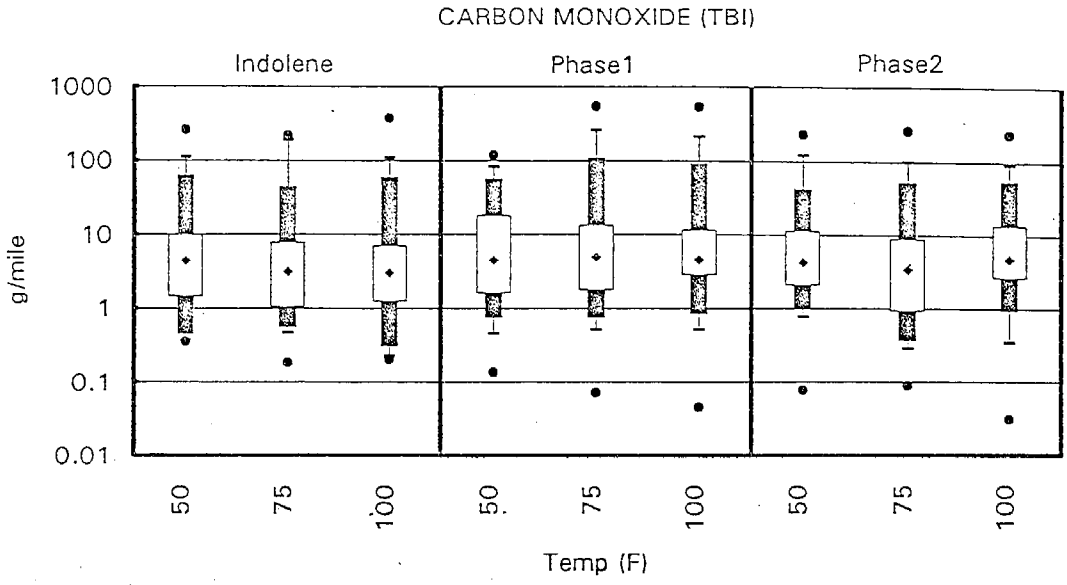

Figure 3.1.1.5 Box plots showing the effects of fuel and temperature on CO exhaust emissions (TBI). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

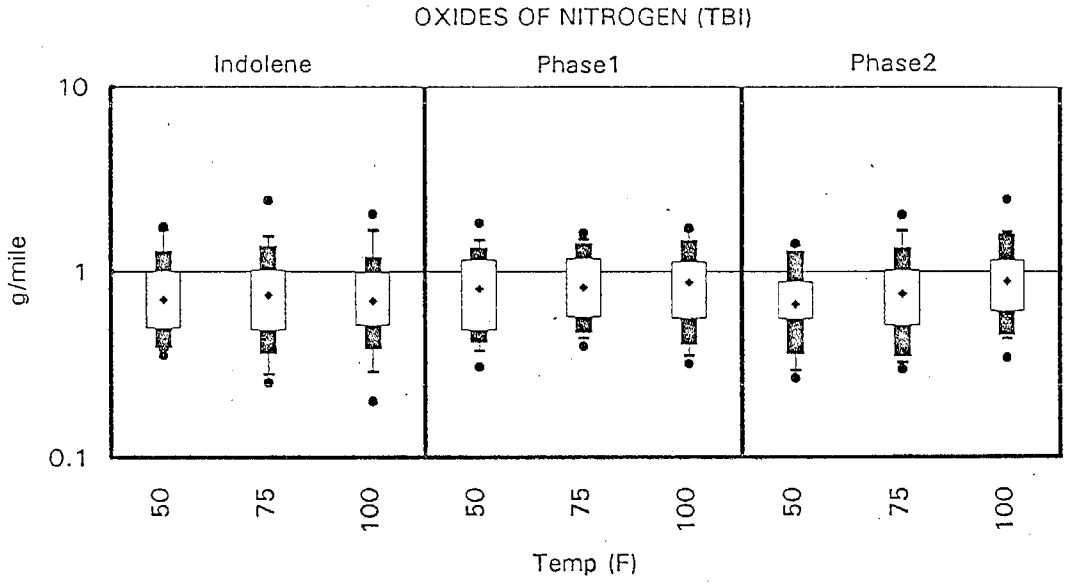

Figure 3.1.1.6 Box plots showing the effects of fuel and temperature on NOx exhaust emissions (TBI). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

Each box plot contains 30 data points based on three vehicles and ten cycles. From the distribution of the box plots, it was evident that both fuel and temperature had minimal effects on HC, CO, and NOx exhaust emissions.

Figures 3.1.1.7 to 3.1.1.9 display the distribution of HC, CO, and NOx exhaust emissions for various combinations of fuel and temperature in the CARBU group. Each box plot contains 30 data points (3 vehicles x 10 cycles). Similar to the previously mentioned MPFI and TBI groups, fuel and temperature appear to have minimal effects on HC, CO, and NOx exhaust emissions.

All 11 vehicles were also examined for the fuel and temperature effects on HC, CO, and NOx exhaust emissions as shown in Figures 3.1.1.10 to 3.1.1.12, where each box plot column contains 110 data (11 vehicles x 10 cycles). The conclusion remains the same as described above, that is, both fuel and temperature appear to have a minimal effect on HC, CO, and NOx exhaust emissions based on all ten cycles. Nevertheless, it was observed that CO emissions had the greatest variation with a range covering approximately six orders of magnitude, while HC and NOx emissions spanned approximately five and three orders of magnitude, respectively. This implies that CO emissions exhibit higher variability than both HC and NOx emissions.

The temperature and fuel effects, if any, could not be seen clearly from the above 12 figures. This was likely the result of cycle-to-cycle and vehicle-to-vehicle variation being greater than and masking the true effects of fuel and temperature. Figure 3.1.1.13 offers an alternative way of presenting Figures 3.1.1.10 to 3.1.1.12 by showing the 95% confidence interval of the population mean of HC, CO, and NOx.

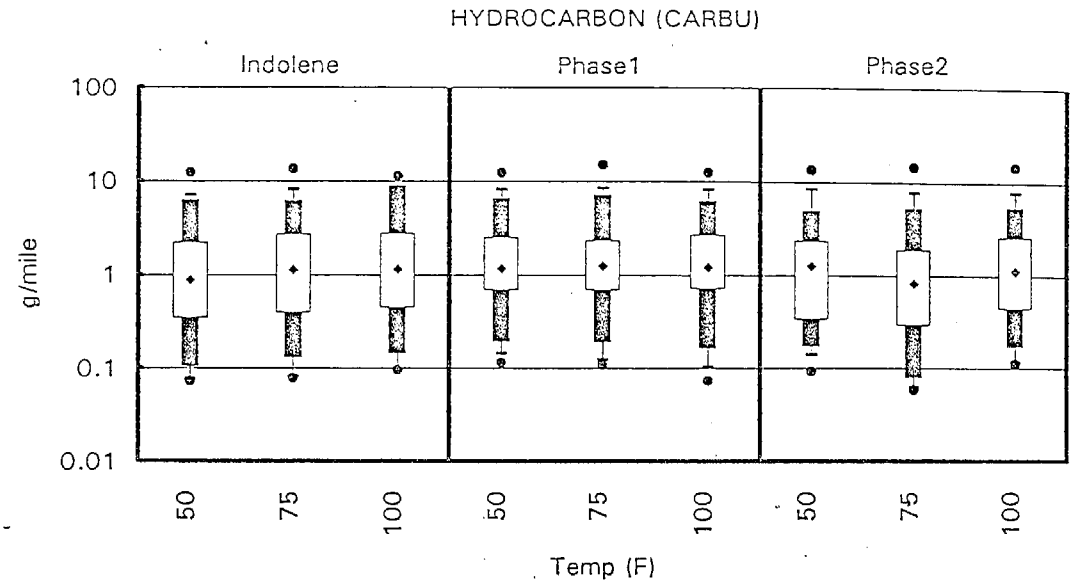

Figure 3.1.1.7 Box plots showing the effects of fuel and temperature on HC exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

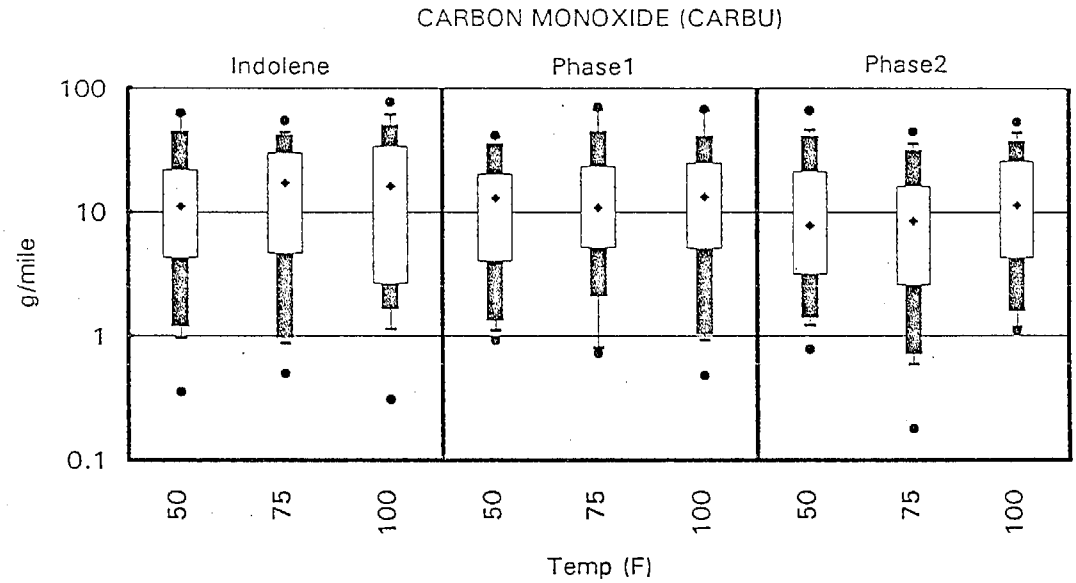

Figure 3.1.1.8 Box plots showing the effects of fuel and temperature on CO exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

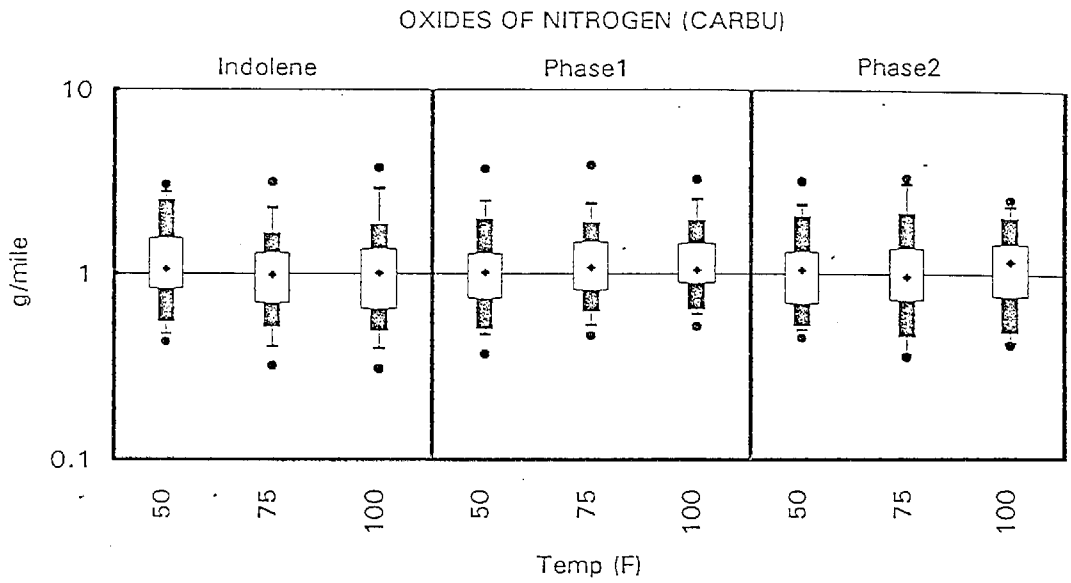

Figure 3.1.1.9 Box plots showing the effects of fuel and temperature on NOx exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

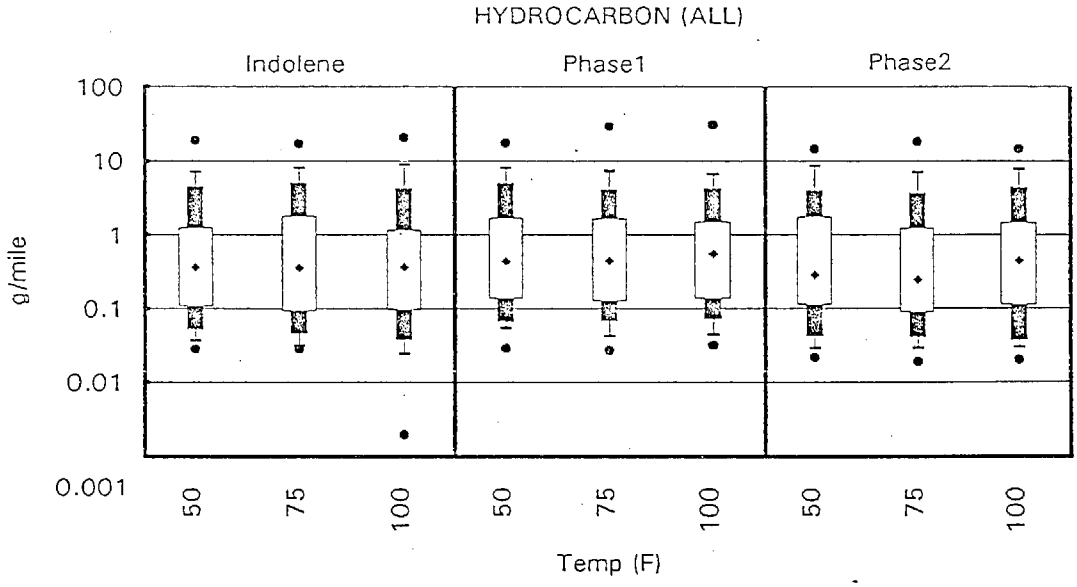

Figure 3.1.1.10 Box plots showing the effects of fuel and temperature on HC exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

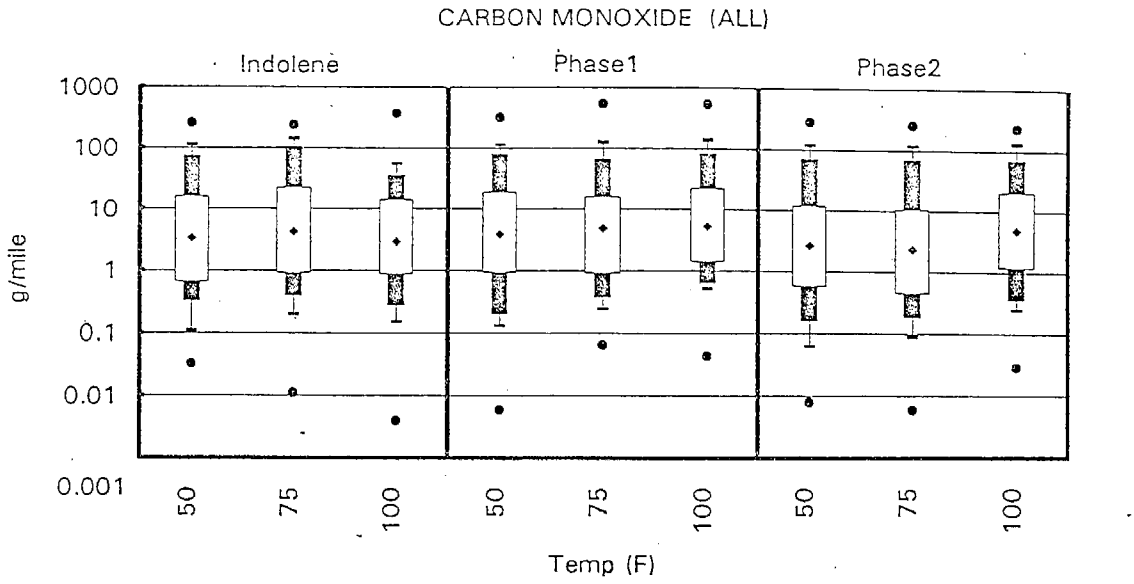

Figure 3.1.1.11 Box plots showing the effects of fuel and temperature on CO exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

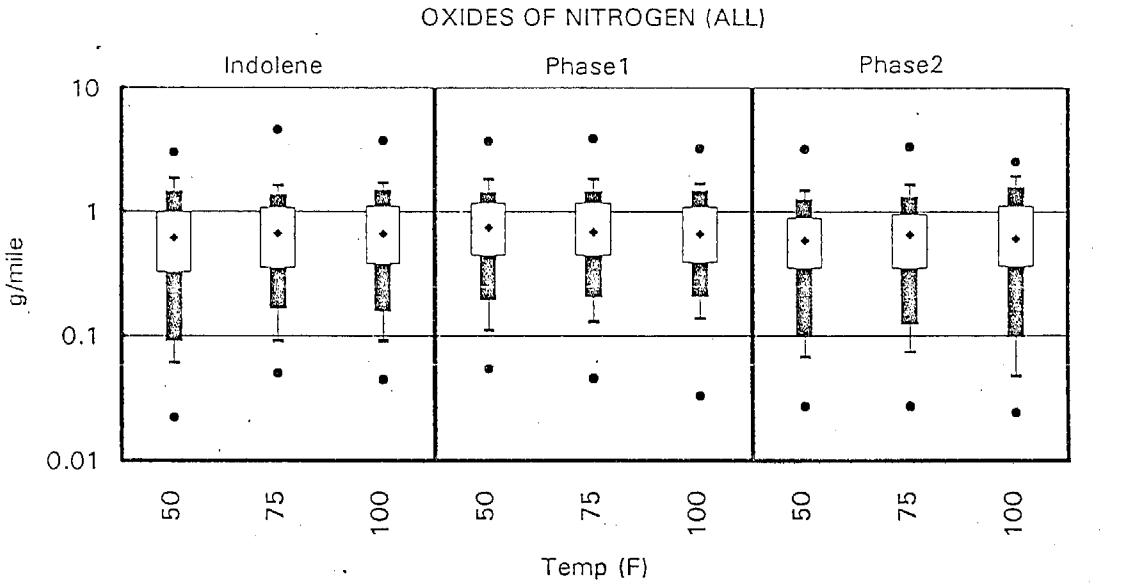

Figure 3.1.1.12 Box plots showing the effects of fuel and temperature on NOx exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles.

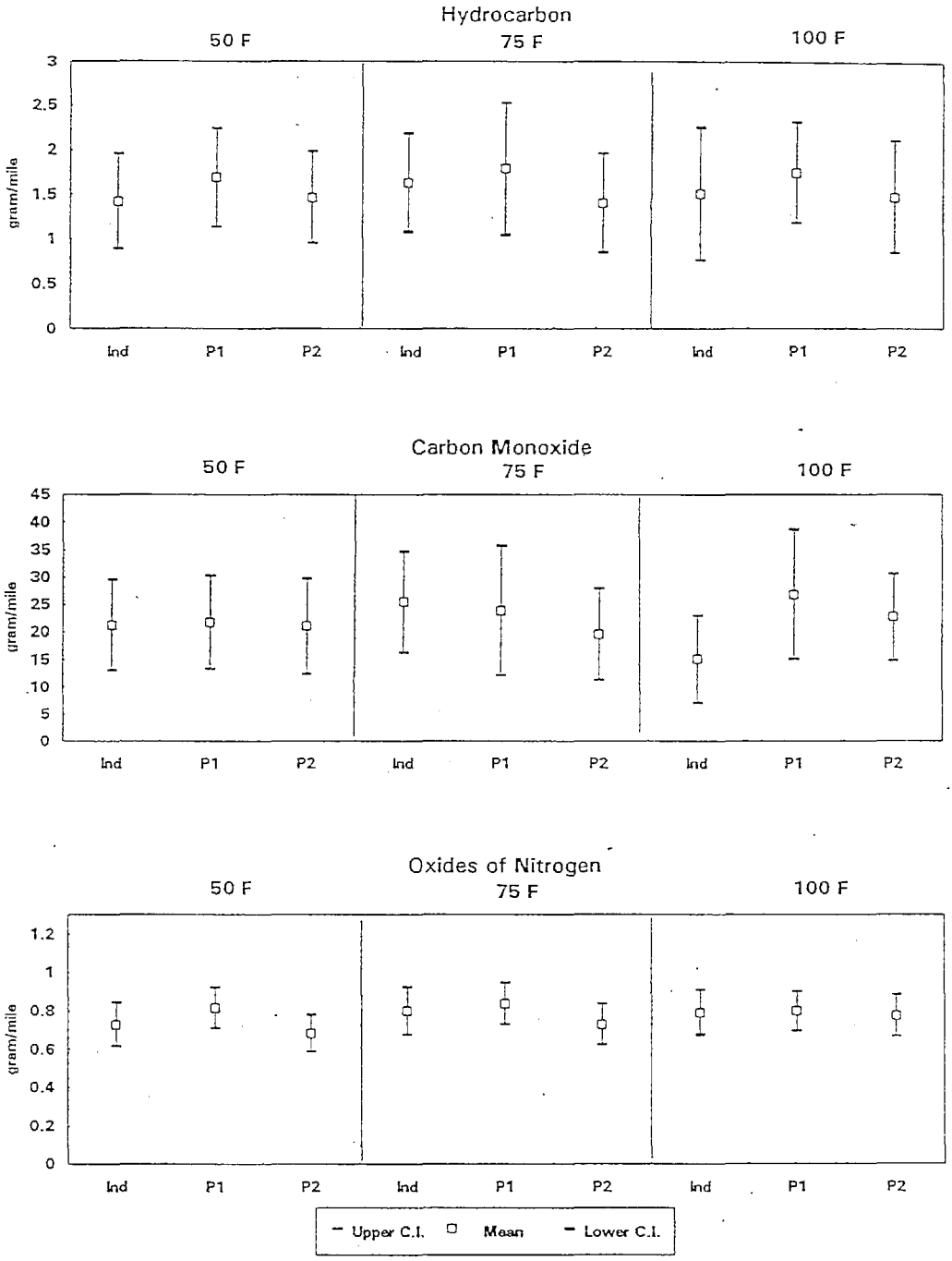

Figure 3.1.1.13 Comparison of temperature and fuel effects on the 95% confidence interval of mean HC, CO, and NOx for all vehicles.

Note that the 95% confidence interval of the population mean was estimated by using the sample mean ± 1.96 times the standard error. Examining the data from this perspective suggested that the HC, CO, and NOx exhaust emissions due to Phase 2 and Indolene were generally lower than Phase 1 fuel.

To substantiate the findings from the graphs, statistical tests were used. The one-way ANOVA was used to compare whether there were any differences among the box plots in each group. The test hypotheses were as follows:

Ho: All sample means are the same.

Ha: At least one of the means differs from the others

where α=0.05

Table 3.1.1.1 presents the p-values based on the comparison of temperature effect within each given fuel type. No statistically significant temperature effects were found within each fuel for Phase 1, Phase 2, and Indolene, except for CO in the MPFI (Indolene), where the temperature effects are significant (p-value = 0.0161). Similarly, Table 3.1.1.2 summarizes the p-values based on the comparison of fuel effects within each temperature. Except for CO from MPFI (100 F) with a p-value of 0.01, and NOx from MPFI (50 F) with a p-value of 0.0028, no fuel effects were found within each temperature for all three technology groups and all vehicles as an aggregate.

Since all the test data used in this presentation were based on hot-stabilized test cycles, it is conceivable that ambient temperature could have a minimal effect on

Table 3.1.1.1 Comparison of temperature effects within each fuel type. The following table summarizes the level of significance (p-value) based on one-way analysis of variance.*

HC

	Ind (50 F, 75 F, 100 F)	P1 (50 F, 75 F, 100 F)	P2 (50 F, 75 F, 100 F)
MPFI	0.1438	0.3461	0.9969
TBI	0.9892	0.7551	0.9979
CARBU	0.6357	0.9561	0.9028
All Vehicles	0.8804	0.9784	0.9735

CO

	Ind (50 F, 75 F, 100 F)	P1 (50 F, 75 F, 100 F)	P2 (50 F, 75 F, 100 F)
MPFI	0.0161	0.5083	0.9716
TBI	0.9728	0.5379	0.9637
CARBU	0.6881	0.6547	0.5124
All Vehicles	0.2452	0.8057	0.8707

NOx

	Ind (50 F, 75 F, 100 F)	P1 (50 F, 75 F, 100 F)	P2 (50 F, 75 F, 100 F)
MPFI	0.1071	0.2762	0.7143
TBI	0.8057	0.8036	0.0645
CARBU	0.5263	0.8487	0.8964
All Vehicles	0.672	0.8678	0.4639

Table 3.1.1.2 Comparison of fuel effects within each temperature. The following table summarizes the level of significance (p-value) based on one-way analysis of variance.*

HC

	50 F (P1, P2 , Ind)	75 F (P1, P2 , Ind)	100 F (P1, P2 , Ind)
MPFI	0.6028	0.5406	0.1991
TBI	0.9832	0.6014	0.6792
CARBU	0.9092	0.7701	0.7822
All Vehicles	0.7637	0.6997	0.7981

CO

	50 F (P1, P2 , Ind)	75 F (P1, P2 , Ind)	100 F (P1, P2 , Ind)
MPFI	0.894	0.35	0.01
TBI	0.92	0.47	0.71
CARBU	0.728	0.159	0.494
All Vehicles	0.993	0.69	0.22

NOx

	50 F (P1, P2 , Ind)	75 F (P1, P2 , Ind)	100 F (P1, P2 , Ind)
MPFI	0.0028	0.3122	0.3956
TBI	0.5263	0.839	0.2881
CARBU	0.5984	0.7158	0.8688
All Vehicles	0.2059	0.4102	0.9608

* Ho: All sample means are same.
Ha: At least one of the means differs from the others.

exhaust emissions. In fact, the effects of fuel and temperature could not be observed, possibly due to the high variation of cycle and vehicle suppressing the true effects of temperature and fuel. The following two sections provide a clear indication of the manner in which cycle type is related to temperature and fuel, respectively.

3.1.2. Comparison of Speed and Temperature Effects

This section examines the relationship between speed and temperature while holding fuel and vehicle factors constant. Note that "speed" is defined as the average speed of the cycle. Exhaust emissions were plotted with respect to the cycle type in an ascending speed from LOW1 (2.5 mph) to XHWY (64.4 mph). Within each cycle, the exhaust emissions at 50 F, 75 F, and 100 F were compared.

The relationship of temperature and speed and HC, CO, and NOx exhaust emissions (in the MPFI group) is illustrated in Figures 3.1.2.1 to 3.1.2.3. There were 15 data (5 vehicles x 3 fuels) per each box plot. Figure 3.1.2.1 indicates that as the average speed of the cycle increased, the HC emissions decreased and remained unchanged from HHWY to XHWY. Figures 3.1.2.2 and 3.1.2.3 show that as speed increased, the CO and NOx emissions appeared to decrease slightly. Moreover, the high variability in the box plot indicated that the vehicle model could have a greater effect on emissions than temperature factors.

For the TBI group, HC and CO emissions decreased as average speed of the cycle increased (see Figures 3.1.2.4 and 3.1.2.5), where each box plot contains 9 data (3 vehicles x 3 fuels). When NOx exhaust emissions were examined, except for the

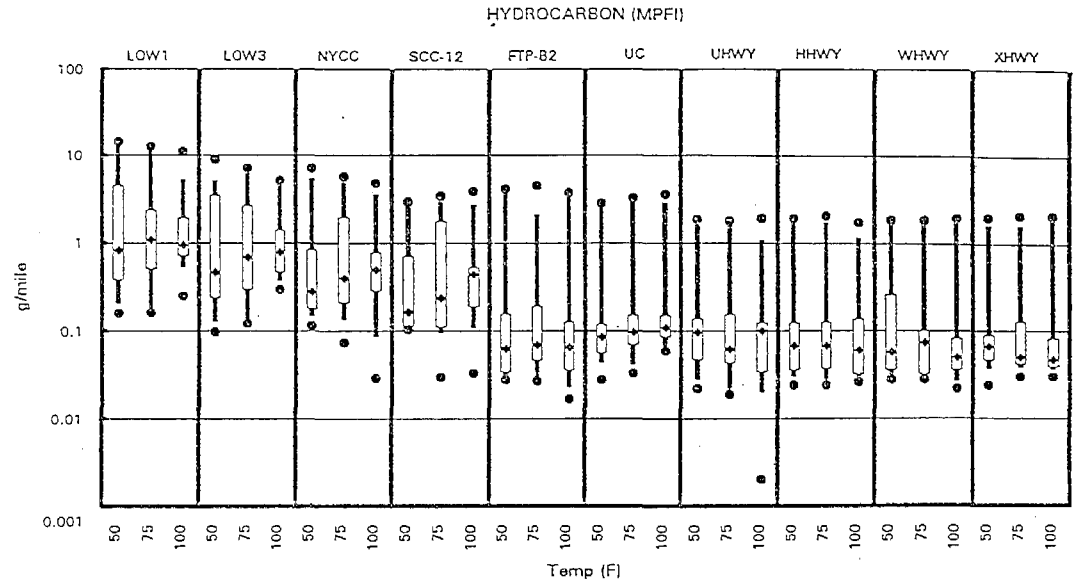

Figure 3.1.2.1 Box plots showing the effects of speed and temperature on HC exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

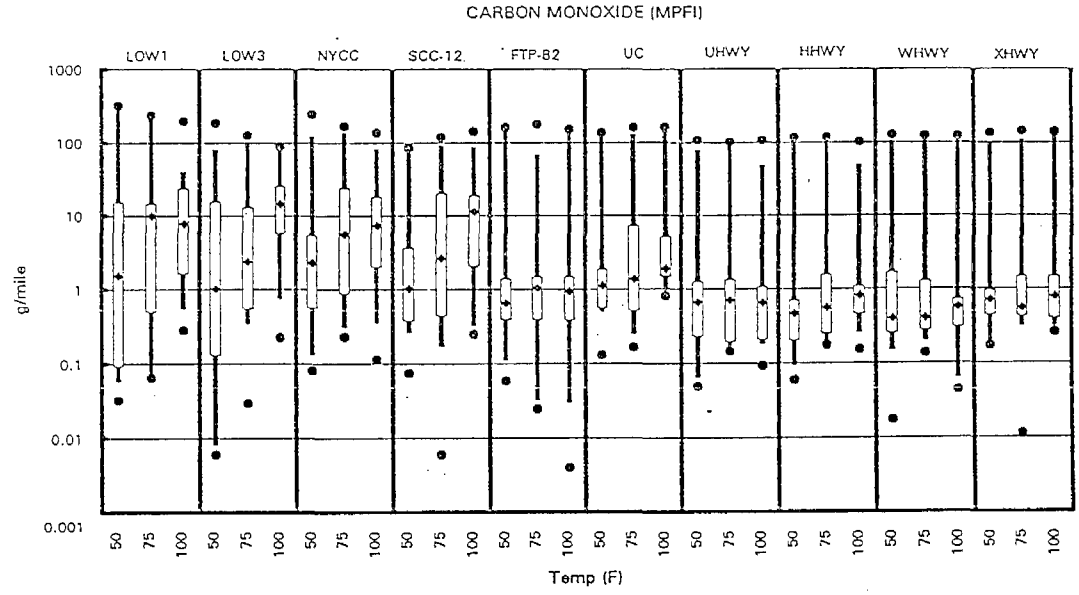

Figure 3.1.2.2 Box plots showing the effects of speed and temperature on CO exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 95th percentiles.

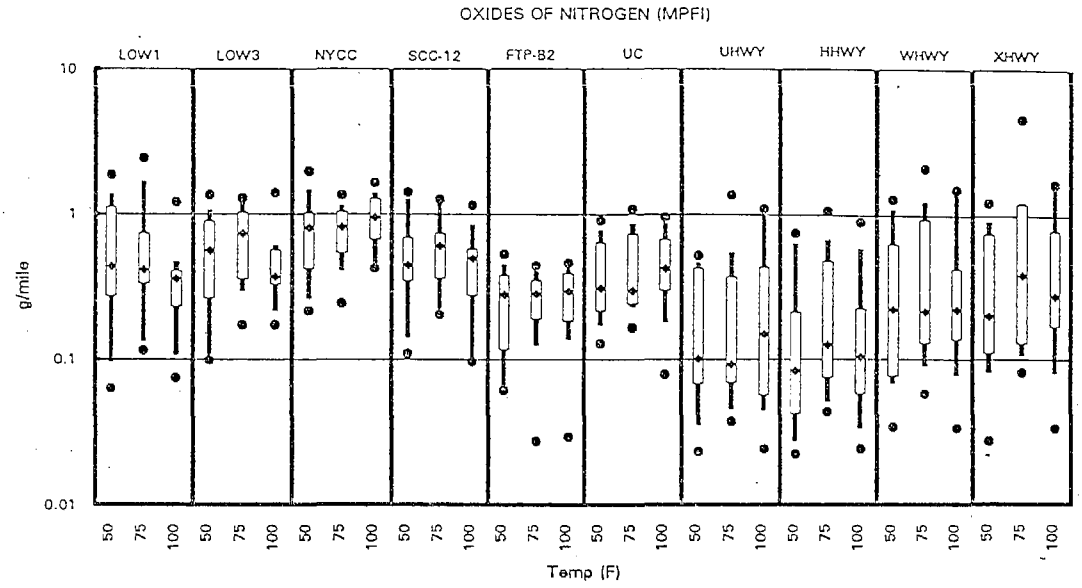

Figure 3.1.2.3 Box plots showing the effects of speed and temperature on NOx exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

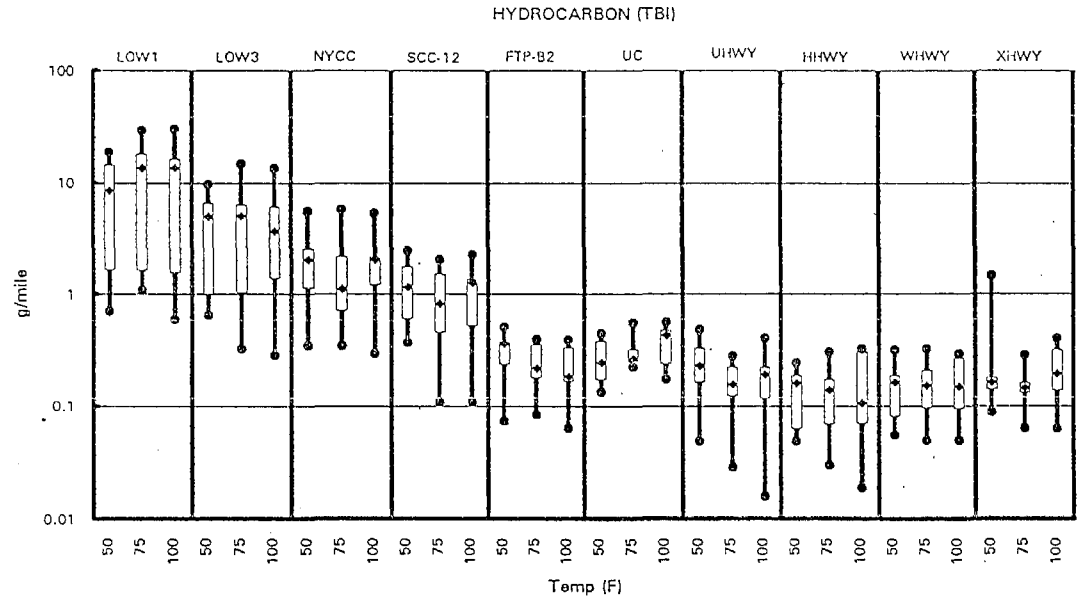

Figure 3.1.2.4 Box plots showing the effects of speed and temperature on HC exhaust emissions (TBI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

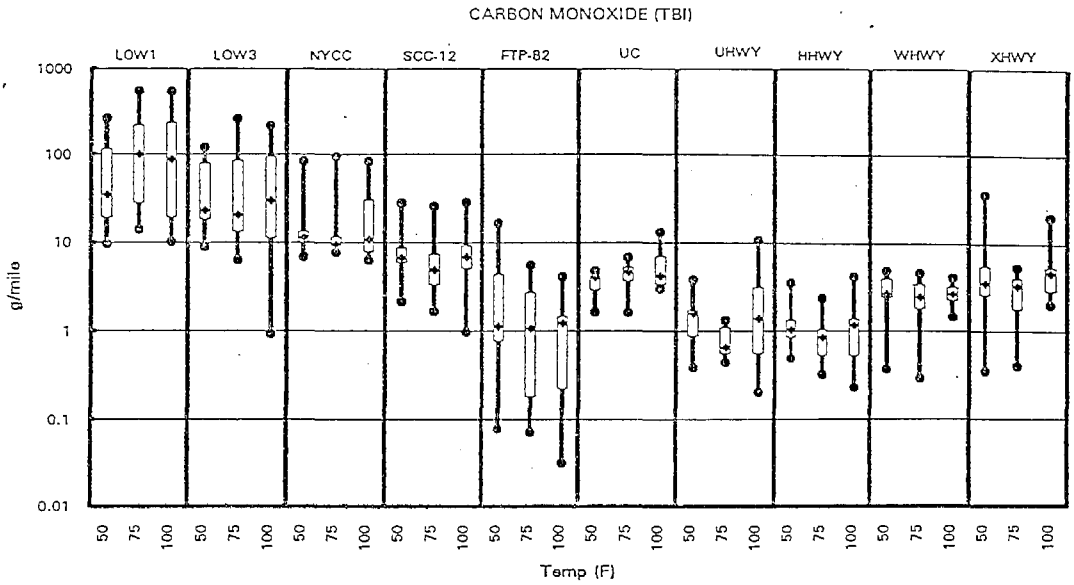

Figure 3.1.2.5 Box plots showing the effects of speed and temperature on CO exhaust emissions (TBI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

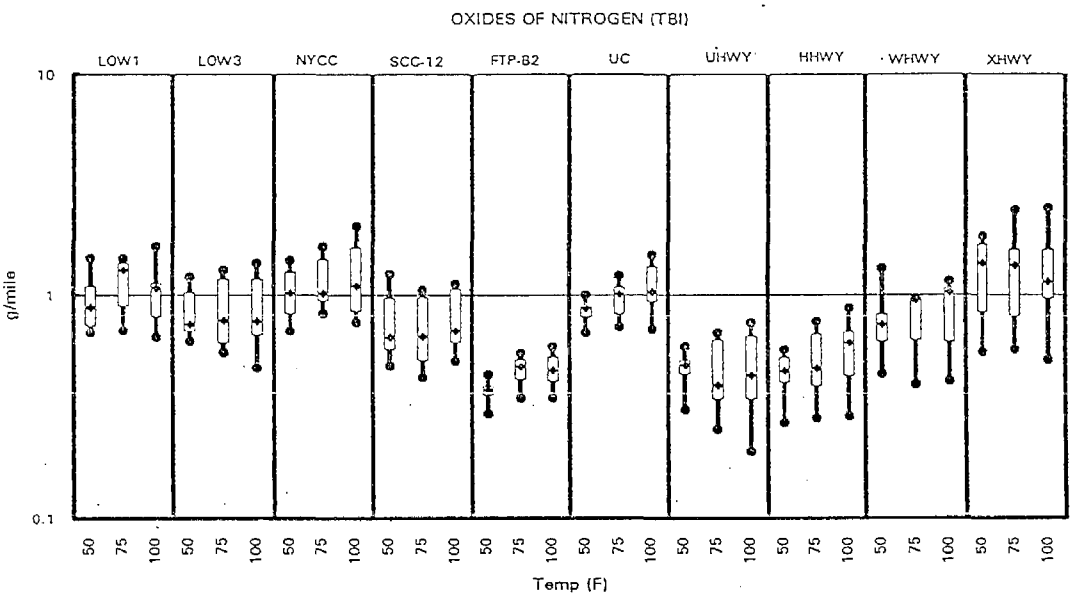

Figure 3.1.2.6 Box plots showing the effects of speed and temperature on NOx exhaust emissions (TBI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

UC, higher emissions were observed at both low and high average speeds (Figure 3.1.2.6).

For the CARBU group, as the average speed of the cycle increased, the HC emissions decreased (see Figure 3.2.1.7). Again, there were 9 data (3 vehicles x 3 fuels) per box plot. Figure 3.2.1.8 indicates that there was a wide variation in CO emissions across all speeds. Additionally, CO emissions were found to be higher at low and high average speeds. Similarly, higher NOx emissions were observed at both low and high average speeds (Figure 3.2.1.9).

There were obvious differences among the technology groups in terms of the data distribution pattern because of the vehicle-to-vehicle variation in each technology group. Figures 3.2.1.10 to 3.2.1.12 present the results based on all vehicles. Each box plot includes 33 data (11 vehicles x 3 fuels). In general, all HC, CO, and NOx emissions were strong functions of speed (as the average speed increased, HC exhaust emissions decreased while CO and NOx exhaust emissions increased at both low and high average speeds). In addition, temperature effects for each cycle were trivial when compared to speed effects. The speed factor is clearly more important than the temperature factor with respect to exhaust emissions.

Figure 3.1.2.13 offers an alternative way to present the data in Figures 3.2.1.10 to 3.2.1.12 and only the mean HC, CO, and NOx emissions with respect to 50 F, 75 F, and 100 F are presented. As anticipated, the temperature effects were minimal as compared to cycle effects for all HC, CO, and NOx emissions.

To substantiate the findings from the above-mentioned 13 figures, one-way

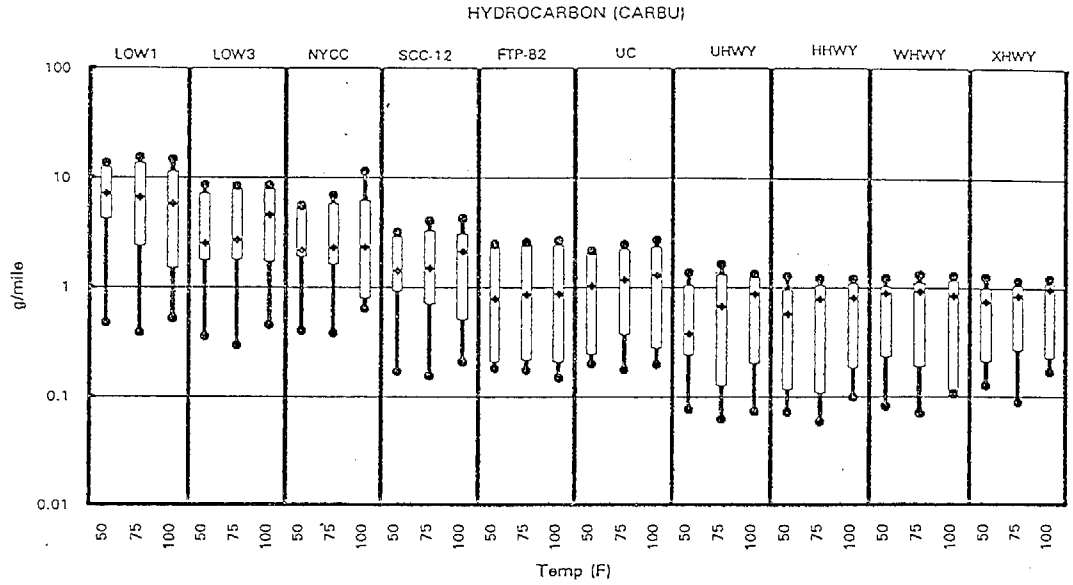

Figure 3.1.2.7 Box plots showing the effects of speed and temperature on HC exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

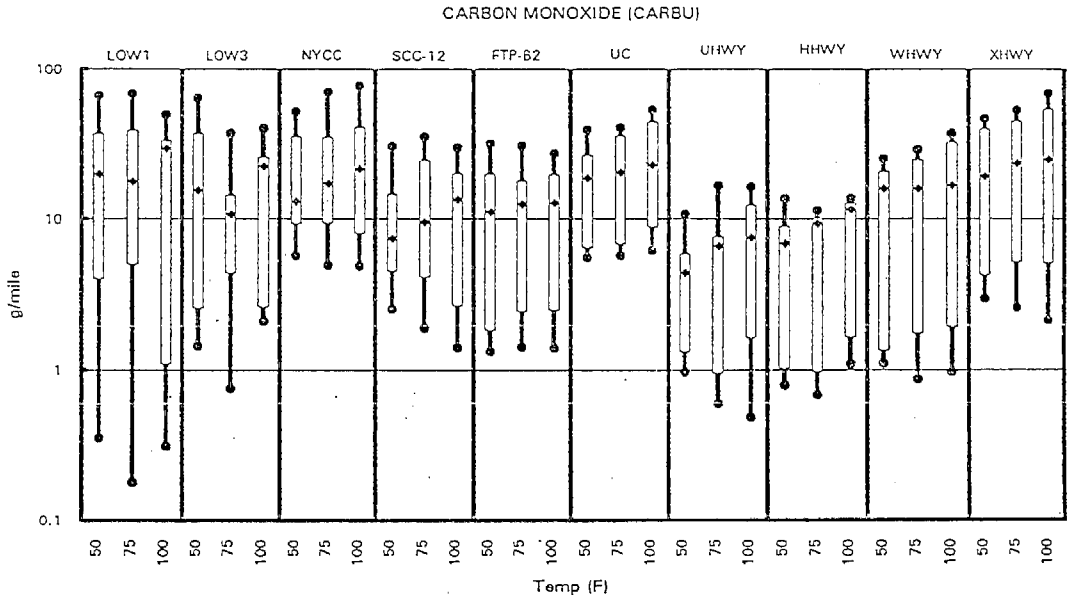

Figure 3.1.2.8 Box plots showing the effects of speed and temperature on CO exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

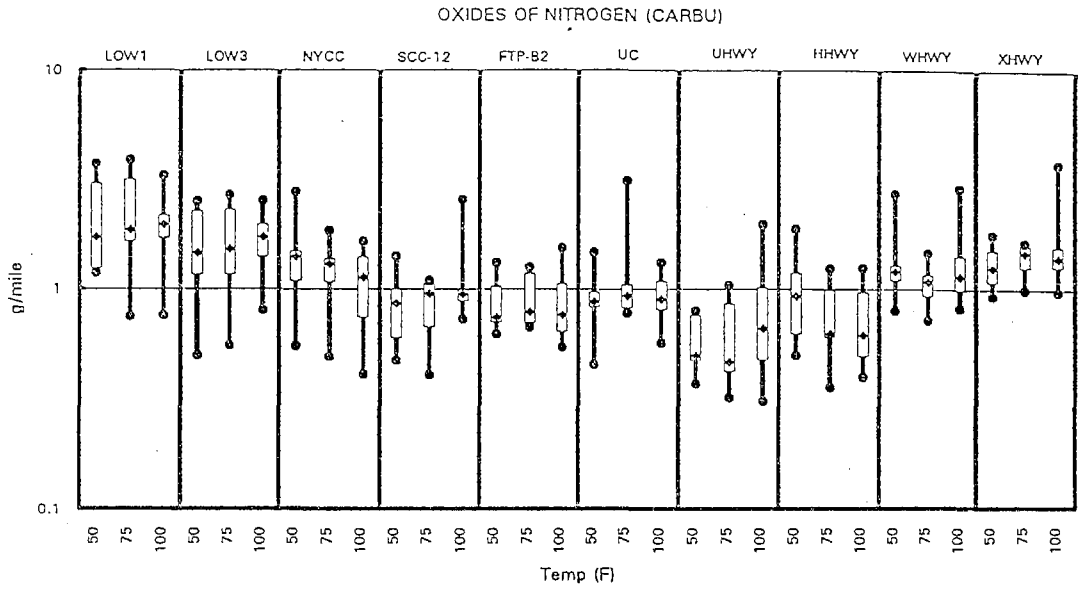

Figure 3.1.2.9 Box plots showing the effects of speed and temperature on NOx exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

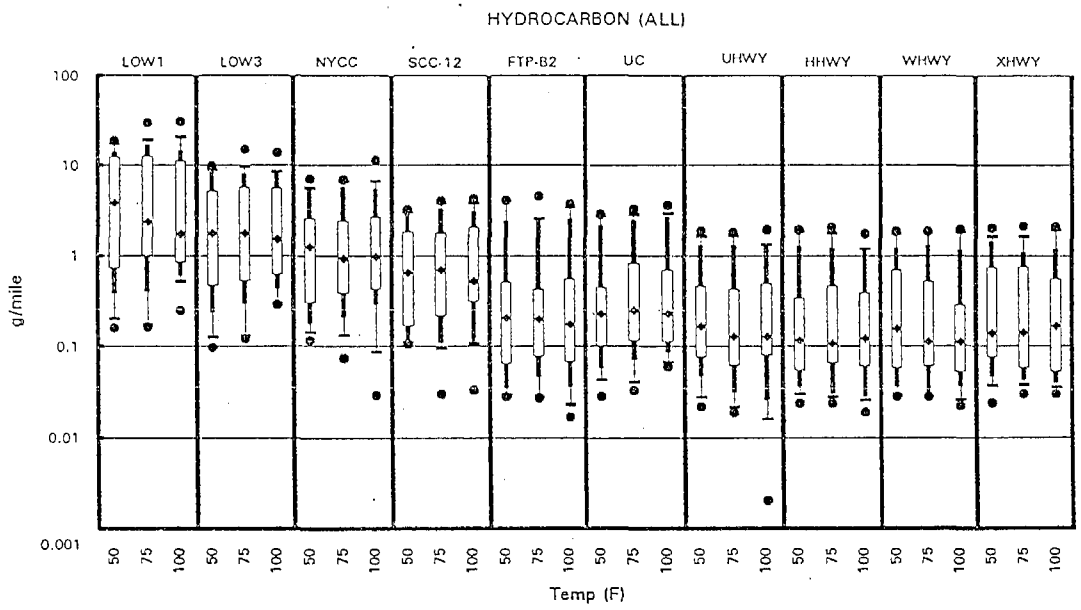

Figure 3.1.2.10 Box plots showing the effects of speed and temperature on HC exhaust emissions for all vehicles Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

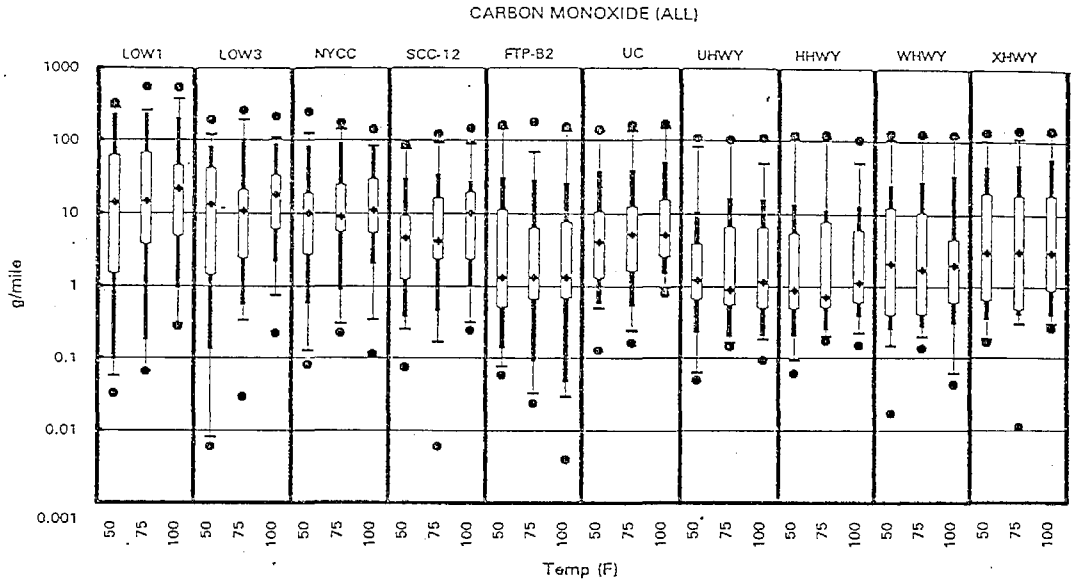

Figure 3.1.2.11 Box plots showing the effects of speed and temperature on CO exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles

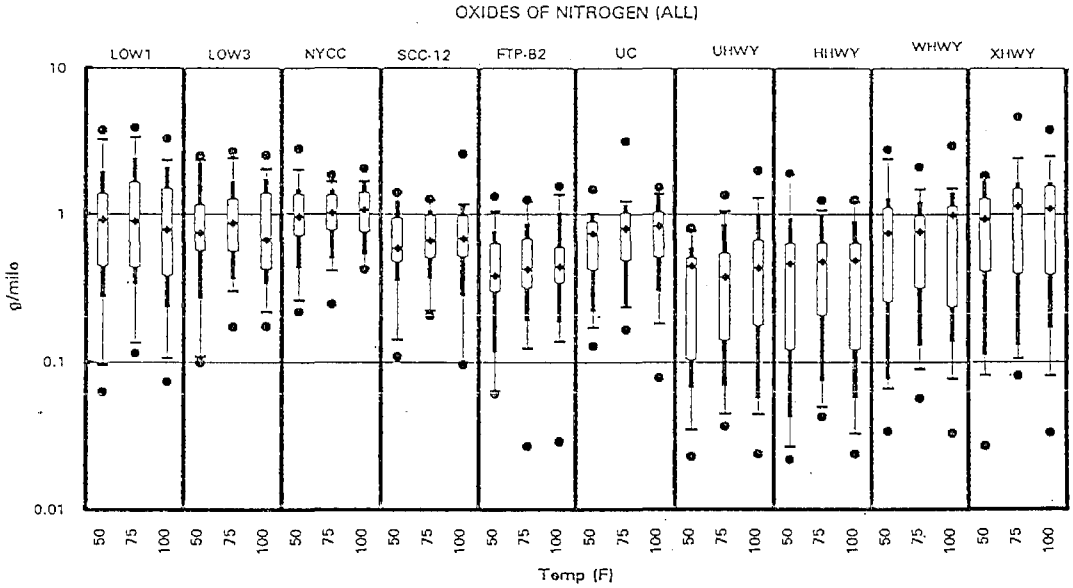

Figure 3.1.2.12 Box plots showing the effects of speed and temperature on NOx exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles.

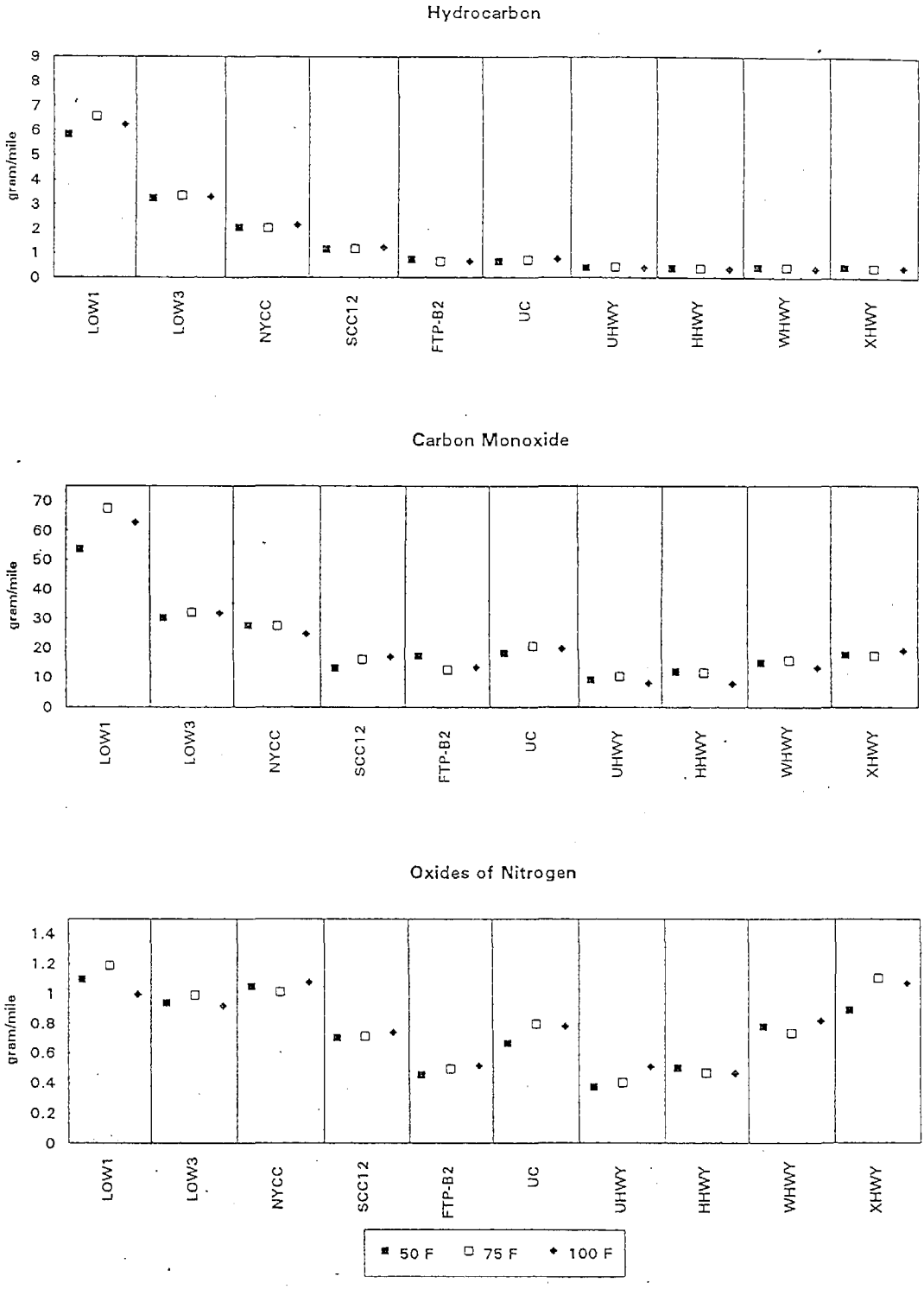

Figure 3.1.2.13 Scatter plot showing the effects of speed and temperature on mean HC, CO, and NOx emissions for all vehicles.

Table 3.1.2.1 Comparison of temperature effects within each cycle. The following table summarizes the level of significance (p-value) based on one-way analysis of variance.*

MPFI

Cycle	HC (50 F, 75 F, 100 F)	CO (50 F, 75 F, 100 F)	NOx (50 F, 75 F, 100 F)
LOW1	0.9068	0.7444	0.0223
LOW3	0.6979	0.7623	0.4902
NYCC	0.8787	0.9207	0.6685
SCC-12	0.9735	0.9332	0.3156
FTP-B2	0.9672	0.975	0.4913
LA92	0.8334	0.8258	0.6543
UHWY	0.9802	0.998	0.3129
HHWY	0.9338	0.9263	0.5841
WHWY	0.8773	0.9147	0.6841
XHWY	0.9217	0.8755	0.5959

CARBU

Cycle	HC (50 F, 75 F, 100 F)	CO (50 F, 75 F, 100 F)	NOx (50 F, 75 F, 100 F)
LOW1	0.8401	0.6901	0.3611
LOW3	0.8445	0.2807	0.8499
NYCC	0.7838	0.7572	0.5879
SCC-12	0.971	0.5277	0.3123
FTP-B2	0.8894	0.5727	0.9391
LA92	0.8936	0.7012	0.8682
UHWY	0.9339	0.7699	0.3906
HHWY	0.8641	0.6751	0.9812
WHWY	0.9652	0.9511	0.3474
XHWY	0.7027	0.8863	0.6183

TBI

Cycle	HC (50 F, 75 F, 100 F)	CO (50 F, 75 F, 100 F)	NOx (50 F, 75 F, 100 F)
LOW1	0.4326	0.6687	0.5426
LOW3	0.6845	0.7555	0.6195
NYCC	0.2056	0.0947	0.9017
SCC-12	0.1296	0.036	0.7919
FTP-B2	0.846	0.7906	0.9804
LA92	0.9208	0.691	0.7741
UHWY	0.7601	0.7275	0.8803
HHWY	0.8165	0.3226	0.9622
WHWY	0.4441	0.5297	0.8976
XHWY	0.3025	0.2576	0.8688

All 11 Vehicles

Cycle	HC (50 F, 75 F, 100 F)	CO (50 F, 75 F, 100 F)	NOx (50 F, 75 F, 100 F)
LOW1	0.6182	0.9351	0.1482
LOW3	0.817	0.7335	0.6845
NYCC	0.6137	0.6216	0.7204
SCC-12	0.7349	0.9141	0.4858
FTP-B2	0.998	0.9932	0.9561
LA92	0.9285	0.8809	0.992
UHWY	0.9207	0.9958	0.8593
HHWY	0.8579	0.9014	0.8467
WHWY	0.8957	0.9281	0.5113
XHWY	0.9938	0.9676	0.618

* Ho: All sample means are same.
Ha: At least one of the means differs from the others.

ANOVA was used to examine the temperature factor within each cycle. The test hypotheses were as follows:

Ho: All sample means are the same.

Ha: At least one of the means differs from the others.

Table 3.1.2.1 summarizes the p-values when the temperature factor was compared within each cycle. Except for the NOx from the MPFI (at LOW1 cycle) with a p-value of 0.0223 and CO from TBI (at SCC-12) with a p-value of 0.036, the statistical analysis suggests there were no temperature effects within each cycle for all three technology groups and all vehicles as an aggregate. In short, these statistical tests confirm that temperature effects within each cycle were statistically insignificant.

3.1.3 Comparison of Speed and Fuel Effects

This section reviews the relationship of speed and fuel in an approach similar to that of Section 3.1.2. Within each cycle, the fuel effects due to Phase 1, Phase 2, and Indolene were examined. The variation in each box plot was due to the variation of vehicles and temperatures.

Figures 3.1.3.1 to 3.1.3.3 present the relationship of speed and fuel effects on the MPFI group. There were 15 data (5 vehicles x 3 temperatures) per box plot. It was found that HC and CO emissions decreased as average speed of the cycle increased. For NOx, the relationship between emissions and average speed of the

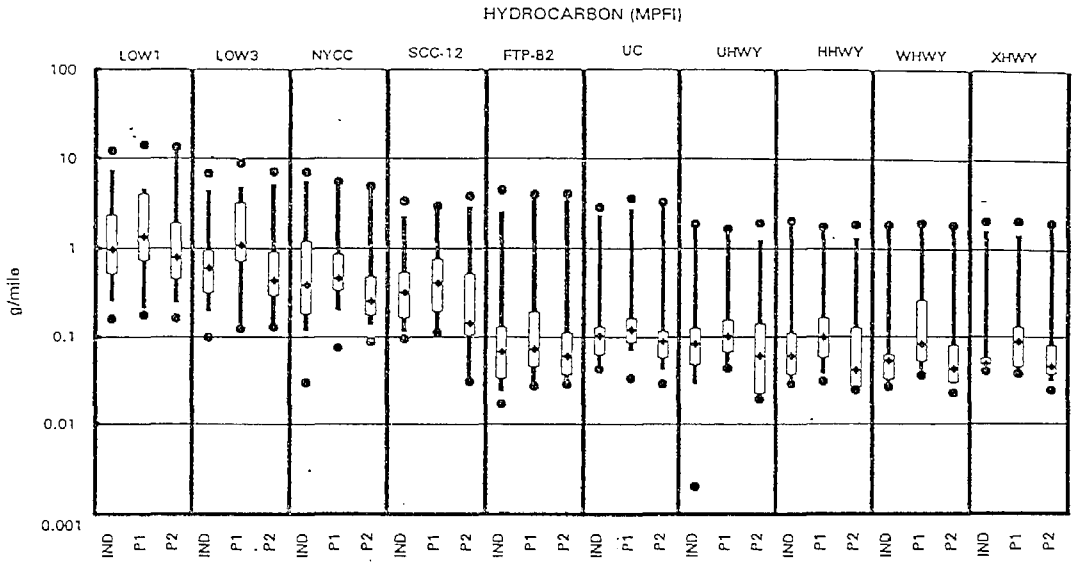

Figure 3.1.3.1 Box plots showing the effects of speed and fuel on HC exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

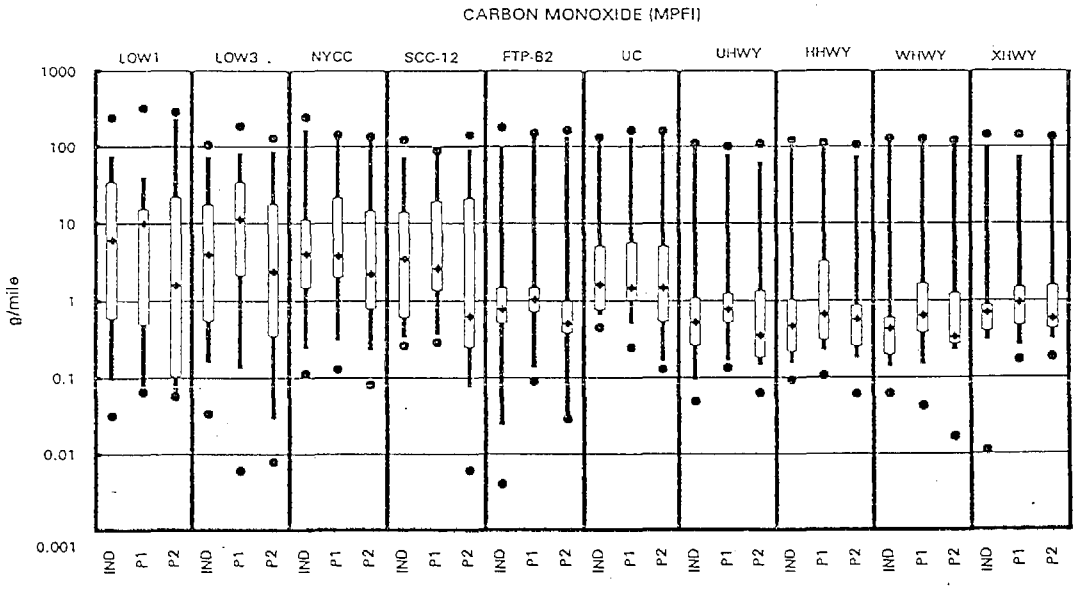

Figure 3.1.3.2 Box plots showing the effects of speed and fuel on CO exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

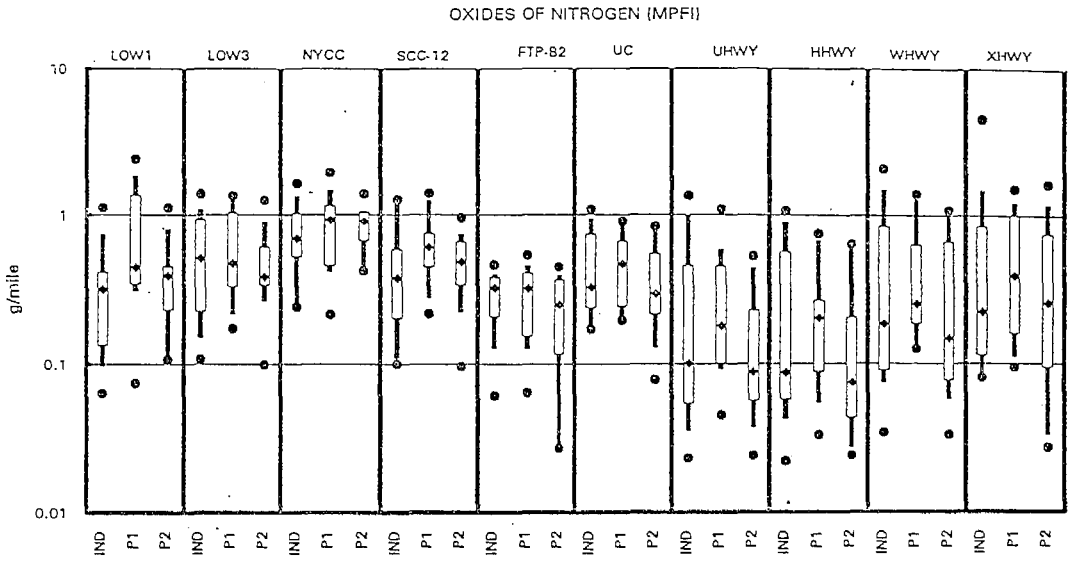

Figure 3.1.3.3 Box plots showing the effects of speed and fuel on NOx exhaust emissions (MPFI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

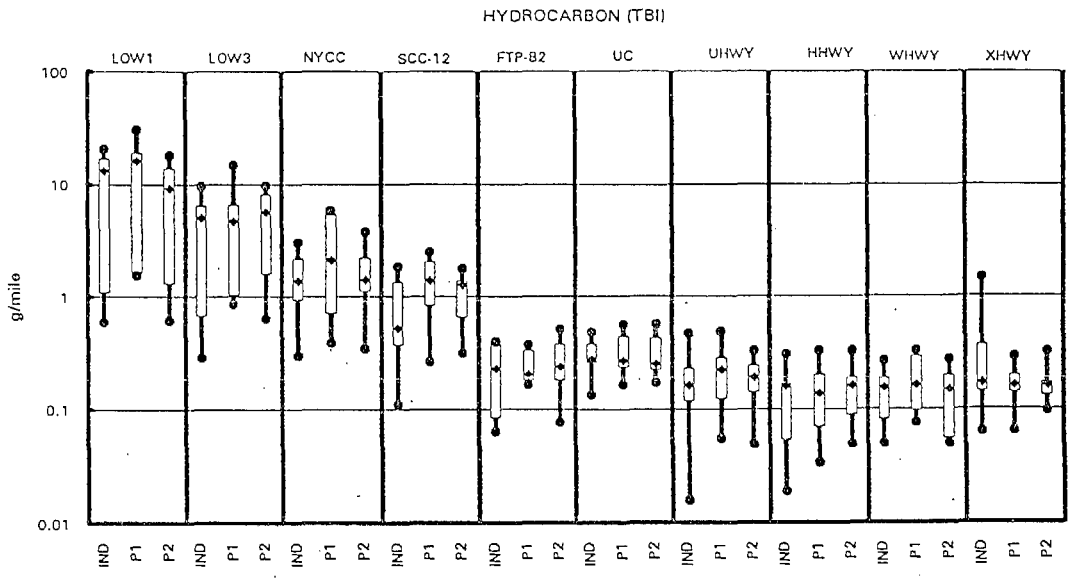

Figure 3.1.3.4 Box plots showing the effects of speed and fuel on HC exhaust emissions (TBI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

cycle was ambiguous because NOx emissions fluctuated widely across all cycles.

From Figures 3.1.3.4 and 3.1.4.5, it can be seen that HC and CO exhaust emissions decreased when average speed of the cycle increased in the TBI group. Note that each box plot contains 9 data (3 vehicles x 3 temperatures). As illustrated in Figure 3.1.3.6, except for the UC, NOx emissions increased slightly at both low and high average speed.

For the CARBU group, it was found that HC exhaust emissions increased as average speed increased (Figure 3.1.3.7). Again, there were 9 data (3 vehicles x 3 temperatures) per box plot. In addition, CO emissions were found to increase slightly at both low and high average speed. In addition, there was a clear trend that medians of CO emissions for Phase 2 fuel were lower among all three fuels (Figure 3.1.3.8). Similarly, higher NOx emissions were found at both low and high average speeds (Figure 3.1.3.9).

The dissimilar data distribution among the three technology groups was probably due to vehicle-to-vehicle variation in each technology group. When all vehicles were combined, it was found that HC emissions decreased as average speed increased (Figure 3.1.3.10), while CO and NOx emissions increased slightly at both low and high average speeds (Figures 3.1.3.11 and 3.1.3.12). Despite the high vehicle variations, speed was the dominant factor when compared with the influence of the fuel.

Figure 3.1.3.13 offers an alternative way to examine the data; the overall emissions average of HC, CO, and NOx due to Phase 1, Phase 2, and Indolene are

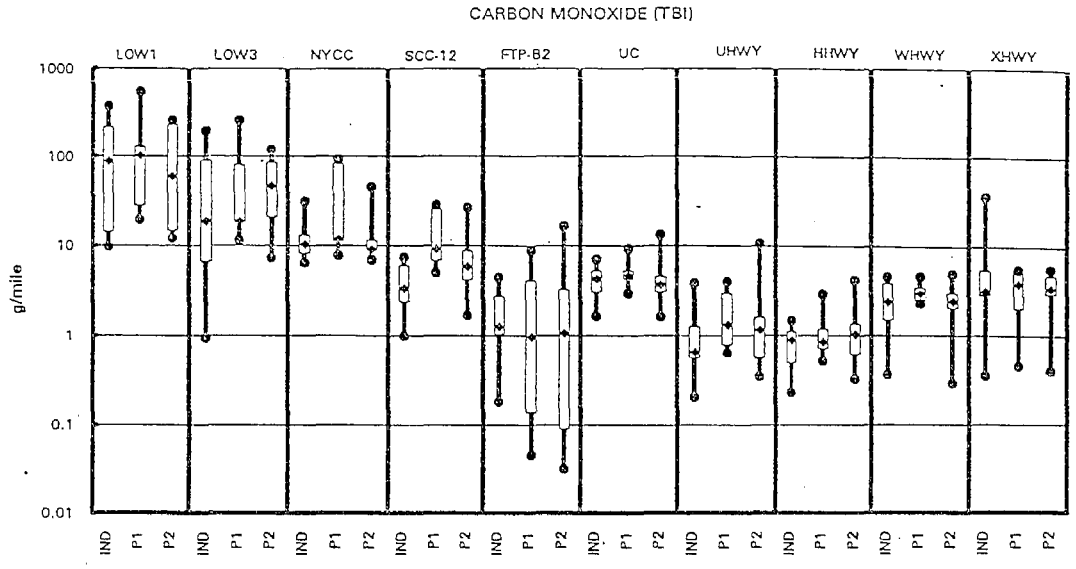

Figure 3.1.3.5 Box plots showing the effects of speed and fuel on CO exhaust emissions (TBI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

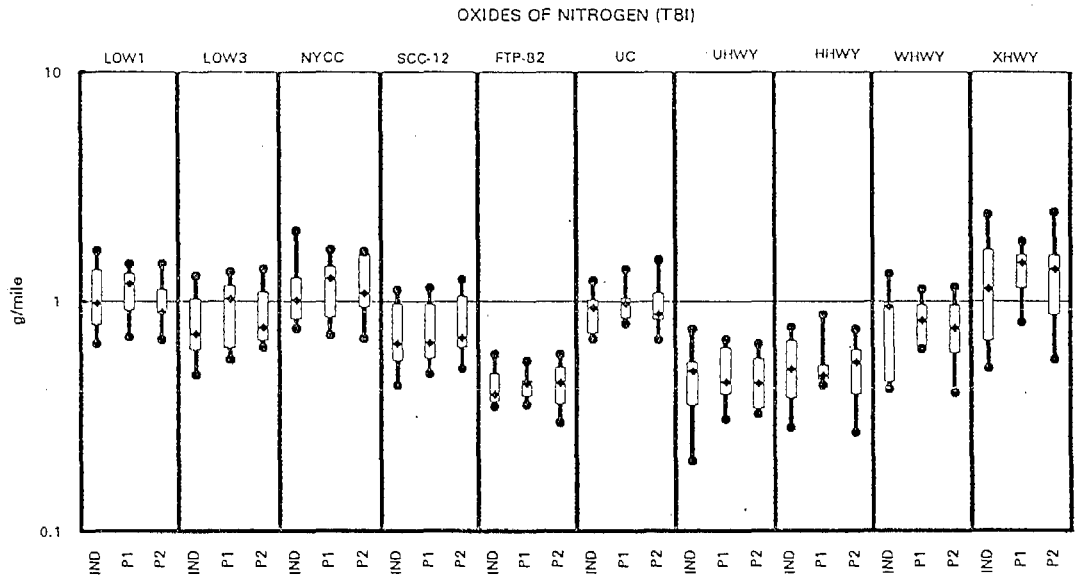

Figure 3.1.3.6 Box plots showing the effects of speed and fuel on NOx exhaust emissions (TBI). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

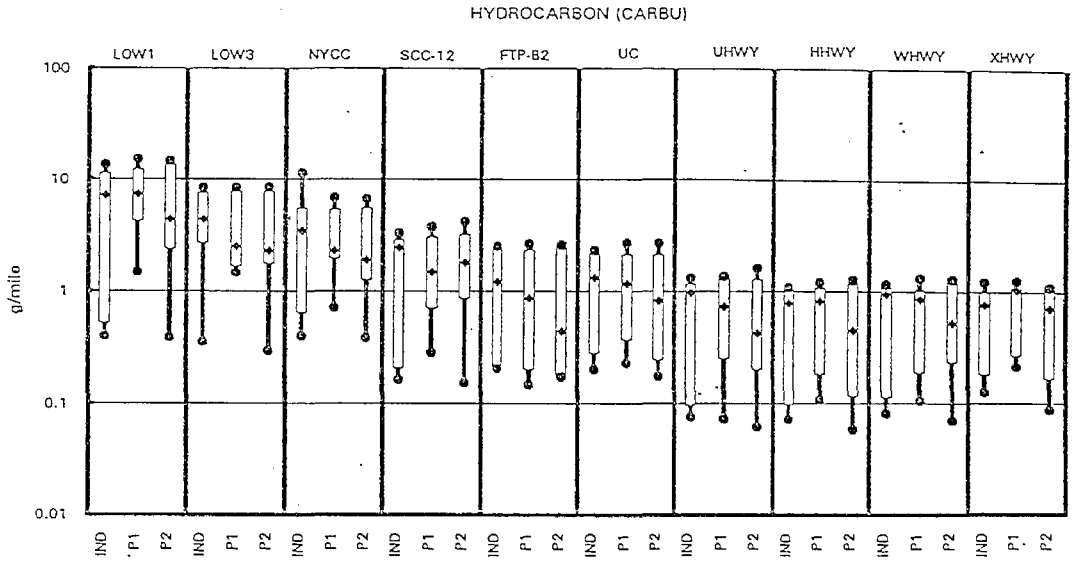

Figure 3.1.3.7 Box plots showing the effects of speed and fuel on HC exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

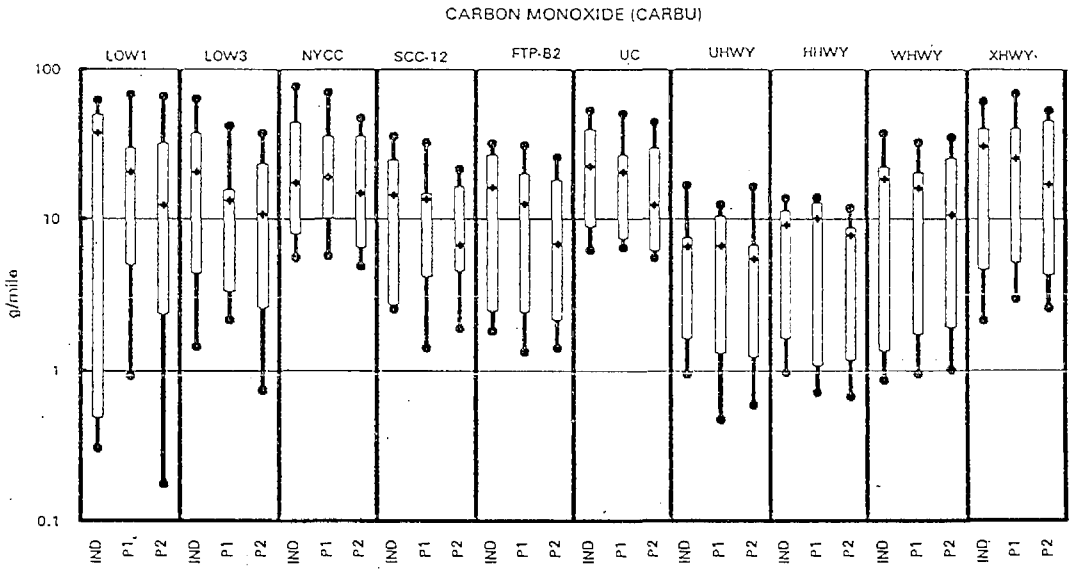

Figure 3.1.3.8 Box plots showing the effects of speed and fuel on CO exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

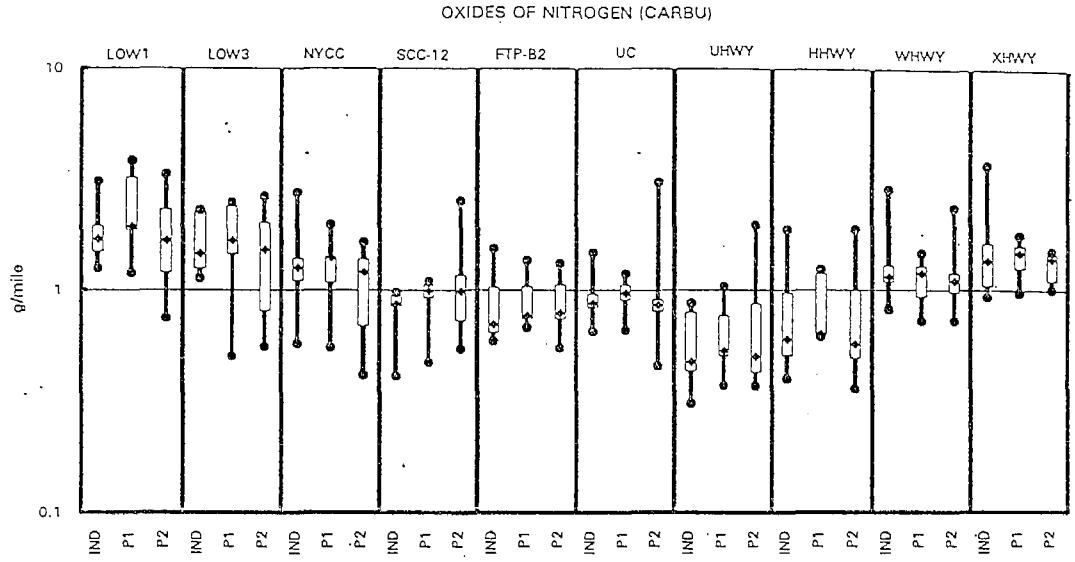

Figure 3.1.3.9 Box plots showing the effects of speed and fuel on NOx exhaust emissions (CARBU). Each box plot includes the minimum, maximum, 10th, 25th, 50th, 75th, and 90th percentiles.

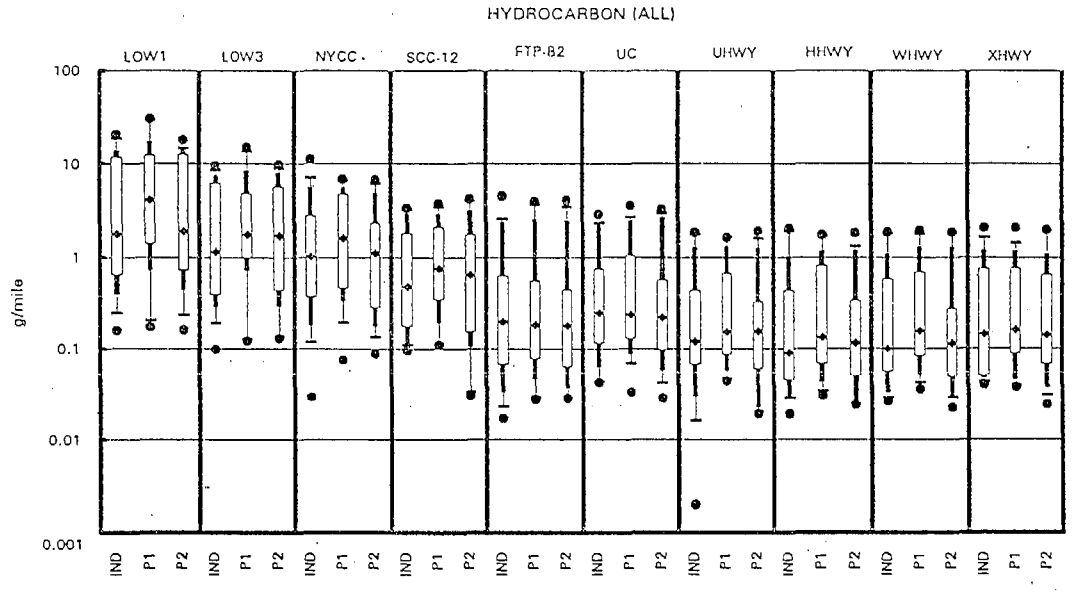

Figure 3.1.3.10 Box plots showing the effects of speed and fuel on HC exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

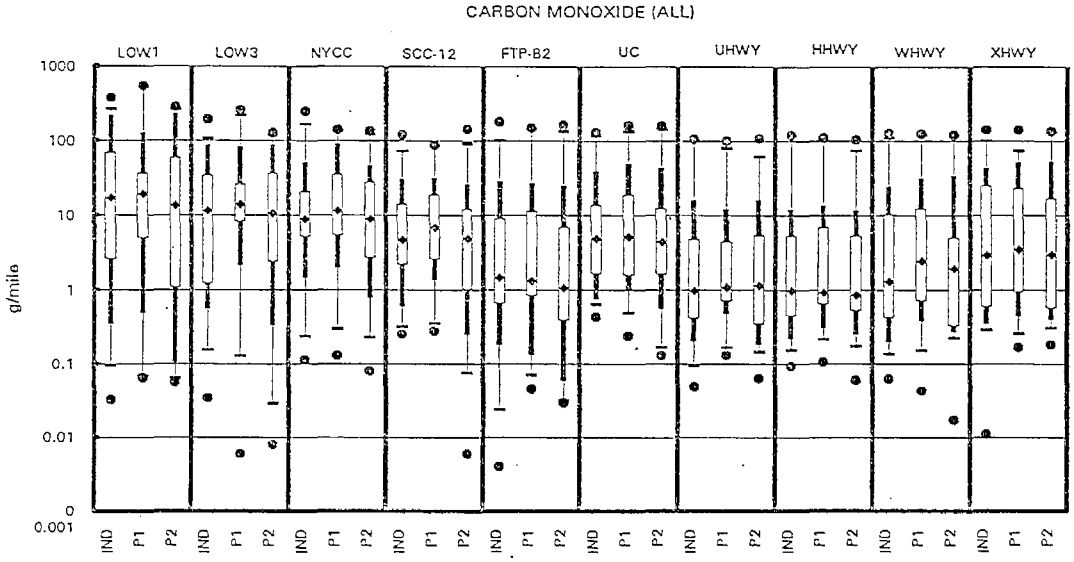

Figure 3.1.3.11 Box plots showing the effects of speed and fuel on CO exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

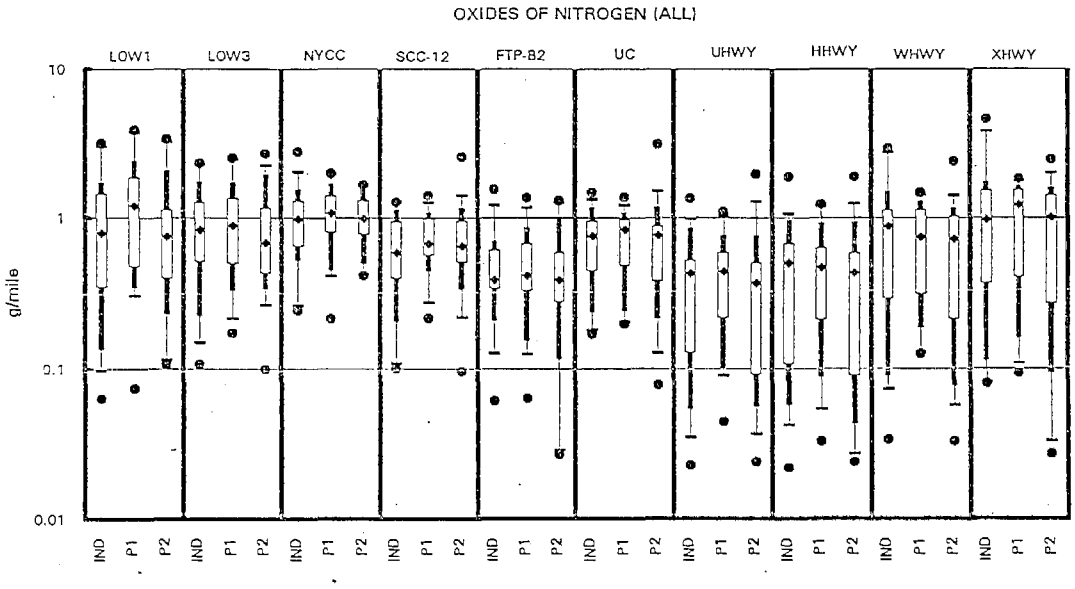

Figure 3.1.3.12 Box plots showing the effects of speed and fuel on NOx exhaust emissions for all vehicles. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

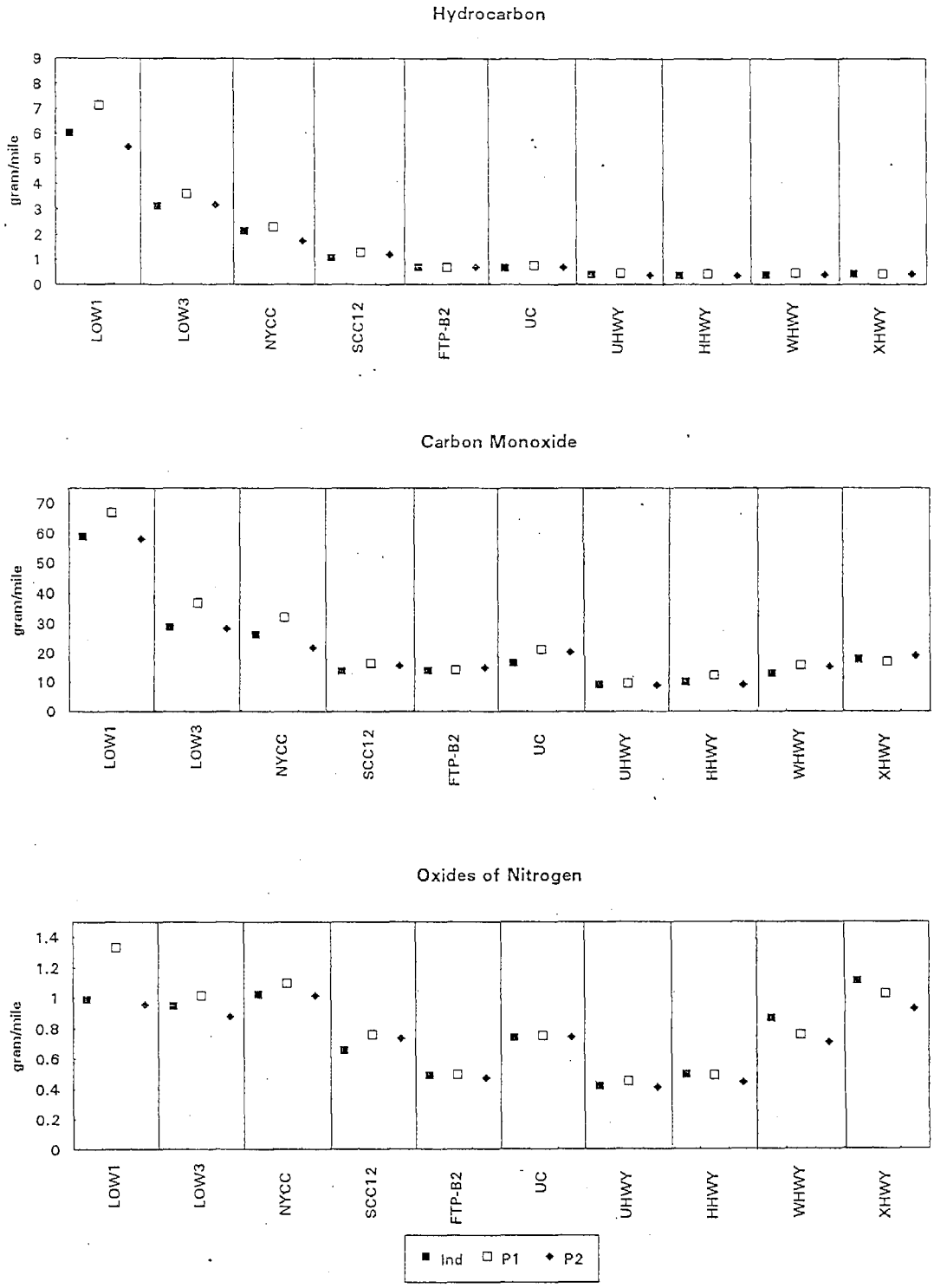

Figure 3.1.3.13 Scatter plot showing the effects of speed and fuel on mean HC, CO,and NOx emissions for all vehicles.

Table 3.1.3.1 Comparison of fuel effect within each cycle. The following table summarizes level of significance (p-value) based on single factor analysis of variance.*

MPFI

Cycle	HC (P1, P2, Ind)	CO (P1, P2, Ind)	NOx (P1, P2, Ind)
LOW1	0.8251	0.7609	0.3333
LOW3	0.9309	0.9569	0.2243
NYCC	0.8371	0.8288	0.5532
SCC-12	0.9433	0.872	0.4492
FTP-B2	0.8762	0.8789	0.8772
LA92	0.9788	0.9628	0.8145
UHWY	0.8992	0.8799	0.5585
HHWY	0.8129	0.7817	0.7293
WHWY	0.9229	0.9259	0.7547
XHWY	0.9759	0.9981	0.4469

CARBU

Cycle	HC (P1, P2, Ind)	CO (P1, P2, Ind)	NOx (P1, P2, Ind)
LOW1	0.9884	0.9732	0.8376
LOW3	0.8336	0.4572	0.989
NYCC	0.6997	0.742	0.3729
SCC-12	0.8385	0.8126	0.2815
FTP-B2	0.9315	0.9876	0.8517
LA92	0.7366	0.5021	0.3975
UHWY	0.841	0.3805	0.215
HHWY	0.9088	0.638	0.1558
WHWY	0.9775	0.8221	0.303
XHWY	0.879	0.7187	0.4242

TBI

Cycle	HC (P1, P2, Ind)	CO (P1, P2, Ind)	NOx (P1, P2, Ind)
LOW1	0.6789	0.5972	0.3125
LOW3	0.9226	0.7821	0.9276
NYCC	0.8875	0.9354	0.3838
SCC-12	0.7247	0.7084	0.773
FTP-B2	0.2658	0.2232	0.0249
LA92	0.1619	0.1734	0.029
UHWY	0.3581	0.1744	0.9296
HHWY	0.8766	0.5535	0.2725
WHWY	0.9911	0.6235	0.5221
XHWY	0.4888	0.5191	0.956

All 11 Vehicles

Cycle	HC (P1, P2, Ind)	CO (P1, P2, Ind)	NOx (P1, P2, Ind)
LOW1	0.9133	0.8747	0.6673
LOW3	0.9925	0.9864	0.8879
NYCC	0.9721	0.9587	0.8477
SCC-12	0.9459	0.83	0.909
FTP-B2	0.933	0.8515	0.7194
LA92	0.8822	0.9668	0.3751
UHWY	0.989	0.9368	0.2056
HHWY	0.9589	0.808	0.9136
WHWY	0.9164	0.9571	0.8446
XHWY	0.9521	0.9737	0.4631

* Ho: All sample means are same.
Ha: At least one of the means differs from the others.

presented within each cycle. For cycles with low average speeds (e.g. LOW1, LOW3, and NYCC), it was clear that average emissions of HC, CO, and NOx due to Phase 2 and Indolene appear to be lower than Phase 1.

To substantiate the findings from the above-mentioned thirteen figures, one-way ANOVA was used to examine the fuel factor within each cycle. The test hypotheses were as follows:

Ho: All sample means are same.

Ha: At least one of the means differs from the others.

Table 3.1.3.1 summarizes the p-values when the fuel factor was compared for each cycle. Except for NOx from the TBI at both FTP-Bag 2 (p-value = 0.0249) and LA92 (p-value = 0.029), the statistical analysis suggests there were no significant fuel effects within each cycle for all three technology groups and all vehicles as an aggregate.

3.1.4 Comparison of the Technology Groups

This section examines the effects of technology and fuel on HC, CO, and NOx exhaust emissions while keeping other factors (vehicles, temperature, and cycles) constant. Note that from Sections 3.1.1 to 3.1.3, it was concluded that in general the wide distribution range in the box plots was probably due to vehicle-to-vehicle variations rather than the influence of the variables under investigation.

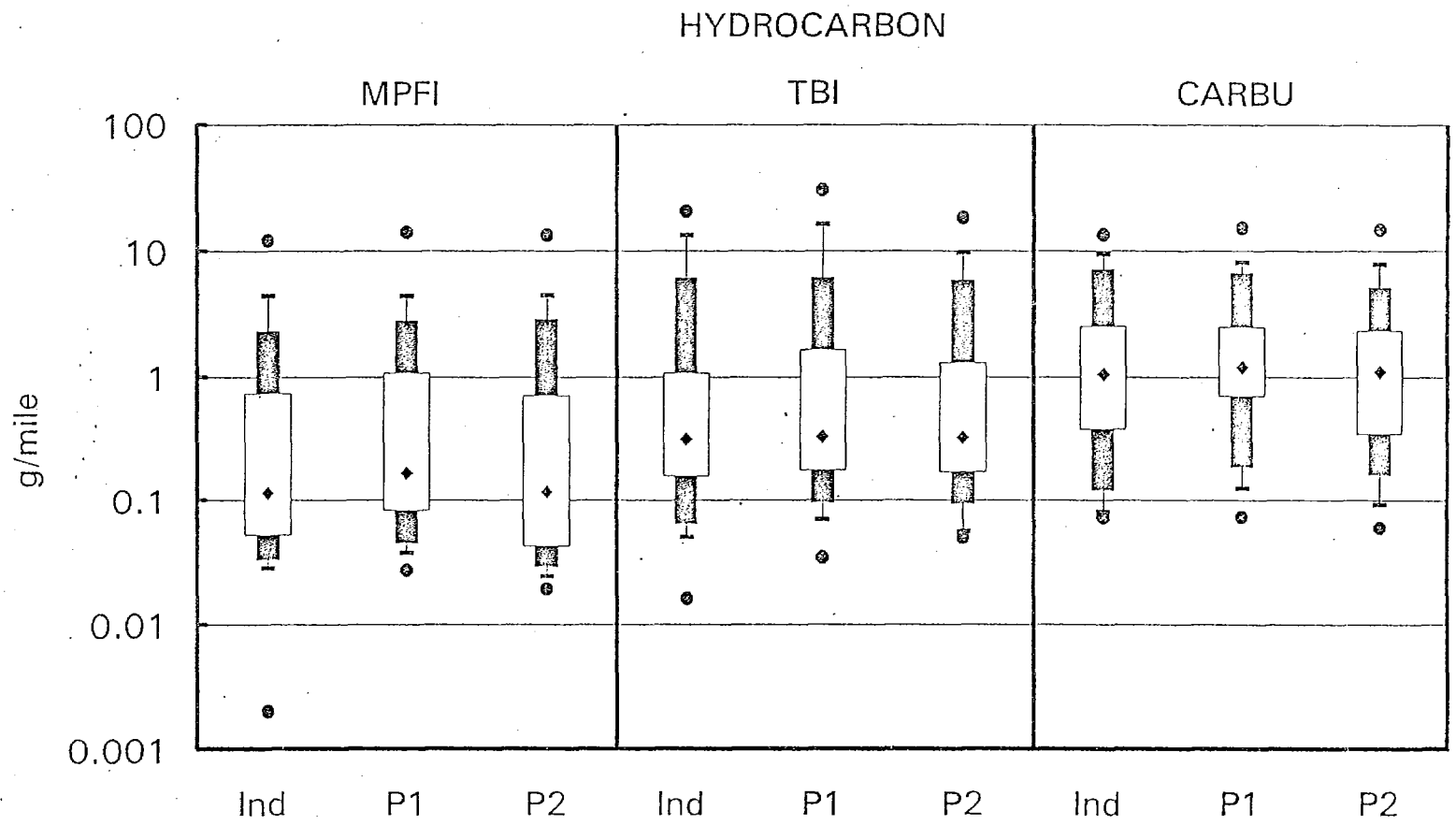

Figure 3.1.4.1 Box plots showing the effects of technology and fuel on HC exhaust emissions. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

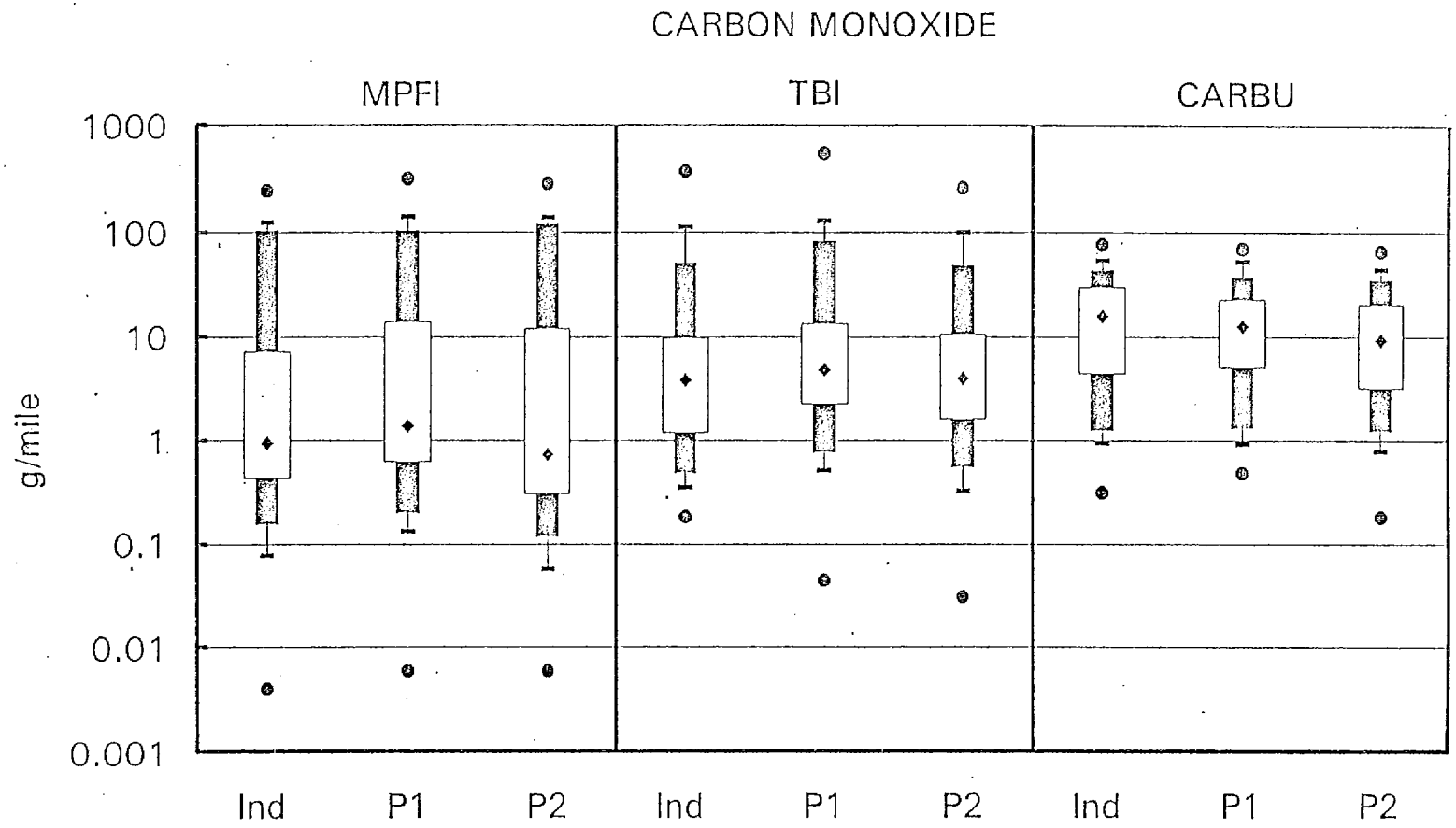

Figure 3.1.4.2 Box plots showing the effects of technology and fuel on CO exhaust emissions. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

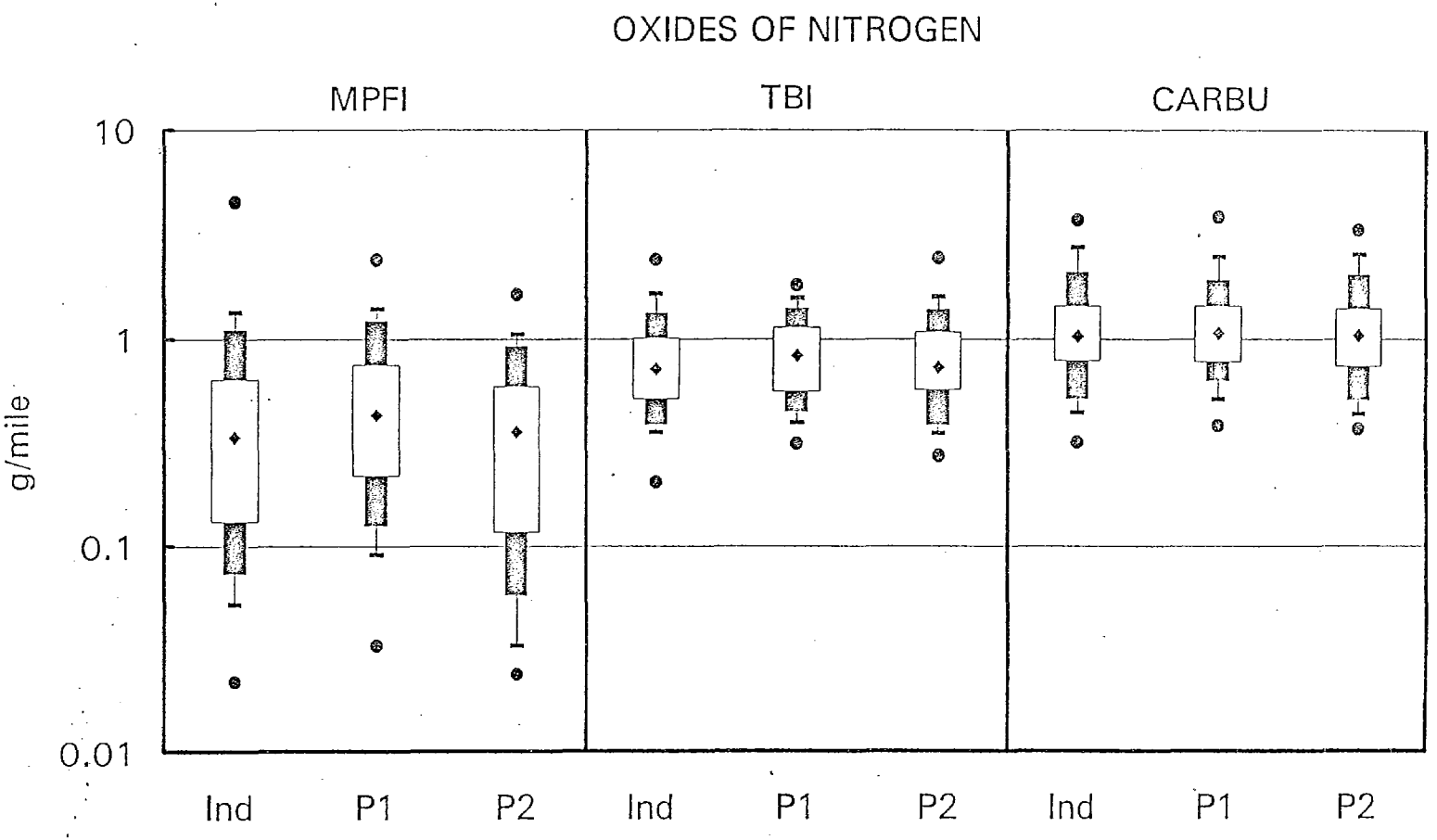

Figure 3.1.4.3 Box plots showing the effects of technology and fuel on NOx exhaust emissions. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

For the MPFI group, each box plot contains 150 data (5 vehicles x 3 temperatures x 10 cycles) whereas in the TBI and CARBU groups, each box plot contains 90 data (3 vehicles x 3 temperatures x 10 cycles).

As shown in Figures 3.1.4.1 and 3.1.4.2, the pattern of HC and CO emissions was different among fuel delivery technology groups. Not only did the HC and CO exhaust emissions descend in the order of MPFI, TBI, and CARBU but the medians of HC and CO emissions in the MPFI group were about one order of magnitude lower than the medians of the CARBU.

When NOx was examined (see Figure 3.1.4.3), it was found that emissions for MPFI were lower than both TBI and the CARBU group. Furthermore, there was no significant difference between the TBI and CARBU groups. This could imply that MPFI reduced NOx emissions more than either TBI or CARBU.

When compared with all technology groups for HC, CO, and NOx exhaust emissions, it was observed that fuel effects within each technology group were minimal. In contrast, despite the large vehicle-to-vehicle variation in each technology group, the fuel delivery system definitely has a major impact on the exhaust emissions.

3.1.5 Comparison of Each Vehicle

While the previous Section 3.1.4 examines the effect of technology group on exhaust emissions, this section examines the vehicle-to-vehicle variation. Except for the Oldsmobile which includes 80 data (10 tests were excluded), all box plots for other vehicles contain 90 data (10 cycles x 3 temp x 3 fuels). Figures 3.1.5.1 and 3.1.5.2

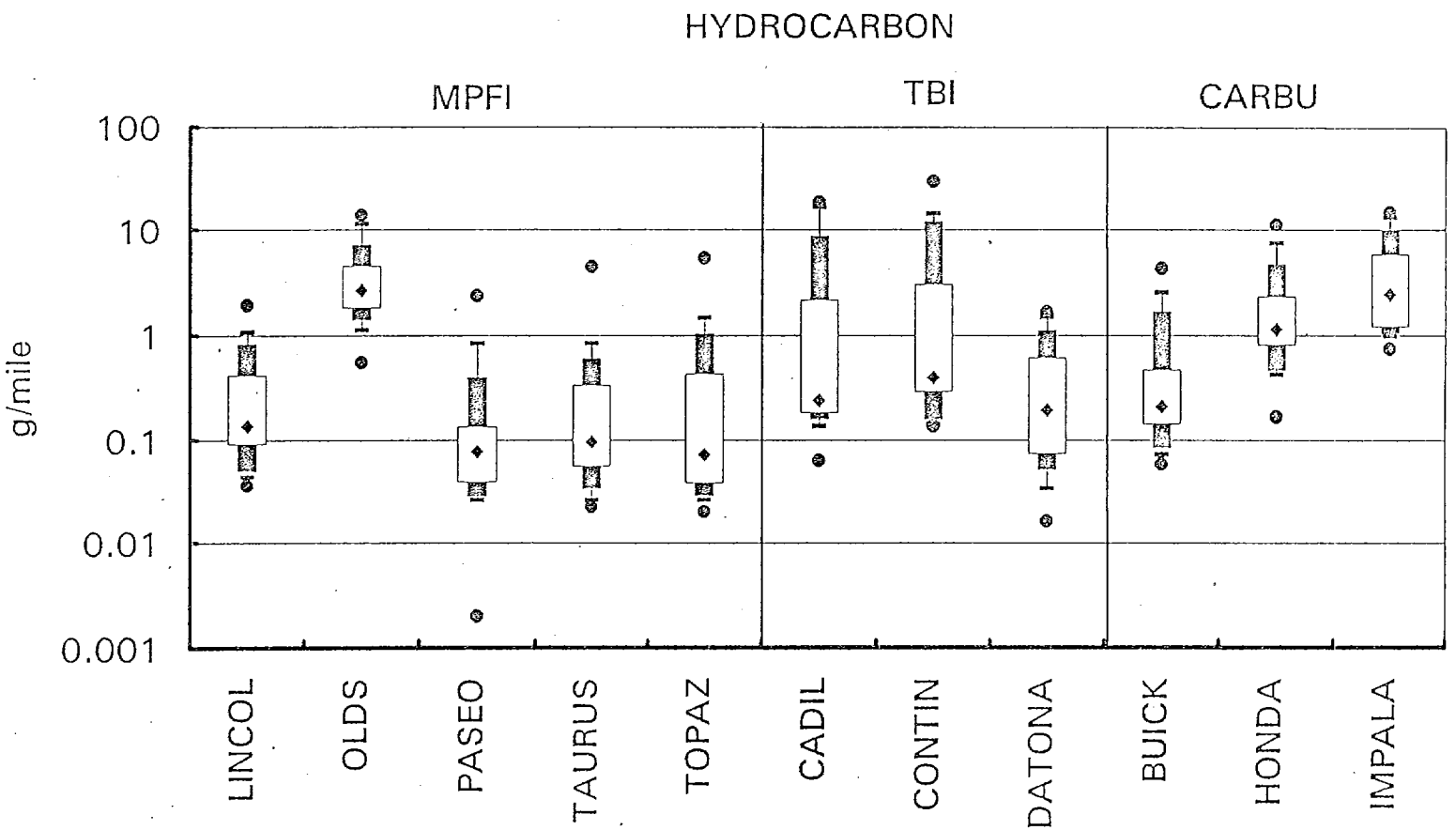

Figure 3.1.5.1 Box plots showing HC exhaust emissions of each vehicle. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

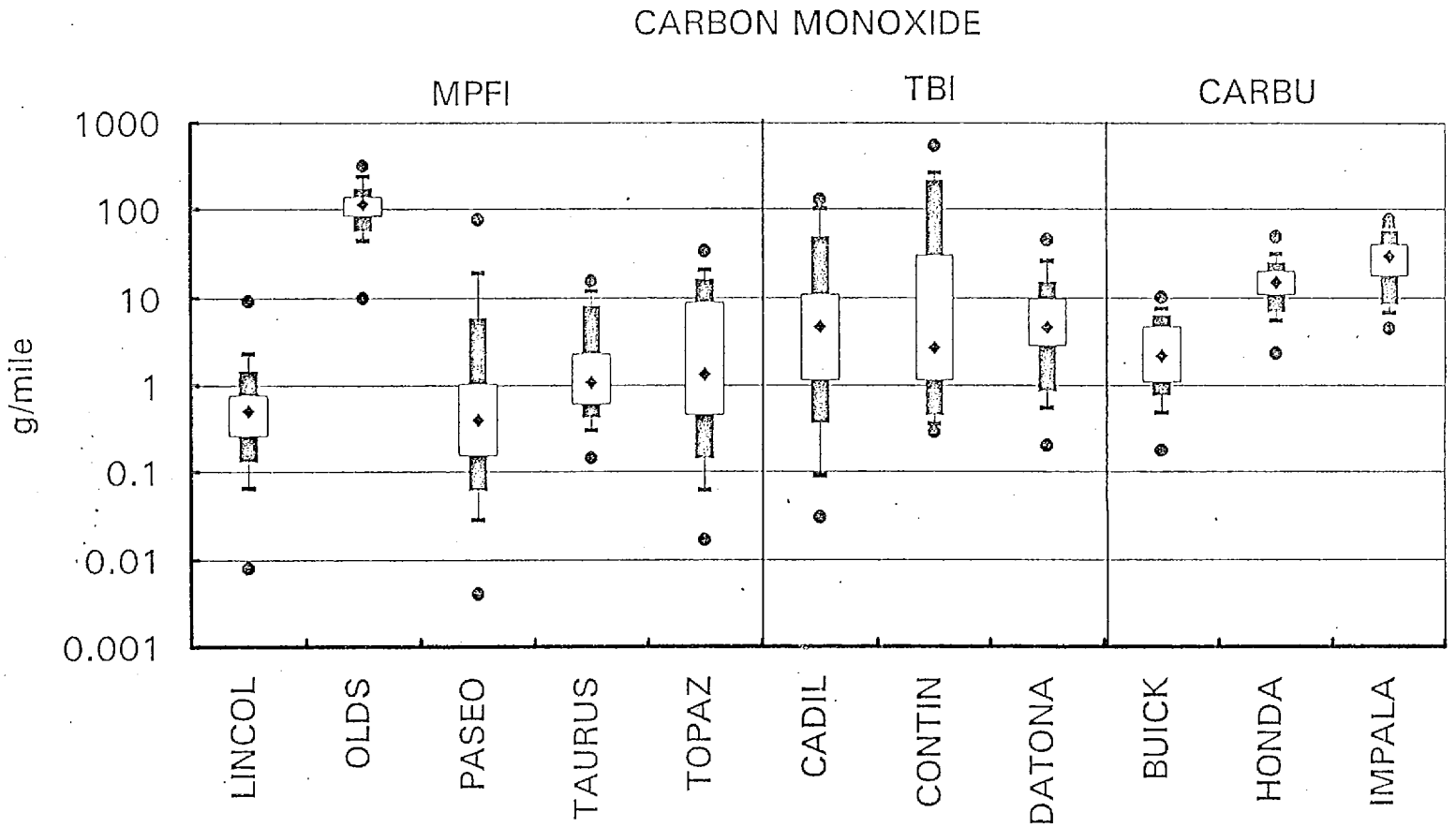

Figure 3.1.5.2 Box plots showing CO exhaust emissions of each vehicle. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

present the HC and CO exhaust emissions. It was clear that the Oldsmobile was the "high emitter" in the MPFI group. In fact, the HC and CO emissions from the Oldsmobile were approximately two orders of magnitude higher than other vehicles within MPFI. In general, the overall HC and CO exhaust emissions in MPFI were lower than TBI, and the emissions from the TBI group were generally lower than the CARBU group.

Figure 3.1.5.3 presents the NOx exhaust emissions of each vehicle. For NOx, the Oldsmobile did not behave as the high emitter in the MPFI group but instead it was similar to the other four vehicles in this group. In addition, it was found the emissions pattern for both TBI and CARBU were similar. Nevertheless, the overall NOx emissions from MPFI were lower than those for TBI and CARBU, and this was consistent with the data discussed in Section 3.1.4.

Similar to the conclusion from Section 3.1.4, vehicles of the MPFI group had the lowest emissions. In general, exhaust emissions were a strong function of the technology group, average mileage and model year of the vehicles. Vehicles of recent model years had lower mileage and more advanced fuel delivery systems when compared with vehicles of older model years and higher mileage. In addition, the emission components (e.g., catalyst) for older vehicles have a higher risk of deterioration when compared to a recent model year vehicle. Thus, it was conceivable the more recent model year vehicles were "cleaner" than older model year vehicles. Nevertheless, high emitters can also be found among new vehicles.

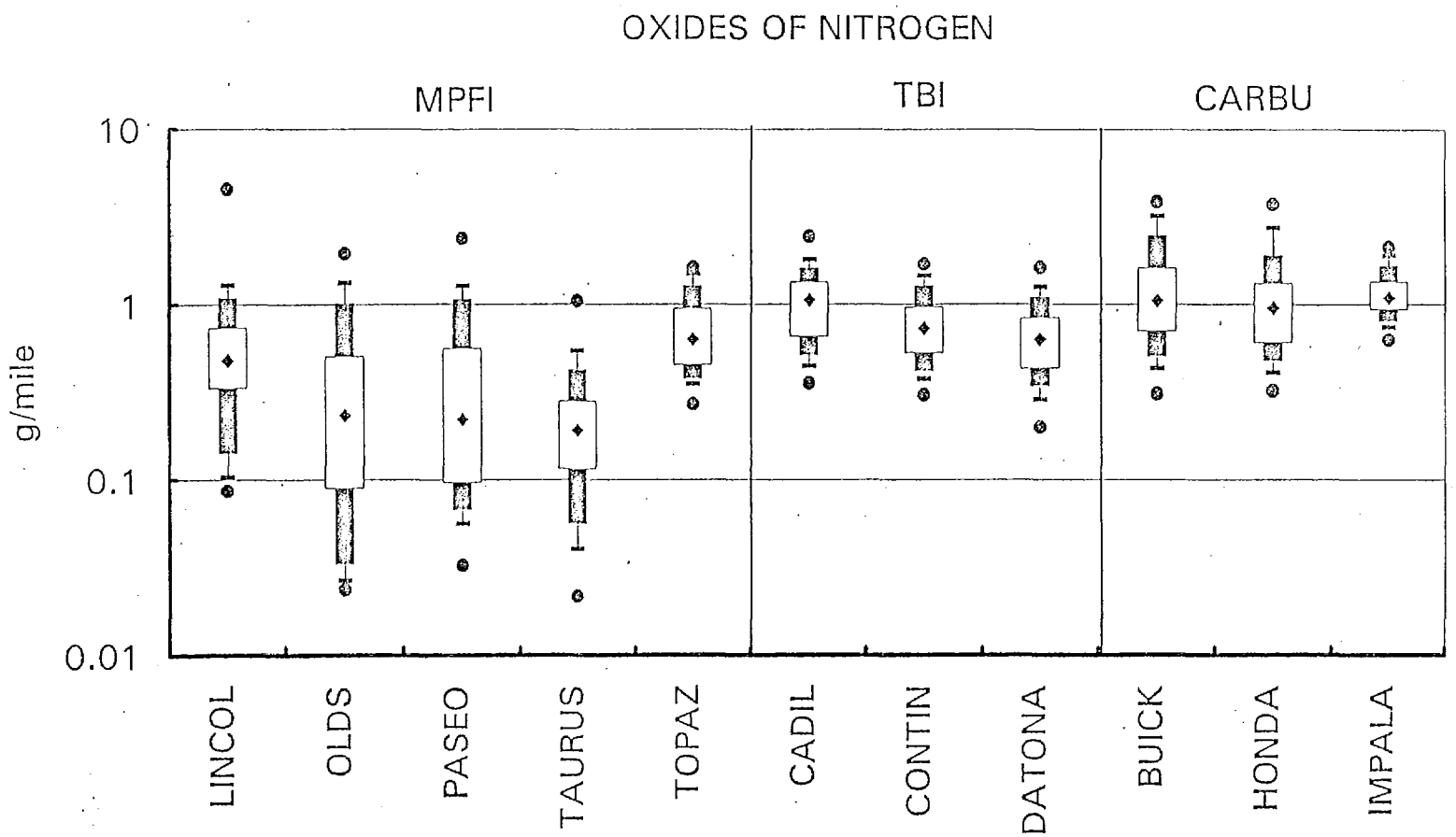

Figure 3.1.5.3 Box plots showing NOx exhaust emissions of each vehicle. Each box plot includes the minimum, maximum, 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles.

3.1.6 Comparison of Fuel Economy

This section reviews the fuel economies based on Phase 1, Phase 2, and Indolene for all three technology groups and all 11 vehicles combined. Note that fuel economy was based on each specific cycle. The fuel economy was plotted with respect to the average speed of the cycle.

Figure 3.1.6.1 shows the average fuel economy with respect to the cycle for MPFI. Fuel economy increased with speed, to a peak of approximately 45 mph where the optimum fuel economy was about 33 miles per gallon, and then decreased beyond 45 mph. In addition, fuel economy for Phase 2 fuel was generally higher than Phase 1 and Indolene across all speeds.

As seen in Figure 3.1.6.2, the relationship of fuel economy with respect to speed for TBI was similar to MPFI. That is, fuel economy increased up to about 45 mph where the optimum fuel economy for TBI was about 30 miles per gallon, then decreased beyond 45 mph. It was also observed that Phase 2 fuel appeared to have higher average fuel economy across all speeds except between 45 to 50 mph, where both Indolene and Phase 1 appeared to provide a higher fuel economy than Phase 2 fuel.

For CARBU (see Figure 3.1.6.3), similar to both the MPFI and TBI groups, fuel economy exhibited a similar trend with respect to speed, and the optimum fuel economy was approximately 28 miles per gallon at about 45 mph. In addition, there was no clear pattern that Phase 1 or Phase 2 fuel performed better across all speeds.

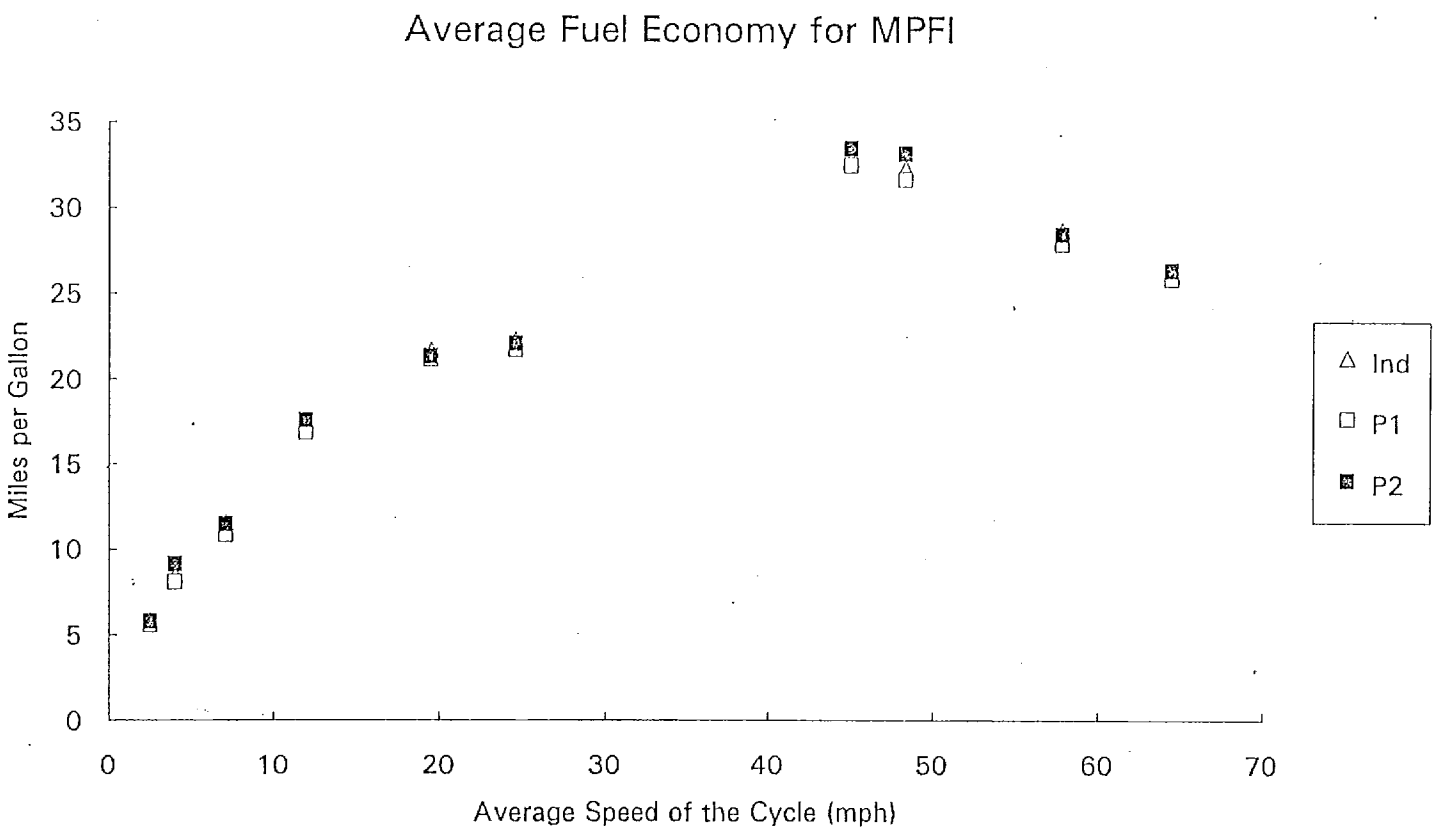

Figure 3.1.6.1 Scatter plot showing the effects of fuel and speed on fuel economy (MPFI)

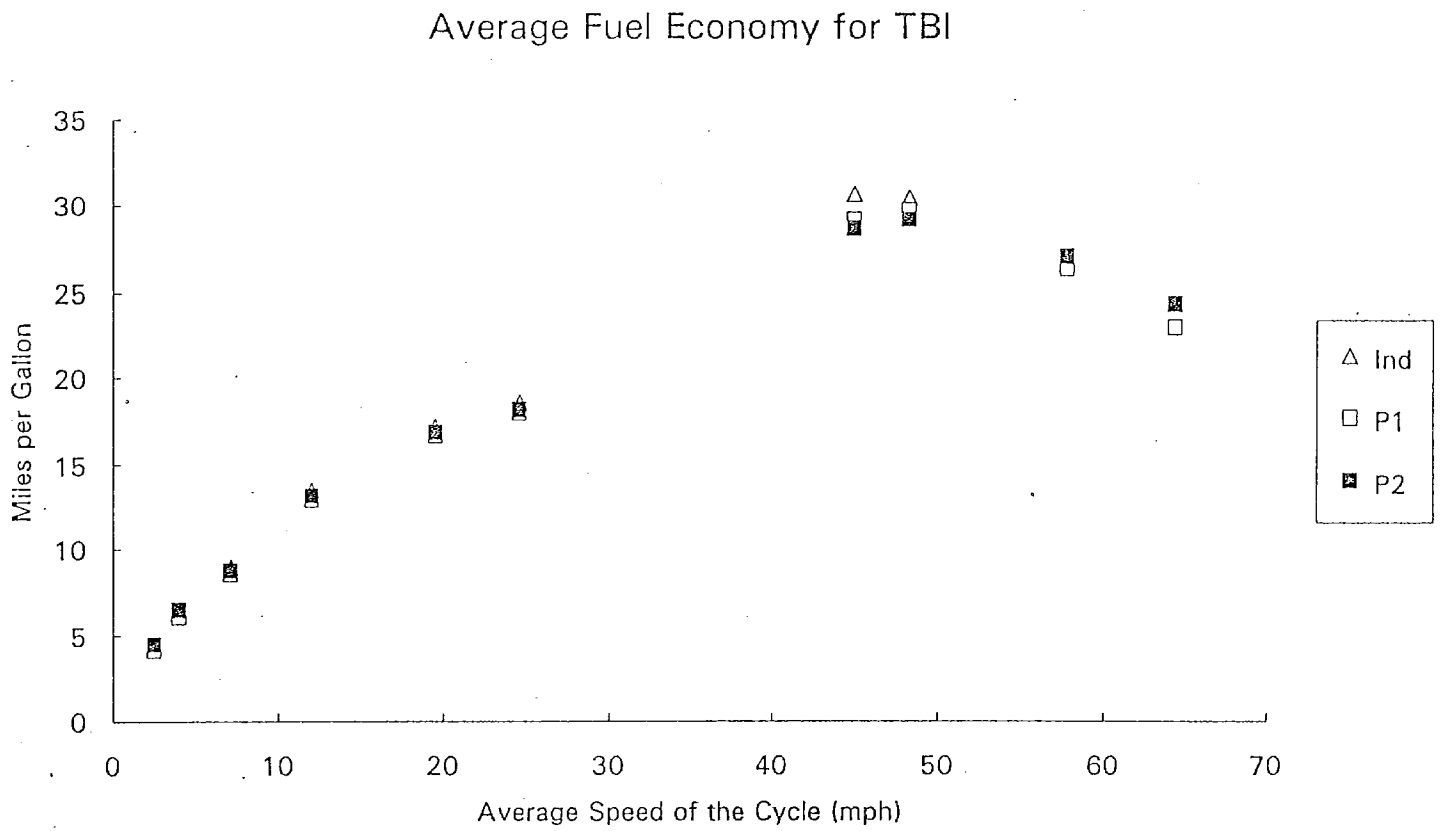

Figure 3.1.6.2 Scatter plot showing the effects of fuel and speed on fuel economy (TBI)

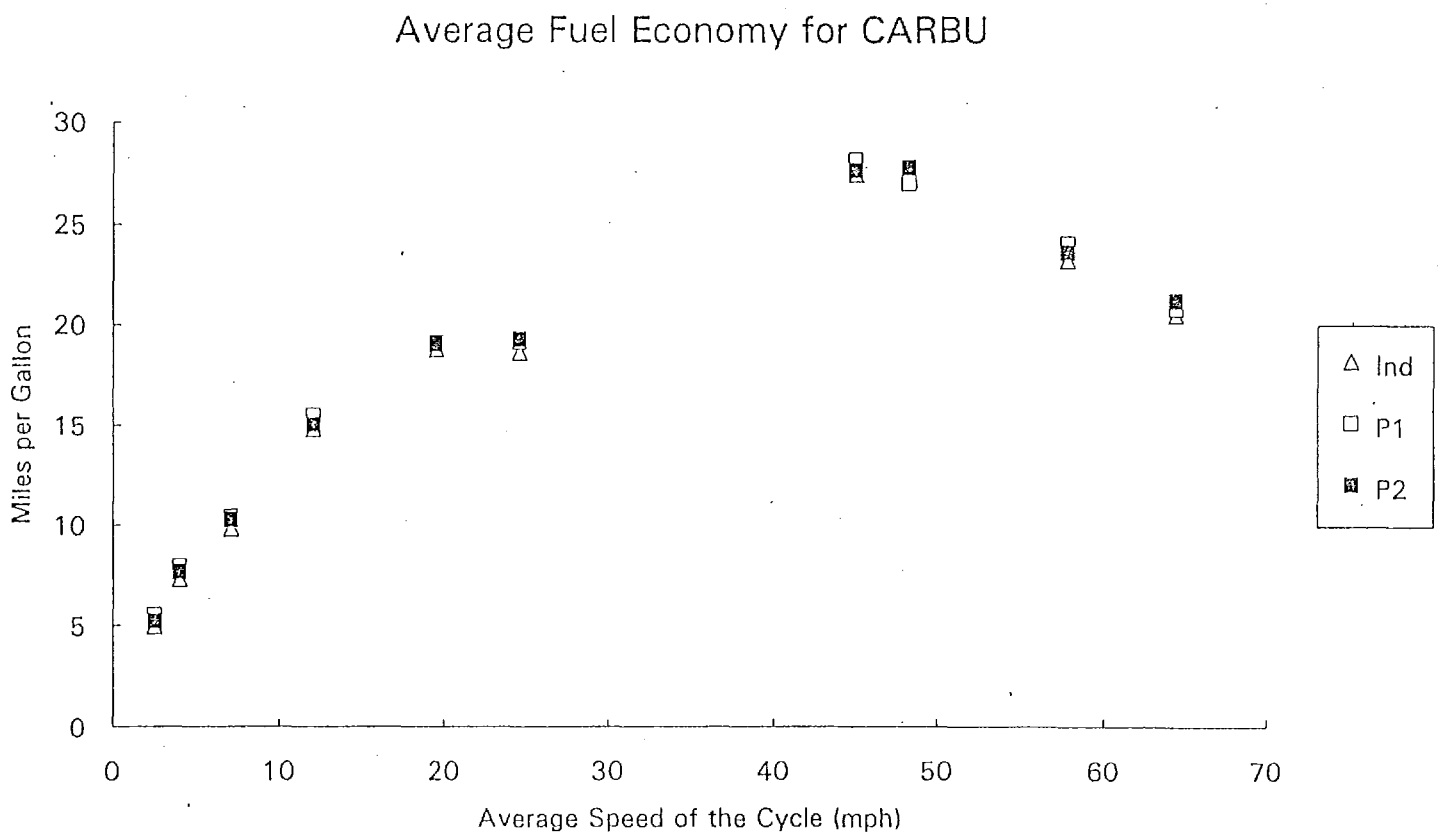

Figure 3.1.6.3 Scatter plot showing the effects of fuel and speed on fuel economy (CARBU)

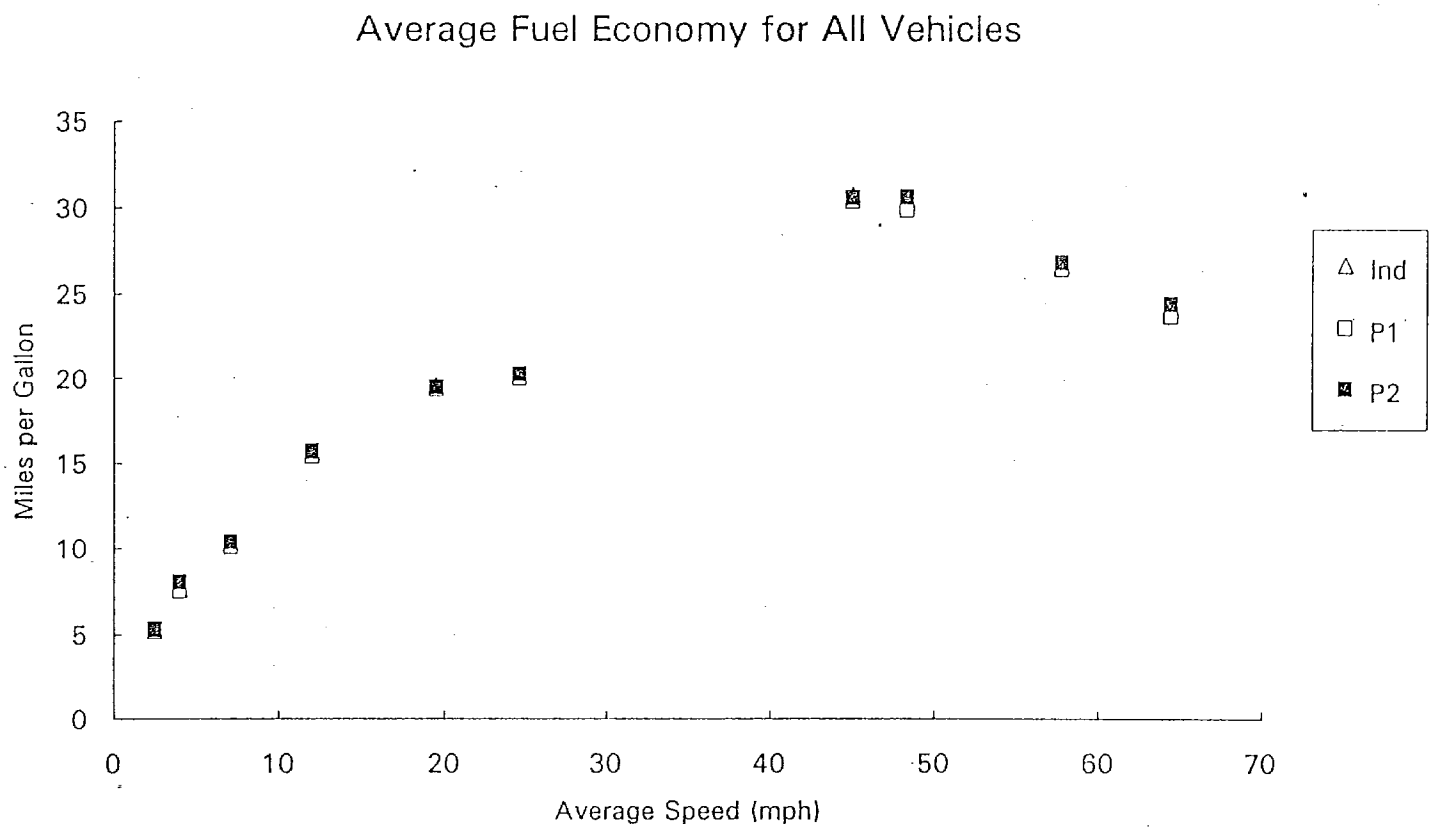

Figure 3.1.6.4 Scatter plot showing the effects of fuel and speed on fuel economy for all vehicles.

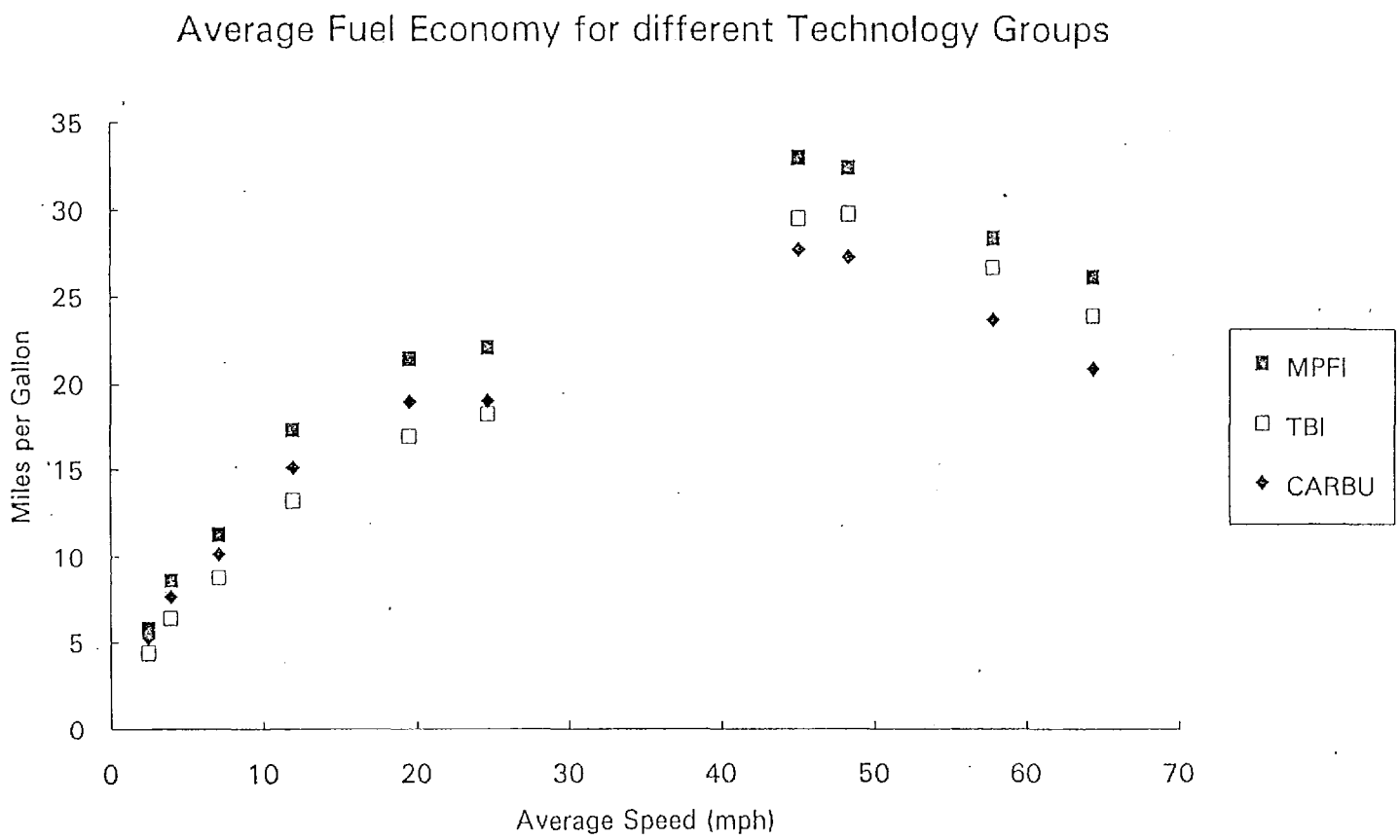

Figure 3.1.6.5 Scatter plots showing the effects of technology groups on fuel economy

Based on Figures 3.1.6.1 to 3.1.6.3, it was clear that technology group could have a major impact on optimum fuel economy as compared to fuel type. In general, recent model year vehicles were more fuel efficient than older model year vehicles.

As indicated in Figure 3.1.6.4, when comparing fuel economy for all vehicles as an aggregate, it was found that based on all 11 vehicles studied in this project, fuel economy due to Phase 2 fuel was higher than for both Phase 1 and Indolene fuels.

Figure 3.1.6.5 compares the average fuel economy based on technology groups and shows that the average fuel economy for MPFI was higher than for TBI and CARBU across all speeds. Nevertheless, it was observed that for speeds below 30 mph, the average fuel economy for CARBU was higher than TBI, while for speeds above 40 mph, the fuel economy for TBI was higher than CARBU.

In short, the best fuel economy for all technology groups was observed at approximately 45 mph, and vehicles from MPFI have better fuel economy than both CARBU and TBI. This was probably due to an improved fuel delivery system, more efficient engine combustion, and improved aerodynamics.

3.1.7 Catalyst Efficiency

This section reports the catalyst efficiency of each vehicle, which was determined when each vehicle was tested for the sequence of 75 F with Indolene. The primary function of a three-way catalyst (TWC) is to facilitate the conversion of HC into water vapor and carbon dioxide, CO into carbon dioxide, and NOx into nitrogen and oxygen, while the oxidation catalyst converts HC and CO into water and carbon

dioxide. In general, the oxidation catalyst is common in older vehicles, while the TWC is common in vehicles of 1981 model year and later.

The catalyst efficiency test was performed under FTP conditions with Indolene at 75 F. Two separate analyzers were used separately to analyze the exhaust streams before entering the catalyst and after the catalyst. By summing the data from these two streams, catalyst efficiency was calculated as follows:

$$\text{Catalyst Efficiency} = \left(\frac{\text{Emissions before Catalyst} - \text{Emissions after Catalyst}}{\text{Emissions before Catalyst}} \right) * 100$$

As exhaust emissions for the FTP were reported for Bag 1, Bag 2, Bag 3, and the Composite, the catalyst efficiency was reported in a similar way. That is, catalyst efficiency was measured for each bag as well as the composite of all three bags.

Figure 3.1.7.1 presents the catalyst efficiency of all vehicles based on the FTP Composite. Note that both the 1983 Honda Accord and 1979 Chevrolet Impala were equipped with an oxidation catalyst (OC) while the remaining vehicles were equipped with a three-way catalyst (TWC). The catalyst of vehicles from the MPFI and TBI groups all appeared functional for HC, CO, and NOx. Moreover, it was observed that while the HC and CO conversion efficiency remained almost unchanged, the conversion efficiency for NOx declined as the vehicle model year became older for these vehicles.

It seems that none of the catalysts in the CARBU group were functional. In

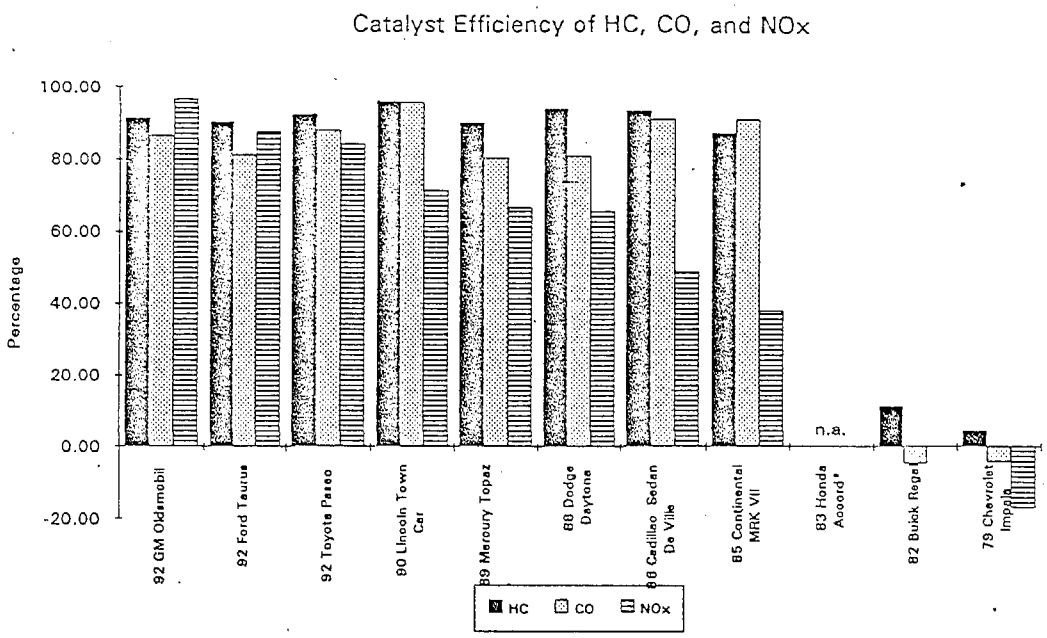

Figure 3.1.7.1 Catalyst effeciency of all vehicles based on composite of FTP (75 F and Indolene)
* Unable to measure meaningful data for the catalyst.

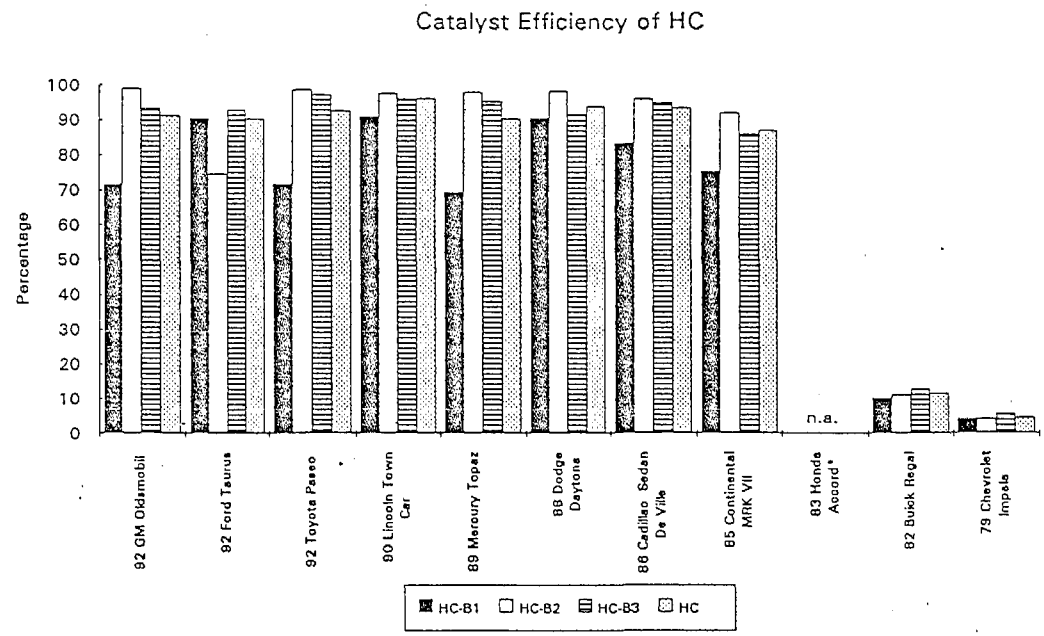

Figure 3.1.7.2 Catalyst effeciency of HC for all vehicles based on Bag 1, Bag 2, Bag 3, and Composite of FTP (Indolene and 75 F). * Unable to measure meaningful data for the catalyst.

fact, the negative readings suggest that the emissions "increased" after the catalyst. For the Buick Regal, the negative conversion efficiency readings for both CO and NOx fall approximately within the ± 4% combined instrumental error from the two analyzers and this could explain the negative readings. On the other hand, for the Chevrolet Impala, the negative conversion efficiency readings for both CO and NOx fall beyond the possible instrumental error of ± 4%. One possible explanation was the formation of NOx inside the OC in Chevrolet Impala. More research is needed to investigate such problem, however, the limited budget of the present study preclude us from further investigating such issue. Note that the catalyst efficiency test for the Honda Accord was invalid. However, it was very likely that it was "dead," similar to other vehicles in the CARBU group.

Figures 3.1.7.2 to 3.1.7.4 present the catalyst efficiency of HC, CO, and NOx for all vehicles based on FTP Bag 1, Bag 2, Bag 3, and the Composite. In general, the Bag 1 catalyst efficiency was always lower than Bag 2 and Bag 3 because the Bag 1 is a cold start mode and the catalyst was unable to reach the optimum operational temperature when the vehicle was started. Therefore, the catalyst efficiency for Bag 1 was lower than the catalyst efficiency of Bag 2, Bag 3, and the Composite. When examining the catalyst efficiency from technology groups with functional catalysts (MPFI and TBI), it was found that the average Bag 1 catalyst efficiencies for HC, CO, and NOx were approximately 88%, 77%, 90%, respectively, compared to the average Composite catalyst efficiency.

In short, vehicles ten years or older were likely to have malfunctioning or

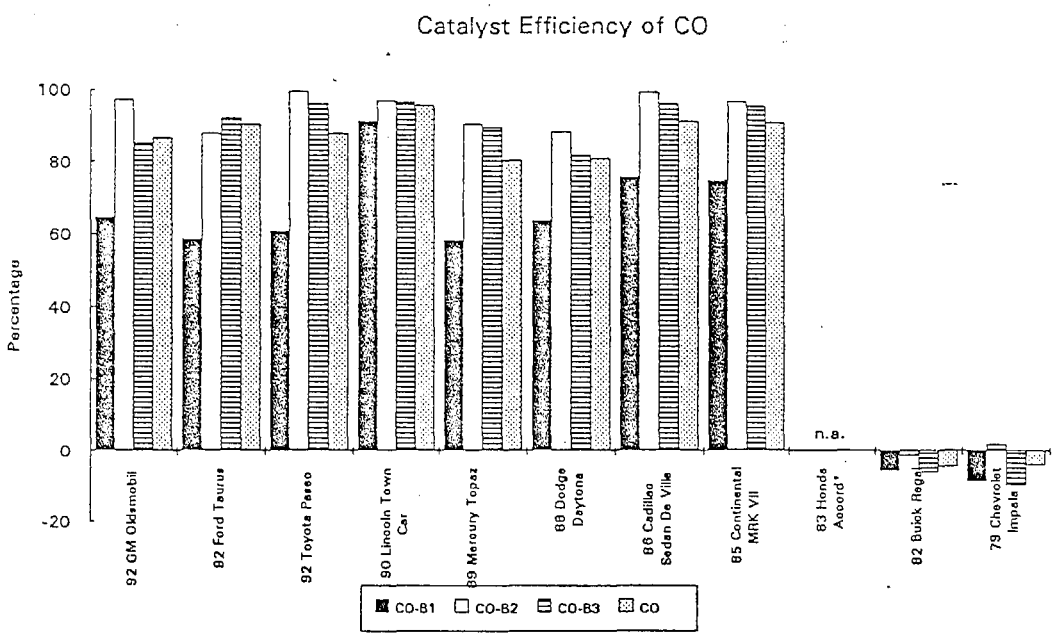

Figure 3.1.7.3 Catalyst effeciency of CO for all vehicles based on Bag 1, Bag 2, Bag 3, and Composite of FTP (Indolene and 75 F). * Unable to measure meaningful data for the catalyst.

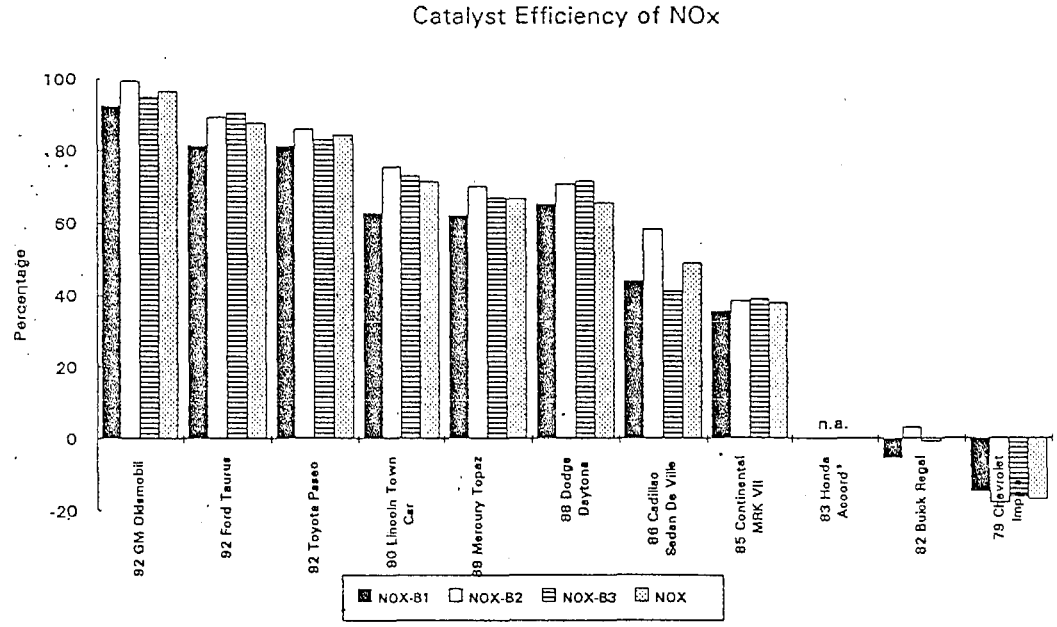

Figure 3.1.7.4 Catalyst effeciency of NOx for all vehicles based on Bag 1, Bag 2, Bag 3, and Composite of FTP (Indolene and 75 F). * Unable to measure meaningful data for the catalyst.

"dead" catalysts and this could explain why older vehicles have a higher tendency to be "high emitters." More importantly, it suggests that soaking temperature has a strong influence on catalyst conversion efficiency, especially during the cold start mode.

3.1.8 Comparison of Phase 1 and Phase 2 Fuel

The previous Section 3.1.8.1 presented the effects of fuel and temperature on exhaust emissions. The high vehicle-to-vehicle and cycle-to-cycle variability masked the potential effect of fuel type on exhaust emissions. Studies from CARB (1994) have reported that when Phase 2 fuel is introduced starting in June, 1996, it will produce an immediate reduction in air pollution. In fact, it was projected that in the 1996 calendar year, the introduction of Phase 2 fuel will cause ROG (including evaporative hydrocarbons), NOx, and CO to decrease by 17%, 11%, and 11%, respectively (CARB, 1994) when compared to Phase 1 fuel.

The present study examined the experimentally difference between Phase 1 (without oxygenates) and Phase 2 (with oxygenates) fuels based on all eleven vehicles operating under the same speed cycle and temperature conditions. In other words, the exhaust emissions due to Phase 1 and Phase 2 fuel were compared for each vehicle under identical test conditions (test cycle and temperature), and 30 comparisons were made per vehicle (10 cycles x 3 temperatures). Student t-test (paired samples for mean) was used to determine the significance of differences observed between Phase 1 and Phase 2 fuels for the identical cycle and temperature. The test hypotheses were as

follows:

Ho: The mean difference in exhaust emissions between Phase 1 and Phase 2 fuel = 0

Ha: The mean difference in exhaust emissions between Phase 1 and Phase 2 fuel $\neq 0$

where α=0.05

Table 3.1.8.1 summarizes p-values based on the paired t-test. It was found that Phase 1 and Phase 2 fuels definitely affect the exhaust emissions differently depending on the technology group. For instance, in the MPFI group, there was a significant difference in NOx emissions whereas in both TBI and CARBU, there was a significant difference in HC and CO emissions. However, when all vehicles were considered, only HC and NOx exhibited significant differences. Figure 3.1.8.1 presents the distribution of population means with 95% confidence intervals based on Table 3.1.8.1. In general, the averages for Phase 2 fuel is lower than Phase 1 except for HC in the MPFI group.

In summary, based on the 11 vehicles investigated in the present study, the emissions reduction between Phase 2 and Phase 1 fuel for HC, CO, and NOx observed here were 17%, 13%, and 11%, respectively. However, CO reduction was not statistically significant based on the paired t-test (α=0.05). Note, the present study did

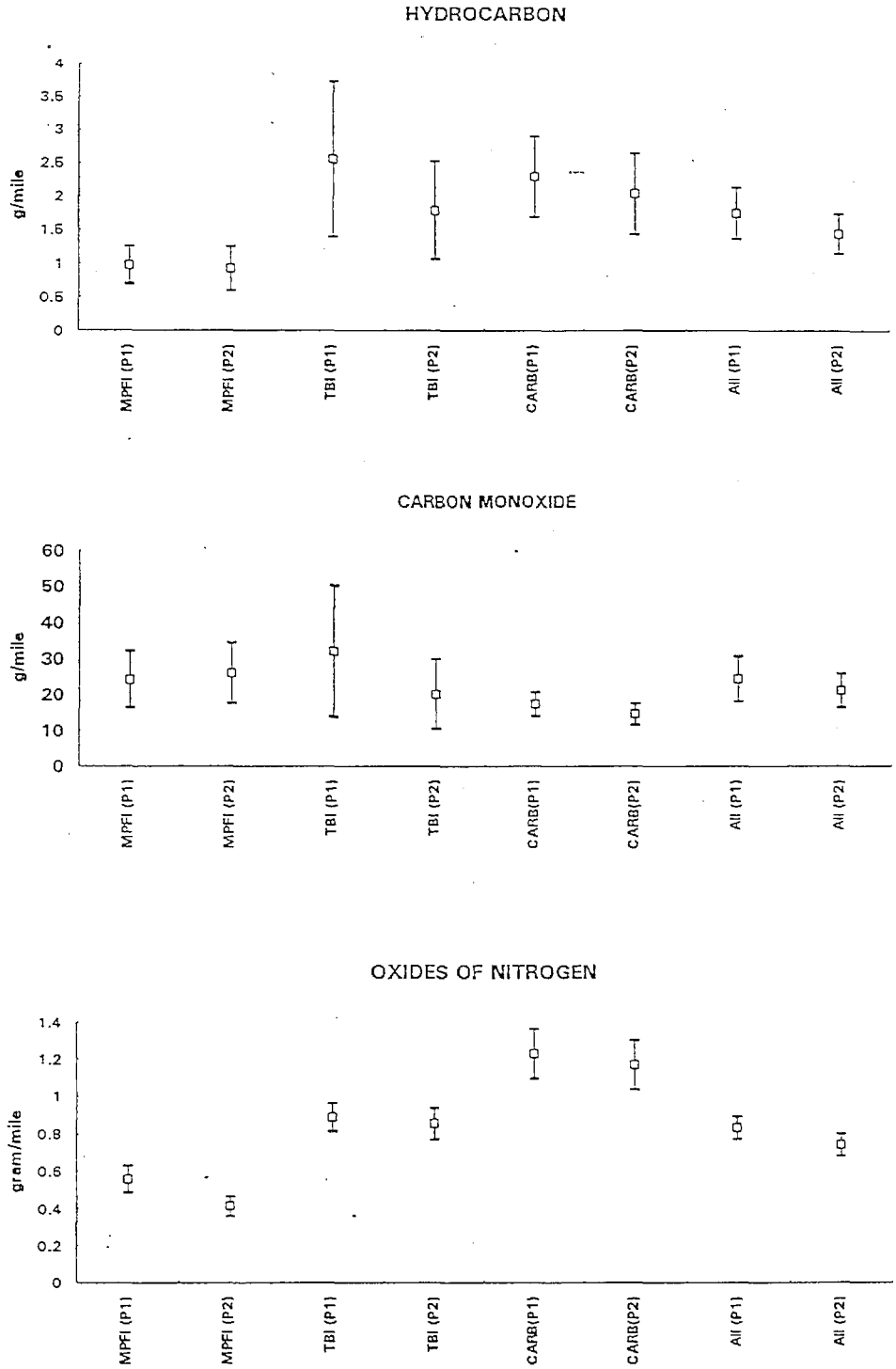

Figure 3.1.8.1 Comparison of exhaust emissions based on Phase 1 and Phase 2 fuel. Each interval represents 95% confidence interval of the population mean.

Table 3.1.8.1 Comparison of Phase 1 and Phase 2 exhaust emissions. The following table summarizes the level of significance (p-value) based on t-Test: Paired two-sample for means.*

	HC		CO		NOx	
MPFI	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Mean	0.968	0.918	24.090	25.837	0.557	0.413
Std Deviation	1.743	2.035	48.923	52.882	0.439	0.334
Std Error	0.142	0.166	3.995	4.318	0.036	0.027
n	150	150	150	150	150	150
p-value	0.647		0.465		**<0.001**	
% Reduction from Phase 2 to Phase 1**	-5.11		7.25		-25.85	
TBI	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Mean	2.557	1.786	31.876	20.020	0.886	0.852
Std Dev	5.660	3.541	88.079	47.045	0.363	0.399
Std Error	0.597	0.373	9.284	4.959	0.038	0.042
n	90	90	90	90	90	90
p-value	**0.027**		**0.048**		0.201	
% Reduction from Phase 2 to Phase 1	-30.14		-37.19		-3.76	
CARB	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Mean	2.288	2.043	17.224	14.532	1.228	1.170
Std Dev	2.895	2.929	16.166	14.197	0.645	0.643
Std Error	0.305	0.309	1.704	1.496	0.068	0.068
n	90	90	90	90	90	90
p-value	**0.012**		**0.004**		0.260	
% Reduction from Phase 2 to Phase 1	-10.70		-15.63		-4.71	
All Vehicles	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Mean	1.761	1.462	24.341	21.168	0.830	0.739
Std Dev	3.584	2.801	57.295	44.069	0.560	0.555
Std Error	0.197	0.154	3.154	2.426	0.031	0.031
n	330	330	330	330	330	330
p-value	**0.008**		0.110		**<0.001**	
% Reduction from Phase 2 to Phase 1	-17.00		-13.04		-10.89	

* Ho: The mean difference in exhaust emissions between Phase 1 and Phase 2 fuel is equal to 0
Ha: The mean difference in exhaust emissions between Phase 1 and Phase 2 fuel is unequal to 0

** % Change = (Phase2- Phase1)*100/ Phase1

not include measurement of evaporative HC emissions. Therefore, the present values for difference between Phase 1 and Phase 2 fuels for HC is expected to be a lower limit. In conclusion, HC and NOx emissions reductions due to Phase 2 fuel observed in the present study were in good agreement with reductions predicted earlier by CARB.

3.1.9 Comparison of Unified Cycle (hot start) and Federal Test Procedure (cold start)

While the data analyses in Sections 3.1.1 and 3.1.2 concluded that ambient temperature has no significant effect on HC, CO and NOx exhaust emissions for all the hot stabilized tests, the effect of temperature on exhaust emissions could be important when cold start of the vehicle was considered. Note that cold start refers to starting the vehicle at the temperature at which the vehicle was soaked for between 12 to 36 hours prior to testing. The soaking temperature affects the conversion efficiency of the catalyst which in turn affects the exhaust emissions because the catalyst has not reached optimum conversion efficiency during a cold start.

Note that both the UC and FTP consist of 3 bags, where Bag 3 is an identical repeat of Bag 1. In the present study, the FTP possesses a cold start for Bag 1 whereas the UC has a hot start in Bag 1. Hence, by examining Bag 1 and Bag 3 of the FTP as well as Bag 1 and Bag 3 of the UC, the effects of cold start and hot start could be compared. Each of the following figures includes 9 blocks, and each block contains exhaust emissions based on Bag 1, Bag 2, Bag 3, and the Composite.

As shown in Figure 3.1.9a, the medians of Bag 1 of the FTP were about half

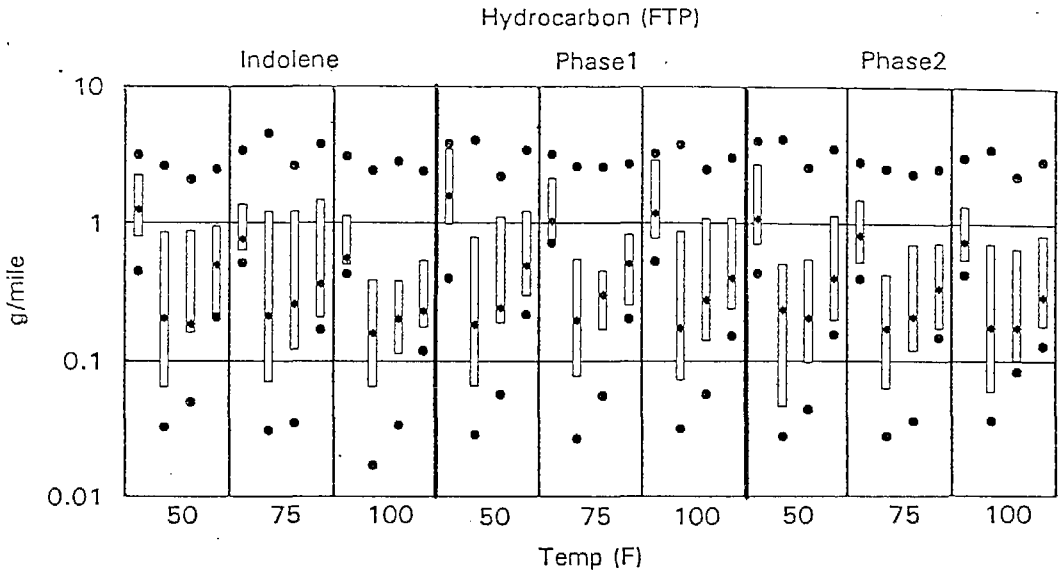

Figure 3.1.9.1a Box plots showing the effects of fuel and temperature on HC exhaust emissions (FTP). There are 4 box plots representing Bag 1, Bag 2, Bag 3 and Composite in each fuel block. Each box plot includes the minimum, maximum, 25th, 50th and 75th percentiles.

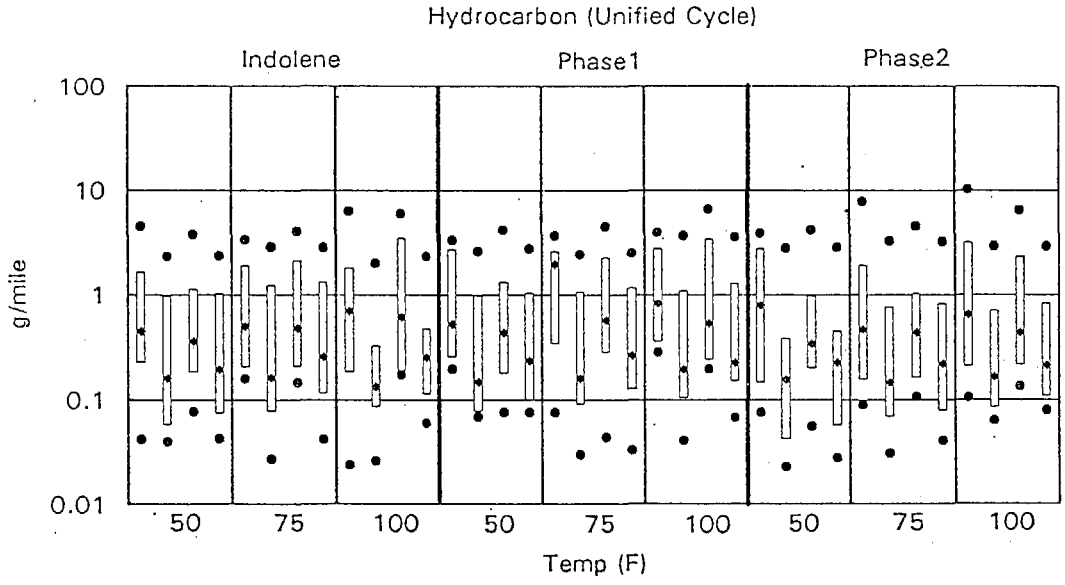

Figure 3.1.9.1b Box plots showing the effects of fuel and temperature on HC exhaust emissions (UC). There are 4 box plots representing Bag 1, Bag 2, Bag 3 and Composite in each fuel block. Each box plot includes the minimum, maximum, 25th, 50th and 75th percentiles.

order of magnitude higher than the medians of Bag 3 for HC emissions. When examining the effect of temperature on all FTP Bag 1 emissions, it appears that the lower the soaking temperature, the higher the Bag 1 emissions for all combinations of fuel and temperature. Since vehicles undergoing the FTP were soaked at the test temperature for at least 12 hours prior to testing, it was obvious that the soaking temperature of 50 F had greater impact than 100 F for the Bag 1 FTP. Therefore, soaking temperature was an important factor in characterizing vehicle start emissions. On the other hand, an examination of UC Bag 1 and Bag 3 suggests there is no difference between Bag 1 and Bag 3 HC exhaust emissions (Figure 3.1.91b).

When CO was examined for Bag 1 and Bag 3 of the FTP (Figure 3.1.9.2a), the medians of Bag 1 appeared to be about one order of magnitude higher than Bag 3 for all combinations of fuel and temperature. However, when the UC was examined, Bag 1 and Bag 3 appeared to have similar distributions for all temperature and fuel combinations (Figure 3.1.9.2b).

According to the NOx emissions from Figure 3.1.9.3a, the FTP Bag 1 appeared to have a higher overall distribution when compared to Bag 3 for all combinations of fuel and temperature. When the UC was inspected, Bag 1 and Bag 3 appeared to have a similar distribution for all temperature and fuel combinations (Figure 3.1.9.3b).

The paired t-test for means was used to compare the differences between Bag 1 and Bag 3 of the FTP and UC, respectively, under different fuel and temperature conditions. They test hypotheses were as follows:

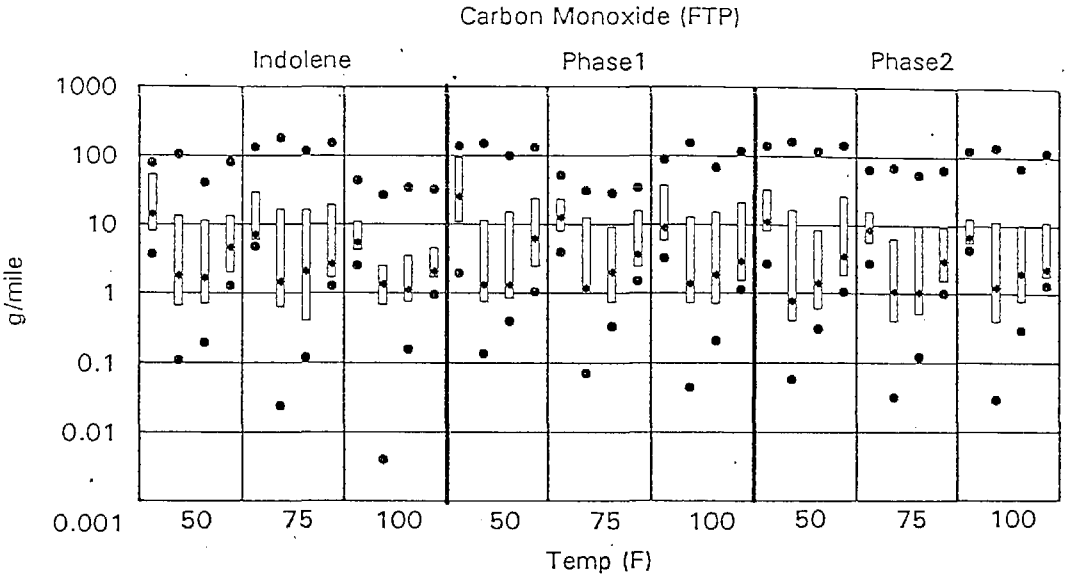

Figure 3.1.9.2a Box plots showing the effects of fuel and temperature on CO exhaust emissions (FTP). There are 4 box plots representing Bag 1, Bag 2, Bag 3, and Composite in each fuel block. Each box plot includes the minimum, maximum, 25th, 50th and 75th percentiles.

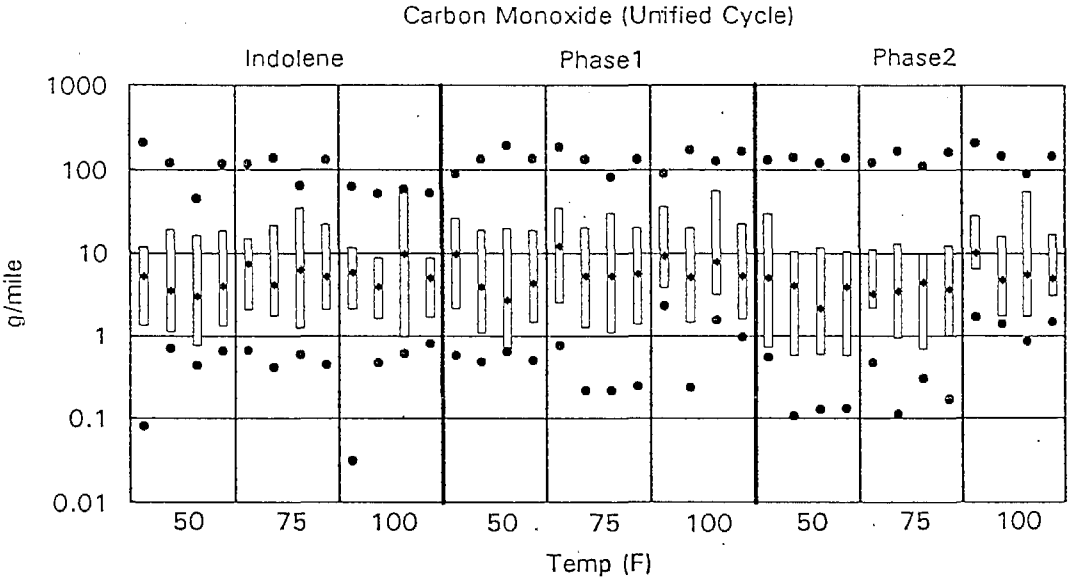

Figure 3.1.9.2b Box plots showing the effects of fuel and temperature on CO exhaust emissions (UC). There are 4 box plots representing Bag 1, Bag 2, Bag 3, and Composite in each fuel block. Each box plot includes the minimum, maximum, 25th, 50th and 75th percentiles.

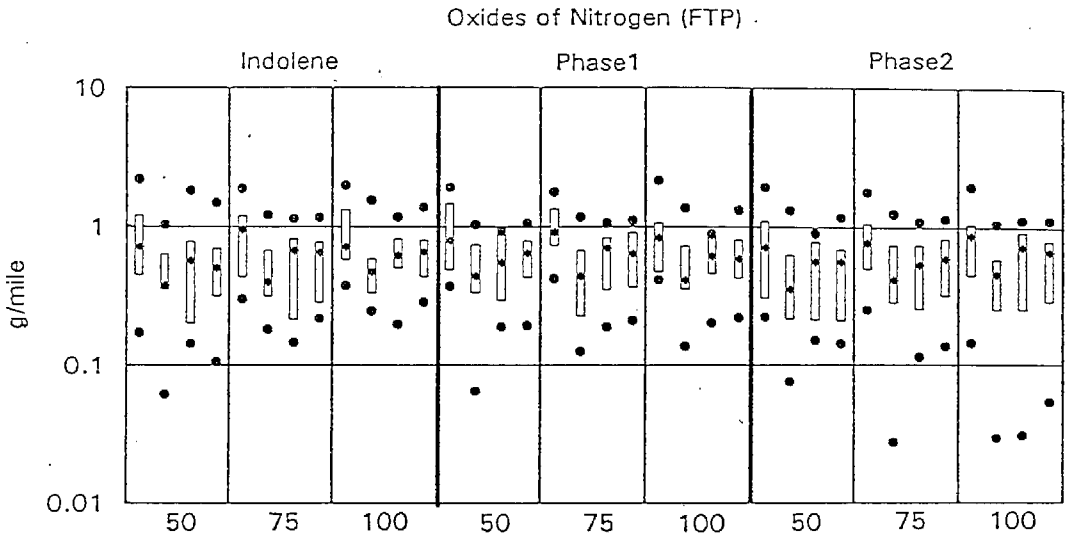

Figure 3.1.9.3a Box plots showing the effects of fuel and temperature on NOx exhaust emissions (FTP). There are 4 box plots representing Bag 1, Bag 2, Bag 3 and Composite in each fuel block. Each box plot includes the minimum, maximum, 25th, 50th and 75th percentiles.

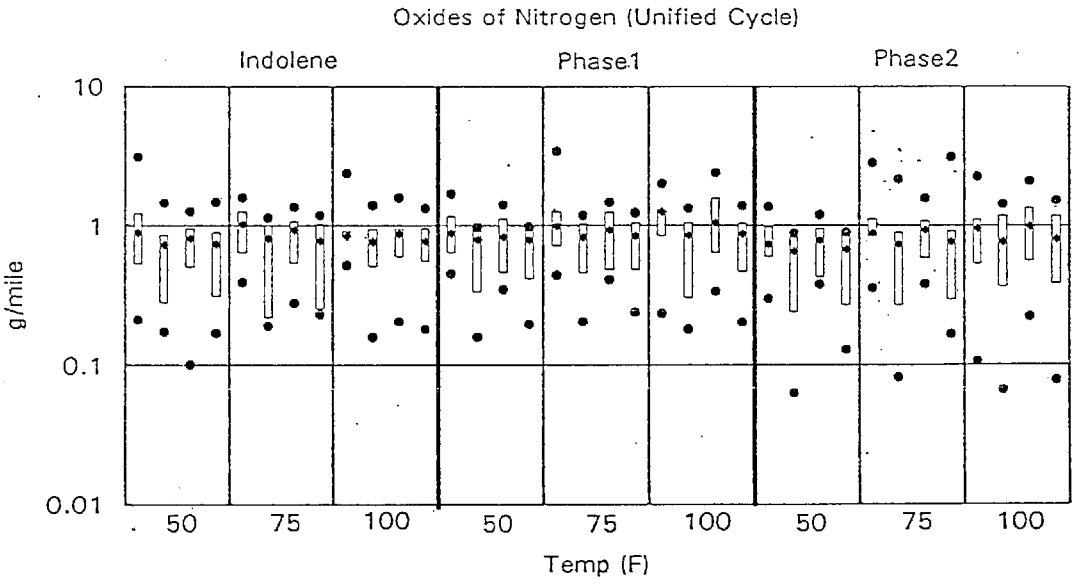

Figure 3.1.9.3b Box plots showing the effects of fuel and temperature on NOx exhaust emissions (UC). There are 4 box plots representing Bag 1, Bag 2, Bag 3 and Composite in each fuel block. Each box plot includes the minimum, maximum, 25th, 50th and 75th percentiles.

Table 3.1.9.1 Comparison of Bag 1 and Bag 3 at different fuel and temperature conditions. The following table summarizes the level of significance (p-value) based on t-test: Paired two-sample for means.*

FTP

	Indolene			Phase 1			Phase 2		
	50 F	75 F	100 F	50 F	75 F	100 F	50 F	75 F	100 F
HC	0.0003	0.0767	4.18E-05	0.0014	0.0006	0.0012	0.0089	9.26E-06	7.25E-05
CO	0.0048	0.0001	0.0002	0.0167	0.0011	0.0885	0.0528	8.39E-05	0.0813
NOx	0.0108	0.0402	0.1347	0.0288	0.0082	0.0473	0.0775	0.0433	0.0736

LA92 or UC

	Indolene			Phase 1			Phase 2		
	50 F	75 F	100 F	50 F	75 F	100 F	50 F	75 F	100 F
HC	0.3238	0.8541	0.6872	0.3333	0.1826	0.4333	0.1065	0.1963	0.4662
CO	0.2880	0.9511	0.1849	0.6157	0.2874	0.2046	0.1094	0.3947	0.4856
NOx	0.2943	0.1120	0.1435	0.1826	0.2000	0.9688	0.1094	0.3530	0.1136

* Ho: The mean difference in exhaust emissions between bag 1 and bag 3 is equal to 0.
Ha: The mean difference in exhaust emissions between bag 1 and bag 3 is not equal to 0.

Ho : The mean difference in exhaust emissions between Bag 1 and Bag 3 = 0

Ha : The mean difference in exhaust emissions between Bag 1 and Bag 3 $\neq 0$

where α=0.05

Table 3.1.9.1 summarizes the p-values for the comparison between Bag 1 and Bag 3 of the FTP and UC, respectively. In general, except for a few cases, it is evident there was a significant difference between Bag 1 and Bag 3 of the FTP, in particular that the cold start Bag 1 exhibited higher HC, CO, and NOx emissions than the hot start Bag 3. Conversely, there was no difference between Bag 1 and Bag 3 of the UC, since both Bag 1 and Bag 3 were in the hot start mode.

In summary, as expected, ambient temperature had a greater emissions implication for the cold start than the hot-stabilized operating mode of the vehicles. Unlike the hot stabilized operating mode of the vehicle, where exhaust is mainly speed dependent, cold start mode depends on the soaking temperature and frequency of cold starts. Therefore, in order to estimate the overall mobile emissions inventory, it is imperative to have a reasonable frequency estimate of cold starts for the entire vehicle fleet.

3.2 Test Repeatability and Vehicle Baseline Drift

The testing for the present study lasted approximately 15 months. All vehicles were tested on the same dynamometer to eliminate any dynamometer-to-dynamometer variation. Six drivers participated in the testing program and were randomly assigned.

In fact, drivers were assigned to the testing based on the daily work load of the contractor (ATDS).

The purpose of repeating tests for each vehicle was to evaluate test repeatability. Ideally, all tests should be repeated at least once in order to estimate the error term. Nevertheless, funding was available to repeat only one sequence (or 10 cycles) at 75 F with Indolene for each vehicle. One particular concern about vehicle testing was the drift of baseline FTP emissions due to emission control component deterioration during the course of testing. This additional repeated sequence allowed us to examine the baseline drift of the vehicles, if any, during the course of the study. There was an idling period for each vehicle between the first 9 sequences and the last repeated sequence and it varied from one to seven months depending on the vehicle testing schedule.

In order to estimate baseline drift of each vehicle, the FTP data were plotted with respect to time, though the FTP was conducted at various fuel and temperature combinations. The FTP was chosen to assess the vehicle's baseline drift because it is a relatively stable test with less test-to-test variability than other test cycles of low and high average speed. Though the FTP was conducted at different temperature and fuel combinations, their effects should be relatively small. Figures 3.2.1 to 3.2.11 present test repeatability and baseline drift for all eleven vehicles. Each figure includes the comparison of exhaust emissions from the first and repeated sequence as well as the baseline drift during the course of testing.

The 1990 Lincoln Town Car was found to be repeatable for HC, CO and NOx

emissions, except for the CO reading in SCC-12 cycle (Figure 3.2.1a). Also, it was observed that CO exhibited greater fluctuation with respect to date, temperature, and fuel when compared to HC and NOx (Figure 3.2.1b).

For the 1992 Oldsmobile, there was a drastic difference between the first and repeated sequence as shown in Figures 3.2.2a and 3.2.2b. It was observed later that toward the end of the 8th test sequence, the on-board diagnostic signal indicated that the oxygen sensor was malfunctioning. The emissions of HC, CO, and NOx decreased dramatically after the oxygen sensor was replaced. There was an approximate two orders of magnitude difference for HC and CO emissions before and after the oxygen sensor was replaced. Nevertheless, baseline NOx was unaffected by replacement of the oxygen sensor.

As shown in Figure 3.2.3a, the 1992 Toyota Paseo experienced episodes of high CO reading in the LOW3 and SCC-12 cycles of the repeated sequence. In addition, it was observed that CO and NOx fluctuated more than HC (Figure 3.2.3b).

The 1989 Mercury Topaz (Figure 3.2.4a) also showed a greater difference in CO between the initial and repeated sequences, especially in cycles of low average speed (i.e., LOW1, LOW3, NYCC, and SCC-12). Again, while HC and NOx remained almost unchanged throughout the course of testing, it was observed that there was high CO variation in the baseline emissions and two major peaks of CO were observed (Figure 3.2.4b). There was no explanation for the cause of these CO "episodes."

For the 1992 Ford Taurus, it was found that except for CO at LOW3 cycle, all

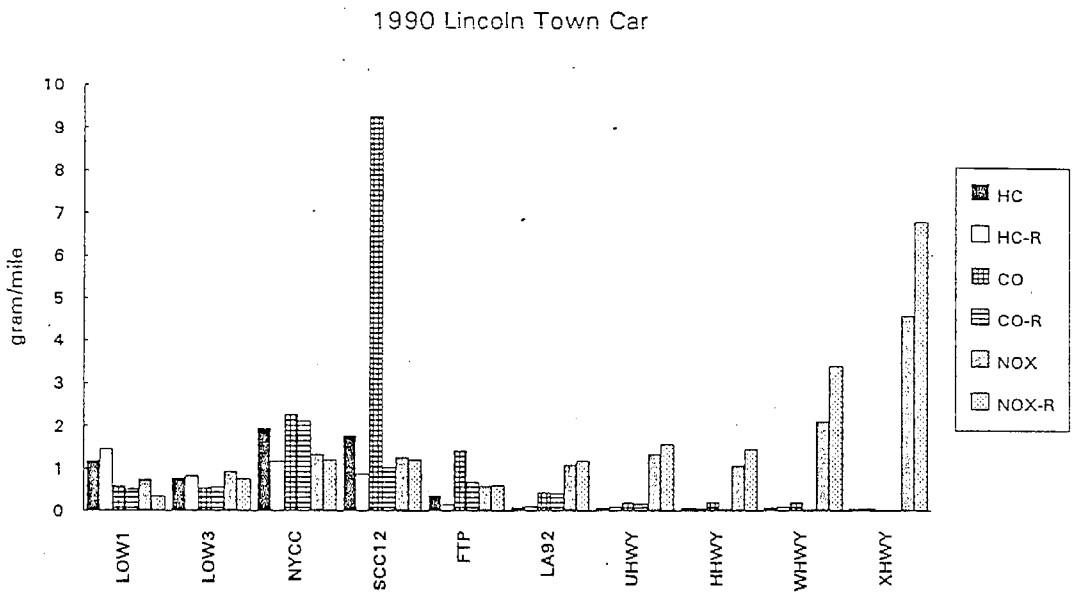

Figure 3.2.1a Repeatability of two test sequences at 75 F and Indolene (1990 Lincoln Town Car)

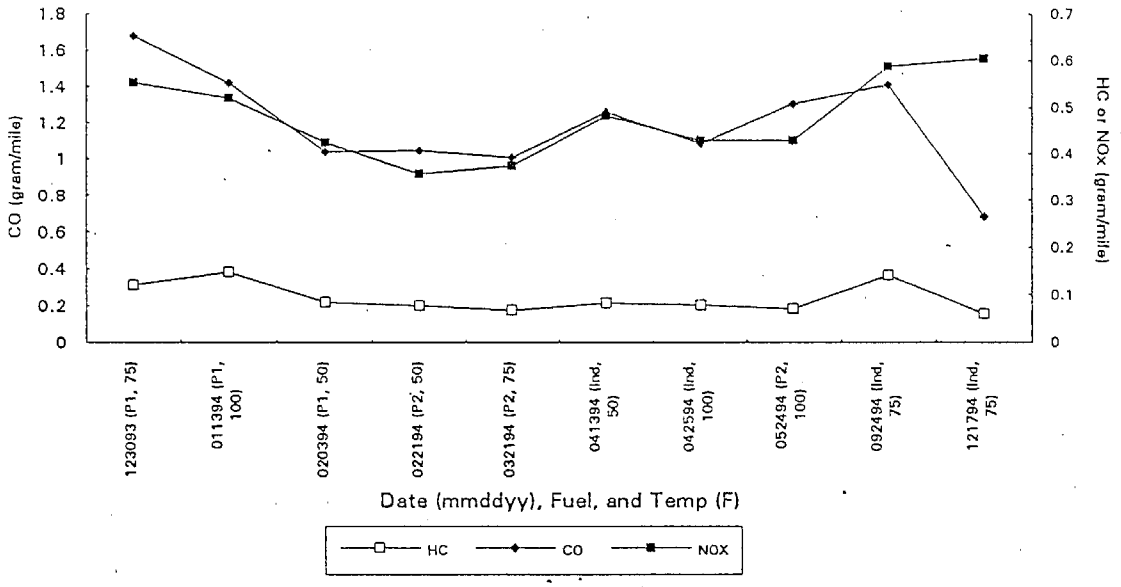

Figure 3.2.1b FTP drift with respect to date, fuel, and temperature (1990 Lincoln Town Car)

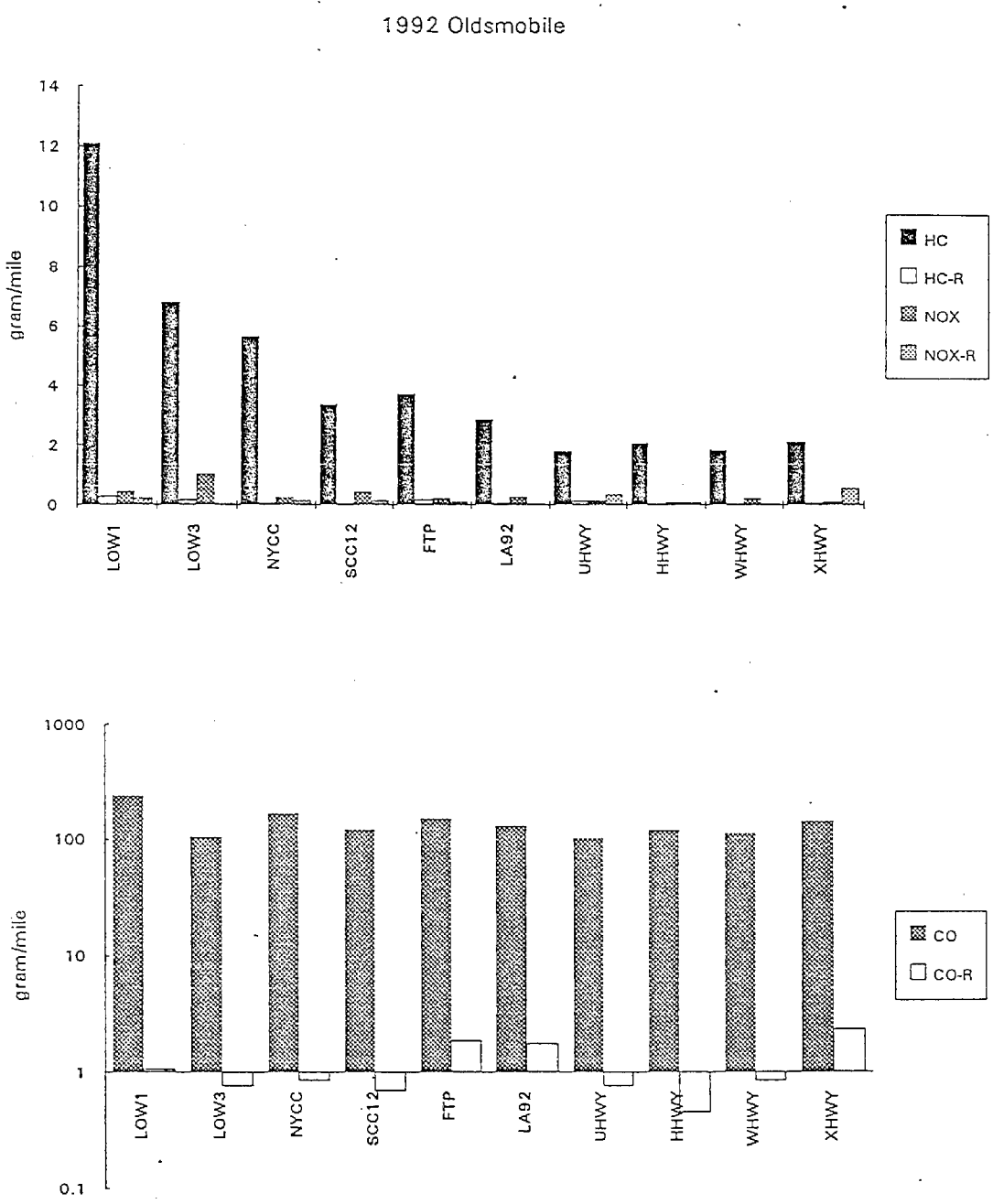

Figure 3.2.2a Repeatability of two test sequences at 75 F and Indolene (1992 Oldsmobile)

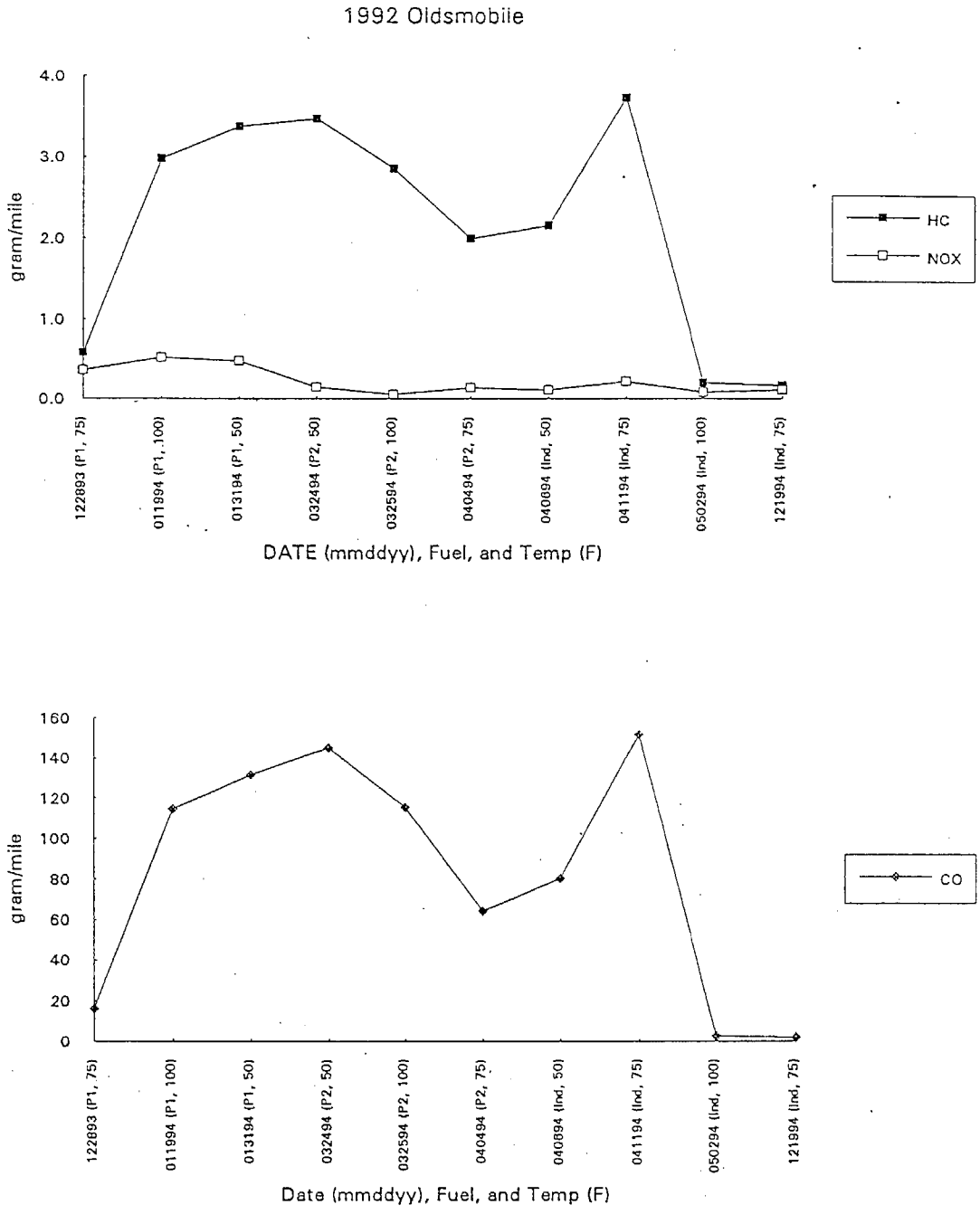

Figure 3.2.2b FTP drift with respect to date, fuel, and temperature (1992 Oldsmobile)

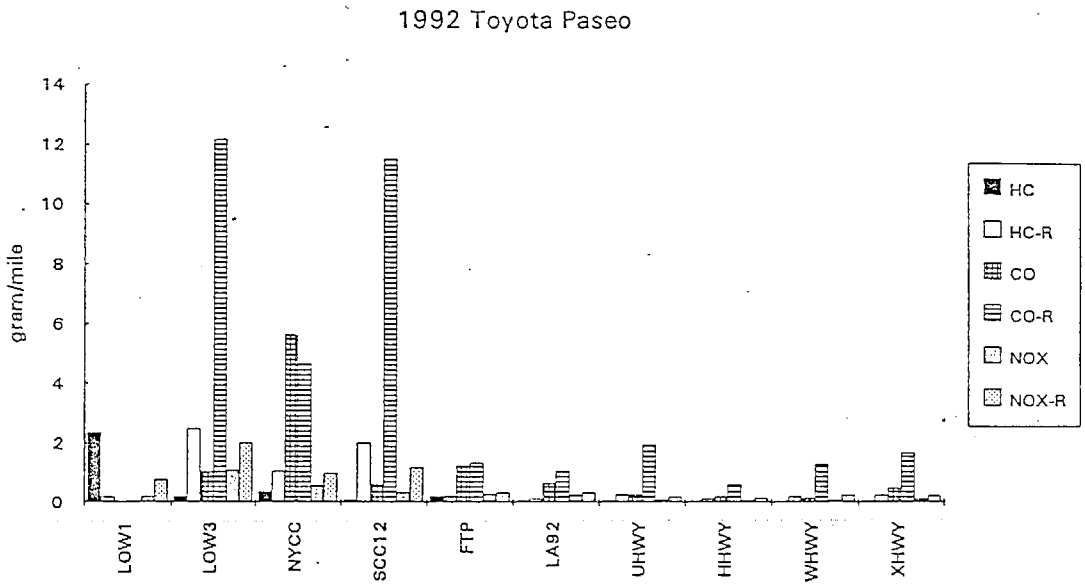

Figure 3.2.3a Repeatability of two test sequences at 75 F and Indolene (1992 Toyota Paseo)

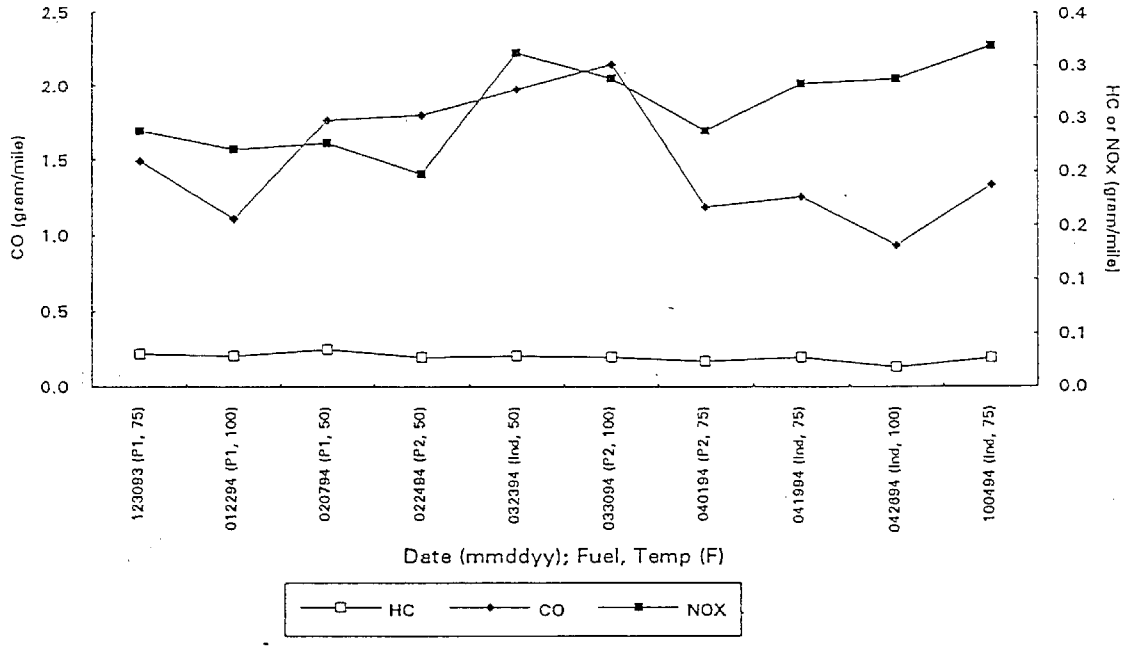

Figure 3.2.3b FTP drift with respect to date, fuel, and temperature (1992 Toyota Paseo)

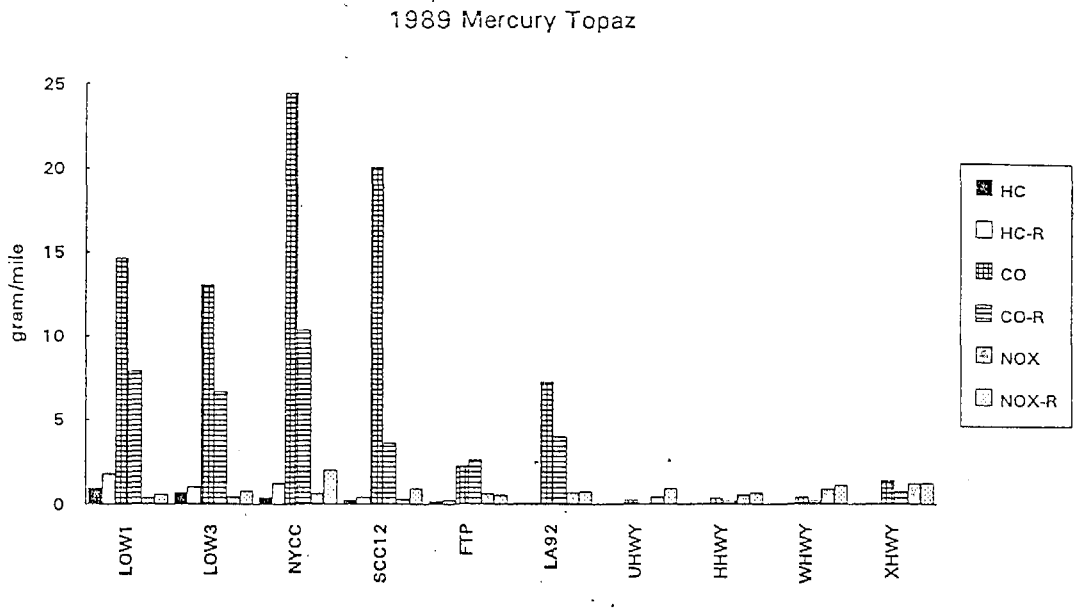

Figure 3.2.4a Repeatability of two test sequences at 75 F and Indolene (1989 Mercury Topaz)

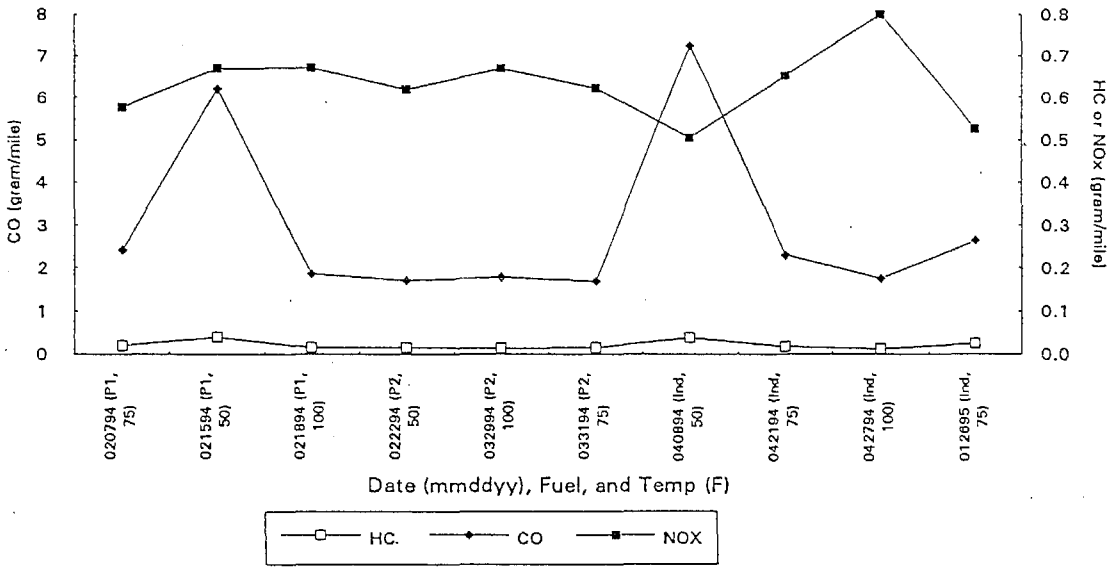

Figure 3.2.4b FTP drift with respect to date, fuel, and temperature (1989 Mercury Topaz)

other cycles in both sequences appeared to be repeatable (Figure 3.2.5a). Furthermore, both HC and NOx remained almost constant while CO experienced a slight fluctuation when the baseline was examined (Figure 3.2.5b).

When examining results from the 1985 Continental MRKVII, 1986 Cadillac De Ville, 1988 Dodge Daytona, and 1979 Chevrolet Impala, (see Figures 3.2.6 to 3.2.9) it appeared that HC, CO, and NOx were generally repeatable. In addition, the baseline of HC and NOx exhibited less variability when compared to CO during the course of testing. In general, CO was observed to fluctuate unpredictably and have higher variation than both HC and NOx.

There was a relatively large difference between the first and repeated sequences for HC, CO, and NOx when the 1982 Buick Regal was examined (Figure 3.2.10a). This phenomenon was also observed when examining the baseline (Figure 3.2.10b). Specifically, it was found that readings of HC, CO, and NOx from the last FTP were almost twofold higher than the previous nine FTP readings. This sudden increase in exhaust emissions may have been due to the fact that the vehicle stood idle for almost 7 months between the 9th and 10th sequences.

When the 1983 Honda was examined, it was observed that CO was not repeatable (Figure 3.2.11a). Examination of the baseline data suggested that HC and NOx remained almost constant while CO fluctuated during the course of testing (Figure 3.2.11b).

In short, except for a few vehicles, it was found that the baseline for HC and NOx emissions were relatively stable when compared with CO throughout the course

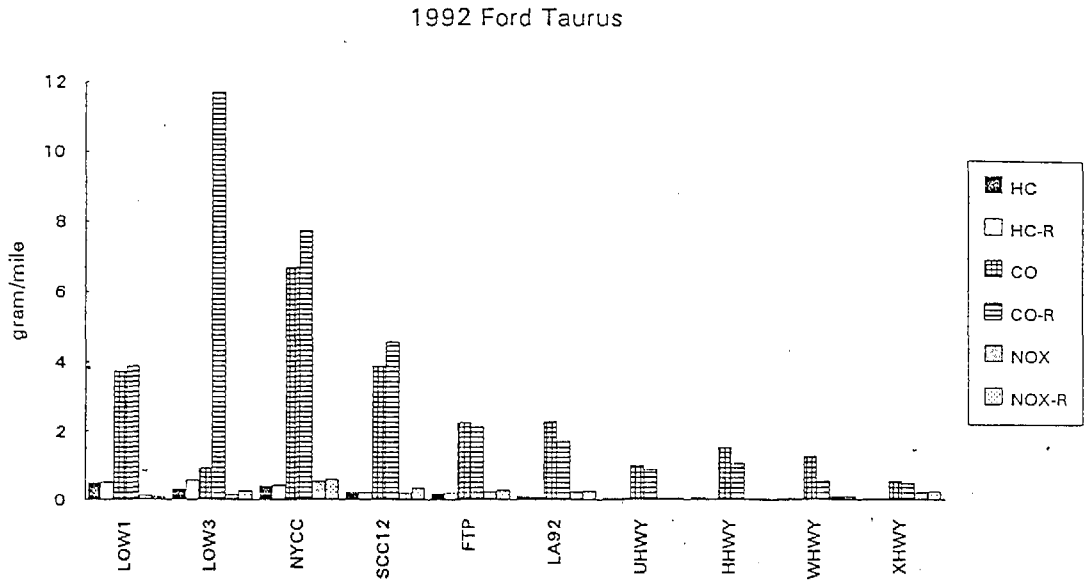

Figure 3.2.5a Repeatability of two test sequences at 75 F and Indolene (1992 Ford Taurus)

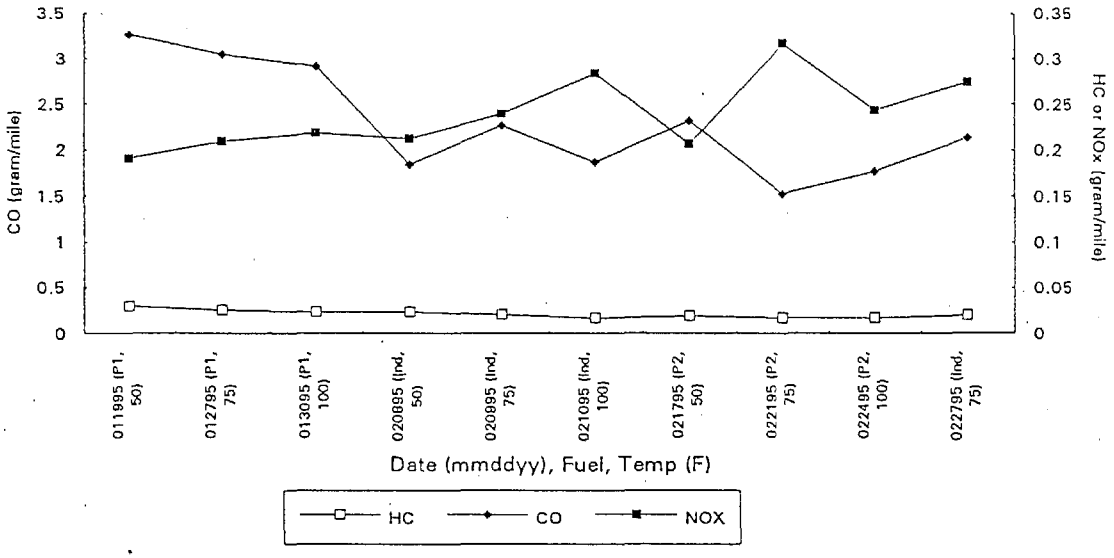

Figure 3.2.5b FTP drift with respect to date, fuel, and temperature (1992 Ford Taurus)

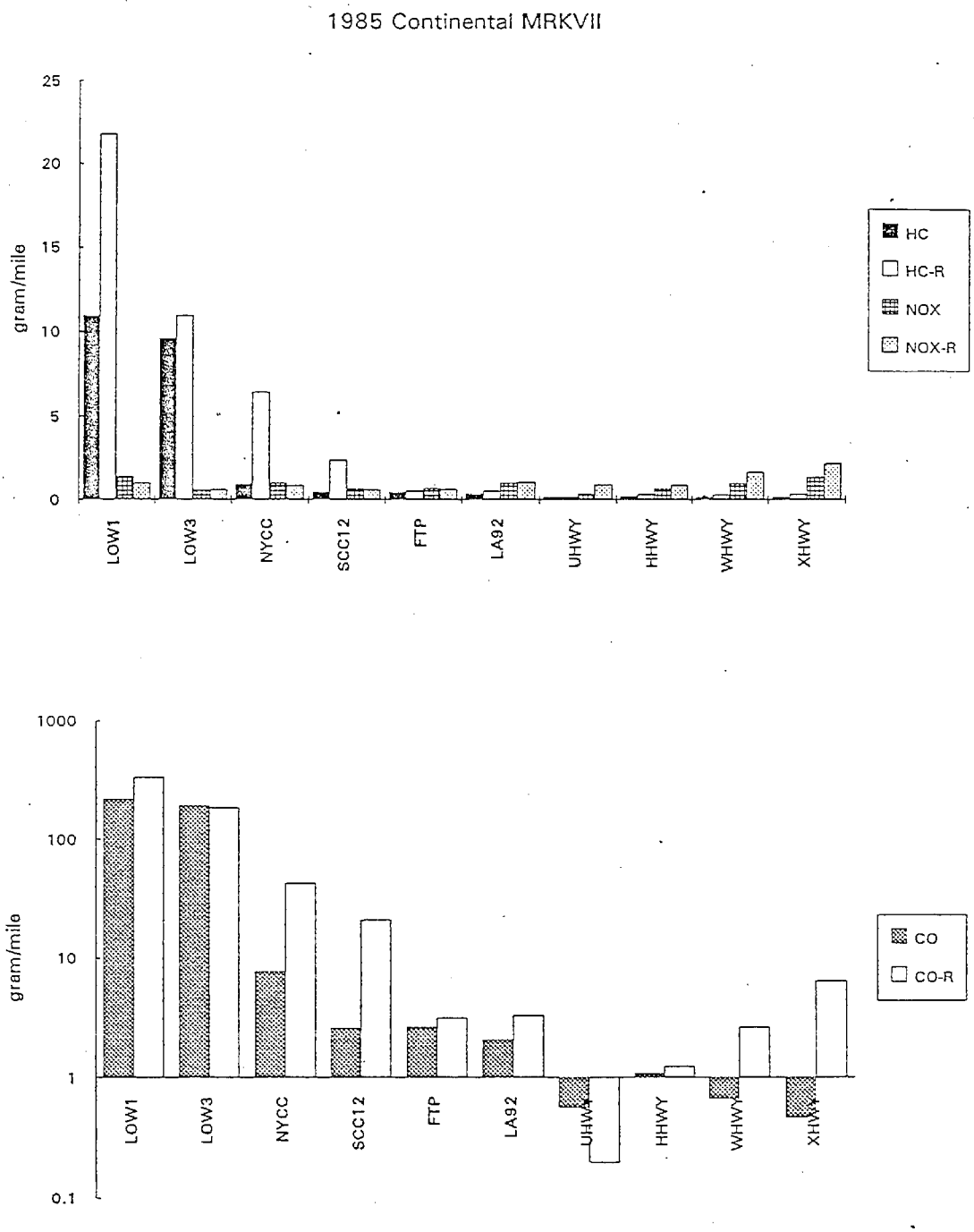

Figure 3.2.6a Repeatability of two test sequences at 75 F and Indolene (1985 Continental MRKVII)

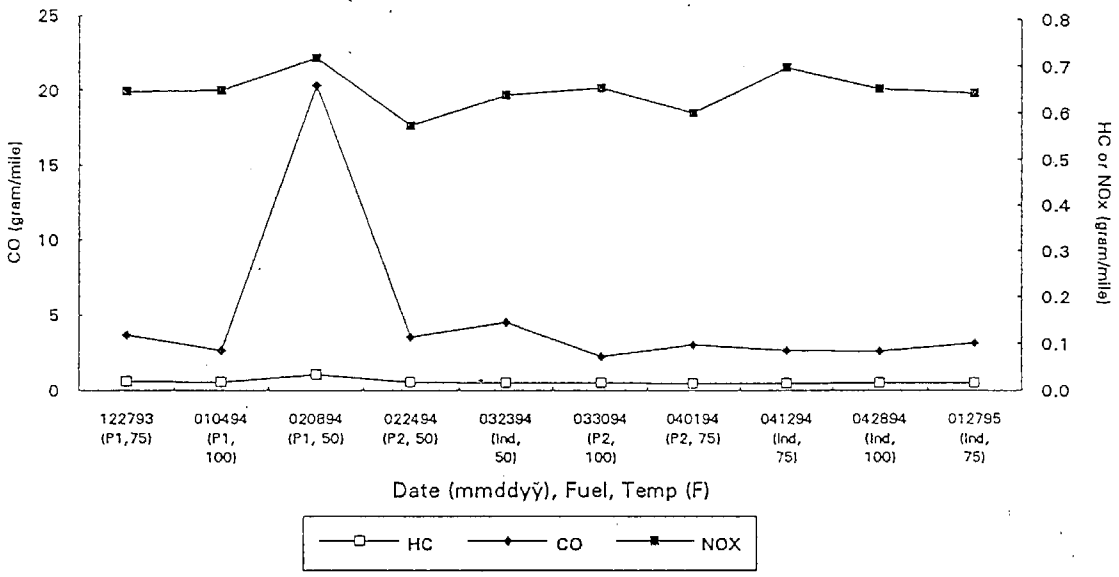

Figure 3.2.6b FTP drift with respect to date, fuel, and temperature (1985 Continental MRKVII)

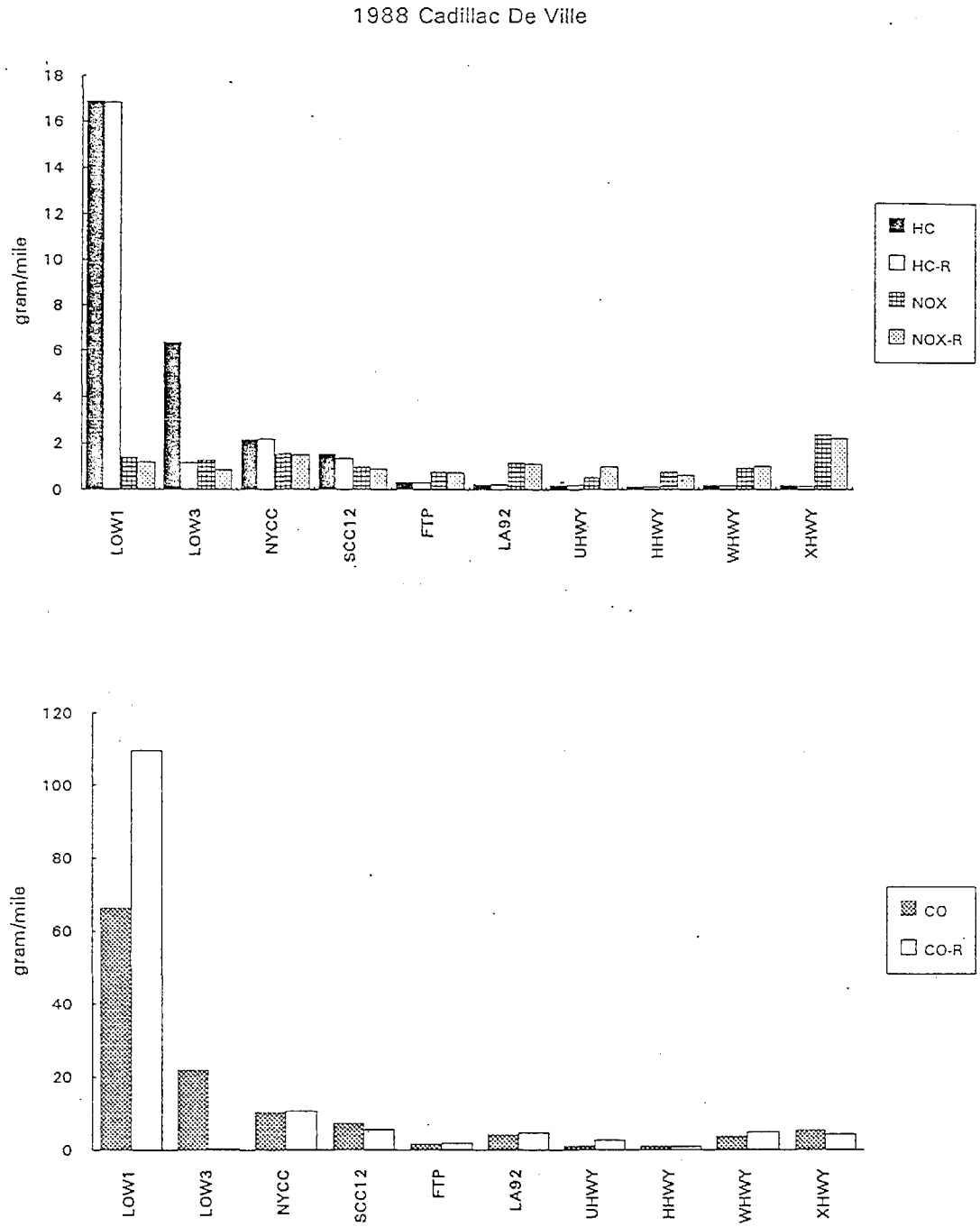

Figure 3.2.7a Repeatability of two test sequences at 75 F and Indolene (1988 Cadillac De Ville)

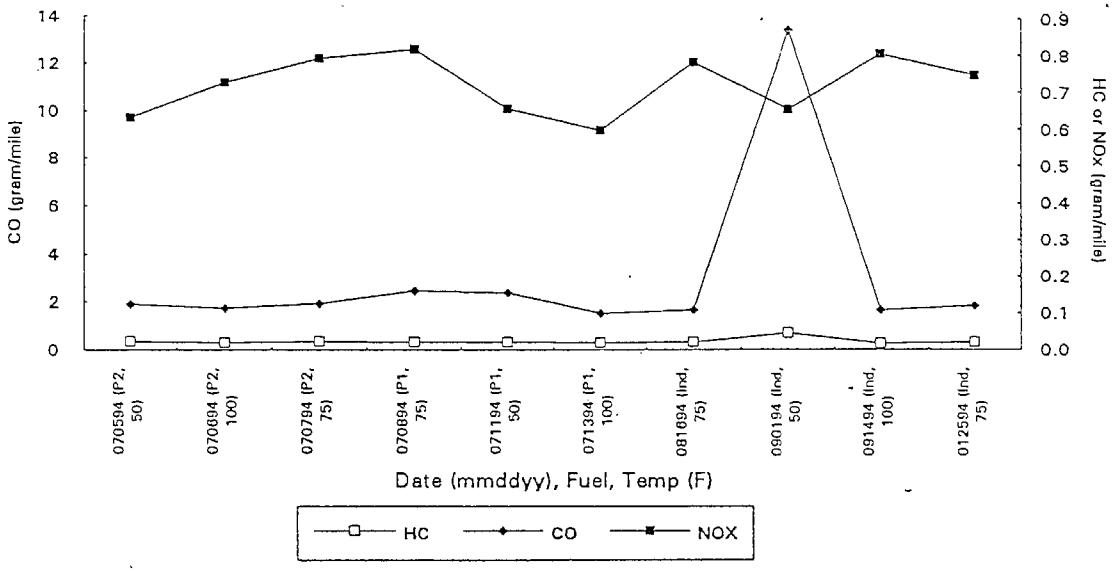

Figure 3.2.7b FTP drift with respect to date, fuel, and temperature (1988 Cadillac De Ville)

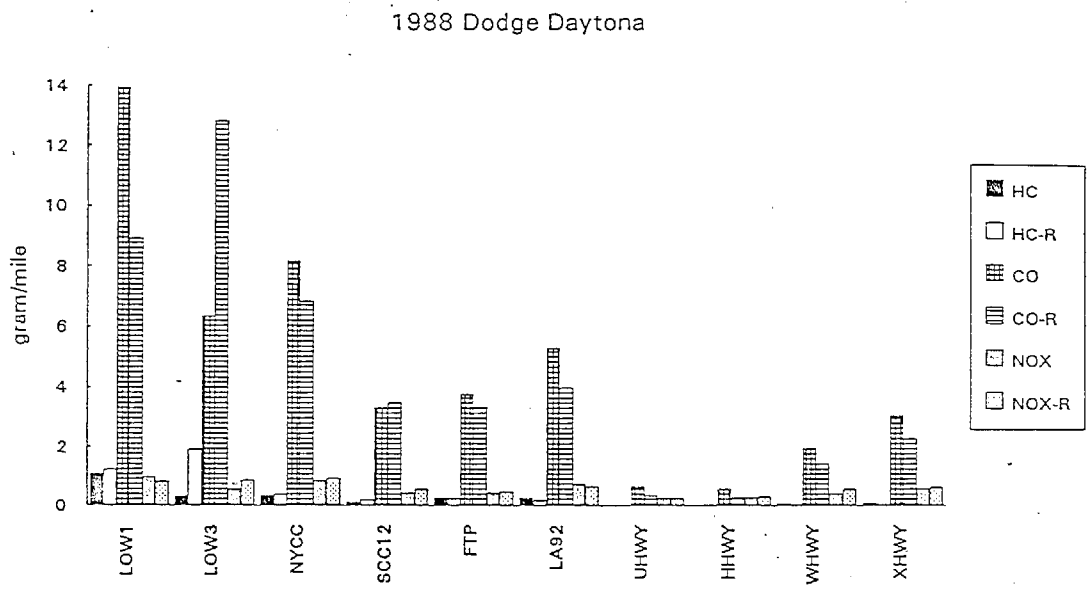

Figure 3.2.8a Repeatability of two test sequences at 75 F and Indolene (1988 Dodge Daytona)

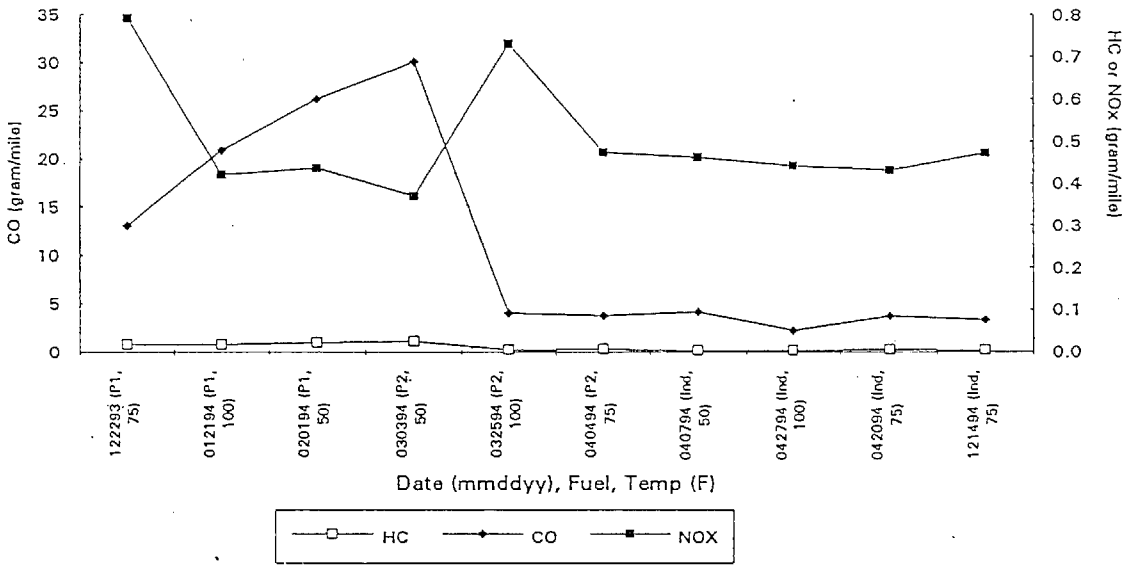

Figure 3.2.8b FTP drift with respect to date, fuel, and temperature (1988 Dodge Daytona)

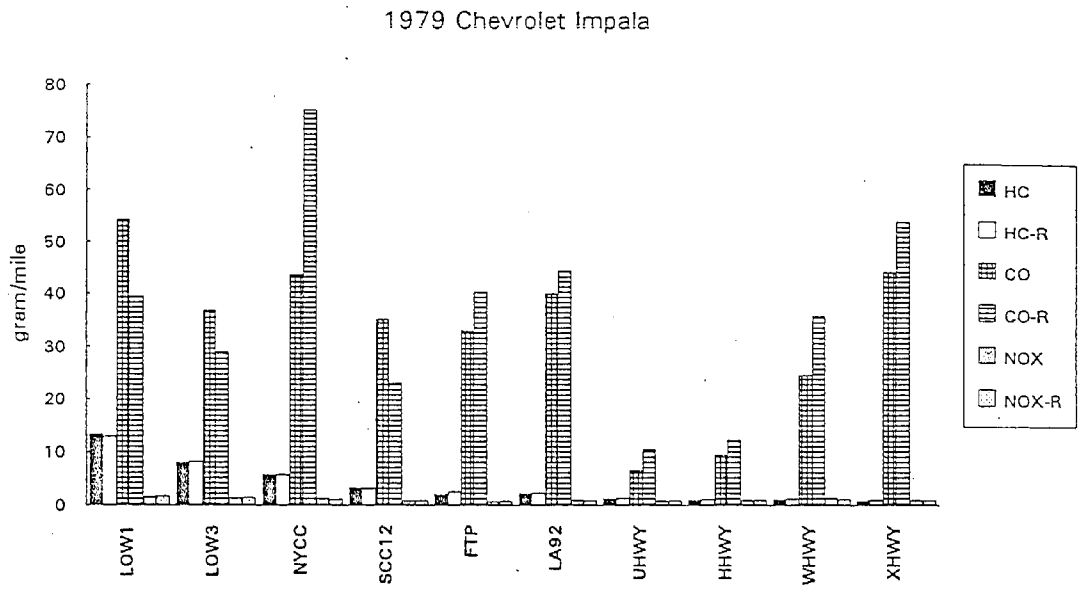

Figure 3.2.9a Repeatability of two test sequences at 75 F and Indolene (1979 Chevrolet Impala)

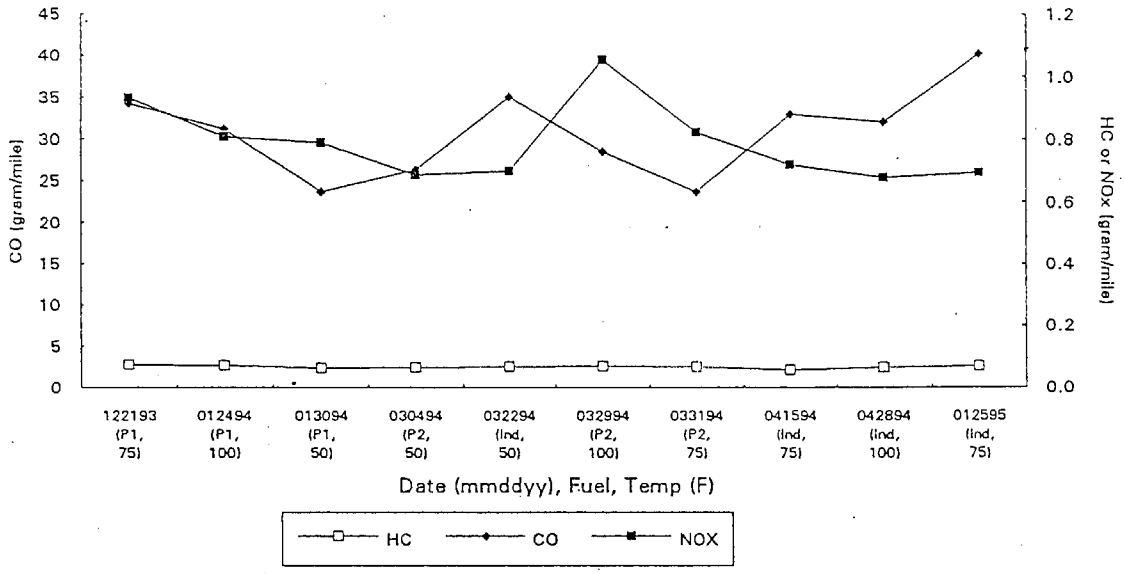

Figure 3.2.9b FTP drift with respect to date, fuel, and temperature (1979 Chevrolet Impala)

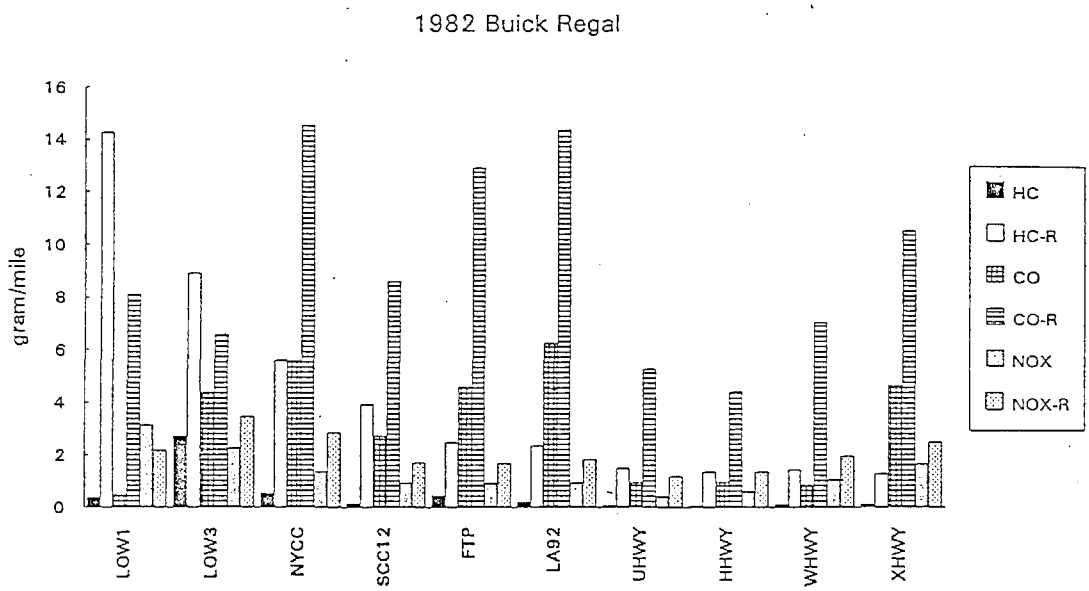

Figure 3.2.10a Repeatability of two test sequences at 75 F and Indolene (1982 Buick Regal)

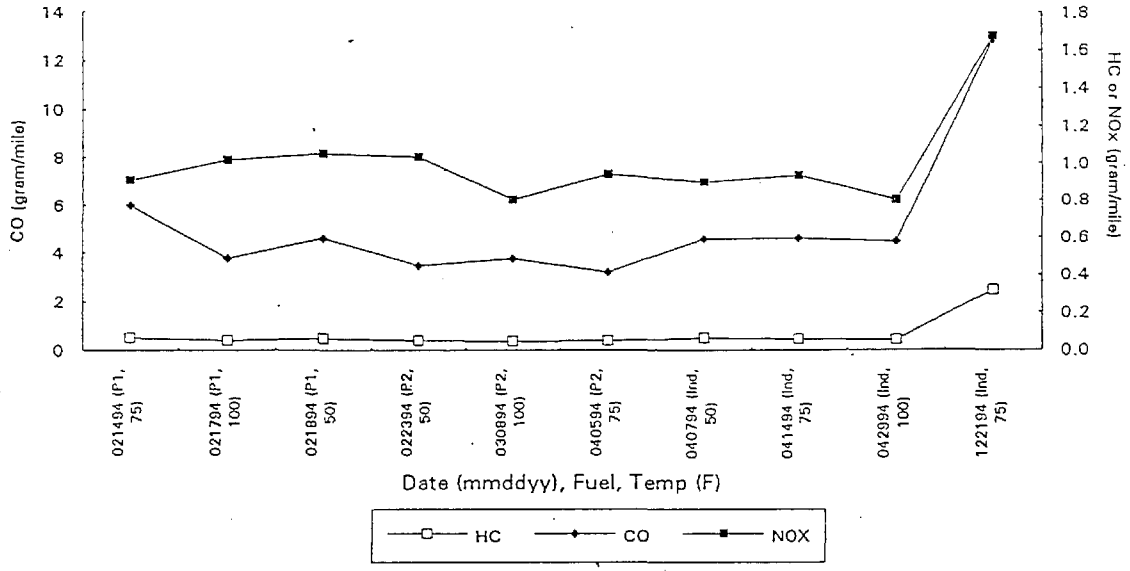

Figure 3.2.10b FTP drift with respect to date, fuel, and temperature (1982 Buick Regal)

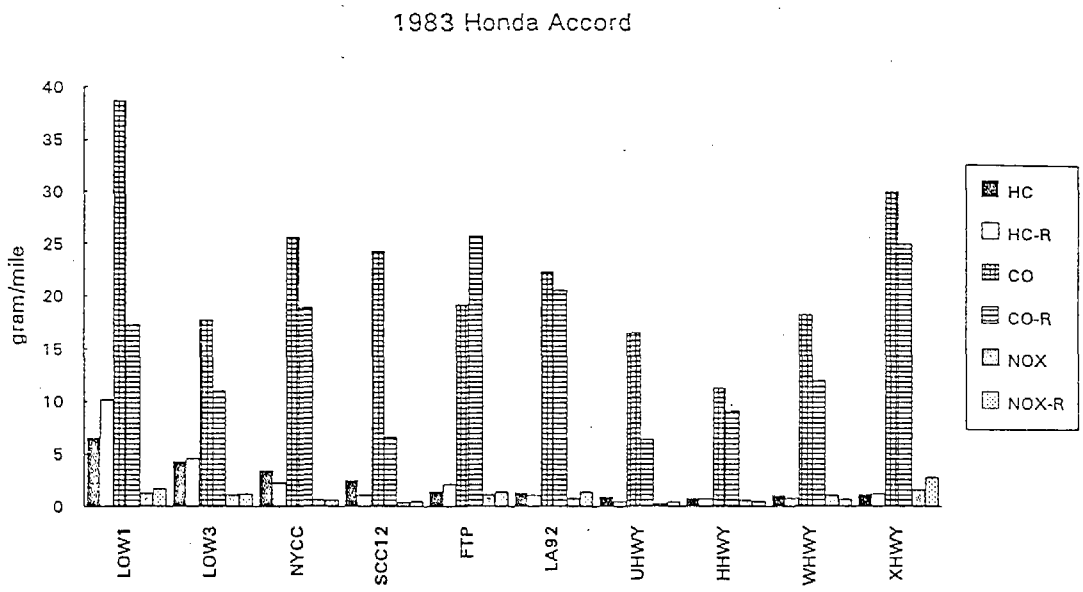

Figure 3.2.11a Repeatability of two test sequences at 75 F and Indolene (1983 Honda Accord)

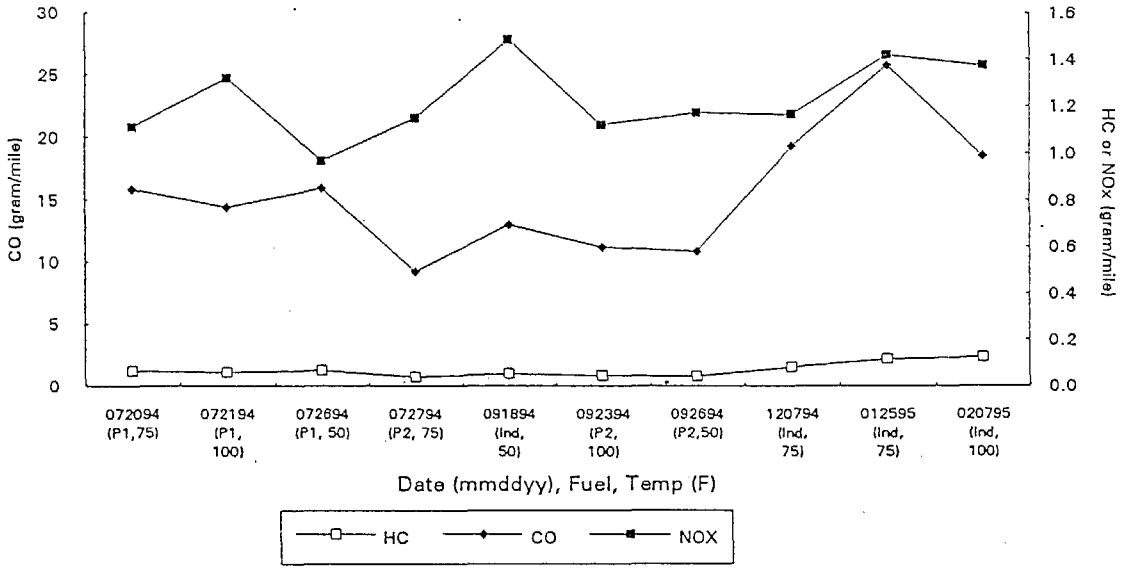

Figure 3.2.11b FTP drift with respect to date, fuel, and temperature (1983 Honda Accord)

of testing. In addition, CO tend to fluctuate unpredictably when compared to HC and NOx.

Student paired t-tests were employed to investigate repeatability of the sequences. The paired-t test was based upon the differences between each test in first and repeated sequences, in particular, to check whether these differences were equal to zero. The null and alternative hypotheses tested were as follows:

Ho: The mean difference in exhaust emissions between two test sequences = 0

Ha: The mean difference in exhaust emissions between two test sequences $\neq 0$

where α=0.05

The results in terms of p-values were presented in Table 3.2.1. It was found that, as expected, CO and HC emissions from the 1992 Oldsmobile were statistically different due to the oxygen sensor replacement. NOx emissions from the 1992 Toyota Paseo and CO emissions from the 1983 Honda Accord were also found to be statistically different. As for the 1989 Mercury Topaz and the 1982 Buick Regal, it was found that HC, CO, and NOx for both vehicles were not repeatable. This suggests that HC, CO, and NOx may be independent of each other for certain vehicles. Thus, if one of the exhaust pollutants did not meet the emission standards, it does not imply that the other exhaust pollutants failed the emission standards.

In general, except for the 1992 Oldsmobile (p-value = 0.00259), 1989 Mercury Topaz (p-value = 0.0480) and 1982 Buick Regal (p-value = 0.0135), HC and NOx

Table 3.2.1 Comparison of two test sequences (75 F and Indolene). The following table summarizes the level of significance (p-value) based on t-Test: Paired two-sample for means.*

Vehicles	HC	CO	NOx
1990 Lincoln Town Car	0.22620	0.26844	0.20475
1992 GM Oldsmobile	0.00259	0	0.24265
1992 Toyota Paseo	0.39054	0.54438	0.01320
1989 Mercury Topaz	0.04880	0.03593	0.04190
1992 Ford Taurus	0.43301	0.36160	0.11200
1985 Continental MRK VII	0.10323	0.18106	0.23127
1986 Cadillac De Ville	0.30190	0.66366	0.38076
1988 Dodge Daytona	0.31140	0.71685	0.28441
1979 Chevrolet Impala	0.67448	0.41427	0.06320
1982 Buick Regal	0.01350	0.00001	0.00564
1983 Honda Accord*	0.85465	0.01969	0.16893

*Ho: The mean difference in exhaust emissions between two test sequences is equal to 0.
Ha: The mean difference in exhaust emissions between two test sequences is unequal to 0.

emissions for the remaining eight vehicles were repeatable. Similarly, except for the 1992 Oldsmobile (p-value = 0) and 1982 Buick Regal (p-value = 0), 1989 Mercury Topaz (p-value = 0.0359), and 1983 Honda Accord (p-value = 0.0197), CO emissions for the remaining seven vehicles were repeatable.

Two possible reasons that the repeated sequences were not comparable to the initial sequence are emission component deterioration and test-to-test variability. Nevertheless, this is a practical problem in vehicle testing and suggests that in future vehicle testing, it is imperative to minimize waiting periods between testing.

3.3 Principal Component Analysis

Principal component analysis (PCA) is considered to be an exploratory statistical technique that may be useful in gaining a better understanding of the interrelationships among many variables and is generally performed to simplify the description of a set of interrelated variables. In principal component analysis, the original variables are treated equally, that is, they are not divided into dependent and independent variables; instead, original variables are transformed into new uncorrelated variables. These new variables are called principal components. Each principal component is a linear combination of the original variables. One way to measure the information of each principal component is its variance. For this reason, the principal components are arranged in order of decreasing variance. Therefore, the most informative principal component is the first, and the least informative is the last.

In the present data analysis, we were interested in discovering the correlation

among variables such as fuel, temperature, speed, mileage, model year, number of cylinders, engine displacement, HC, CO, and NOx exhaust emissions. Since all variables must be numerical, the Reid Vapor Pressure (RVP) of each fuel was used to quantify the fuel variables. As mileage and model year, as well as number of cylinders and engine displacement, were correlated to each other, the number of cylinders and model year were excluded from the analysis to simplify the PCA.

The PCA was performed on all 11 vehicles as a group. The correlation matrix in Table 3.3.1 shows the correlation among all the variables in the PCA. It was found that HC correlated highly to CO (0.7461), correlated negatively to speed (-0.3840), and correlated positively to the engine displacement (0.2594). In addition, CO was positively correlated to HC (0.7461) and engine displacement (0.1926), while negatively correlated to speed (-0.1754). Further, NOx was found to be correlated to the mileage of the vehicle (0.5026), negatively correlated to engine displacement (0.1732), and negatively correlated to speed (-0.1273).

Table 3.3.2 reveals all eight principal components. Each principal component was evaluated as to whether or not it made sense from the perspective of vehicle engineering principles. In general, PCA attempts to summarize the data with a linear combination of all variables, and typically the first few principal components account for the most of the variance and afford the most useful information. The eigenvectors, or coefficients, in each principal component, also provide us with information on the weight of each variable in the linear model.

The first principal component suggested that the most useful information in

Table 3.3.1 Correlation matrix of principal component analysis

	Speed	Temp	Fuel	HC	CO	NOx	Mileage	Eng. Displ.
Speed	1.0000	0.0000	0.0000	-0.3840	-0.1754	-0.1273	0.0000	0.0000
Temp	0.0000	1.0000	-0.0172	0.0081	0.0037	0.0316	0.0168	-0.0028
Fuel	0.0000	-0.0172	1.0000	0.0003	-0.0095	0.0182	0.0185	-0.0031
HC	-0.3840	0.0081	0.0003	1.0000	0.7461	0.2160	0.2364	0.2594
CO	-0.1754	0.0037	-0.0095	0.7461	1.0000	-0.0340	-0.0805	0.1926
NOx	-0.1273	0.0316	0.0182	0.2160	-0.0340	1.0000	0.5026	0.1732
Mileage	0.0000	0.0168	0.0185	0.2364	-0.0805	0.5026	1.0000	0.4020
Eng. Displ.	0.0000	-0.0028	-0.0031	0.2594	0.1926	0.1732	0.4020	1.0000

Table 3.3.2 Eigenvalues of the correlation matrix

Principal Component	Eigenvalue	Difference	Proportion	Cumulative
Principal Component 1	2.1809	0.6324	0.2726	0.2726
Principal Component 2	1.5485	0.5311	0.1936	0.4662
Principal Component 3	1.0174	0.0123	0.1272	0.5934
Principal Component 4	1.0051	0.0347	0.1256	0.7190
Principal Component 5	0.9703	0.2848	0.1213	0.8403
Principal Component 6	0.6856	0.2515	0.0857	0.9260
Principal Component 7	0.4341	0.2759	0.0543	0.9802
Principal Component 8	0.1582	n.a.	0.0198	1.0000

Table 3.3.3 Eigenvectors of principal component analysis

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Speed	-0.2924	0.2478	0.0259	0.5580	0.4287	0.5676	0.0194	0.1863
Temp	0.0184	0.0343	-0.7327	-0.3544	0.5766	-0.0598	-0.0077	0.0026
Fuel	0.0061	0.0407	0.6771	-0.4590	0.5730	-0.0272	0.0071	-0.0004
HC	0.5874	-0.2856	0.0056	-0.0012	0.0185	0.1899	-0.2020	0.7044
CO	0.4412	-0.4900	0.0131	0.2089	0.1943	0.2911	0.0822	-0.6263
NOx	0.3326	0.4693	-0.0386	-0.3066	-0.2237	0.4285	0.5824	-0.0298
Mileage	0.3556	0.5714	0.0089	0.0325	-0.0192	0.0276	-0.6873	-0.2689
Eng. Displ.	0.3707	0.2595	0.0473	0.4622	0.2587	-0.6069	0.3747	0.0607

depicting the dataset was: speed, HC, CO, NOx, mileage, and engine displacement. When interpreting this physically, it is true that HC, CO, and NOx could be inversely related to speed especially for cycles of low average speed. In addition, it is generally true that the higher the vehicle's mileage, the greater the exhaust emissions.

The second principal component indicated that HC and CO emissions were also inversely related to the speed. However, no more useful information can be drawn from the second principal component. When the third principal component was considered, it suggested that fuel and temperature were inversely related to each other. Since temperature and fuel are independent variables in this study, there was no correlation between them and this suggests that the PCA may not be providing useful information beyond the second principal component.

In short, only the first principal component and correlation matrix provides some useful information in this data analysis for it supports the relative importance of speed to fuel and temperature concerning HC, CO, and NOx exhaust emissions.

3.4 Analysis of Variance

The objective of this analysis was to detect any synergistic effects among speed, temperature, and fuel factors as well as to discover the relative significance of these three factors for exhaust emissions. Analysis of variance (ANOVA) with $\alpha = 0.05$ was used to examine the main and interaction effects of speed, temperature, and fuel on exhaust emissions. Note that only 980 tests were used for data analysis as ten tests from the Oldsmobile were eliminated due to oxygen sensor malfunctioning.

Table 3.4.1 ANOVA table for three-level study.*

Source	Sum of Square (SS)	Degree of Freedom (DF)	Mean Square (MS)
Main Effect			
Speed (A)	SSA	9	MSA = SSA/9
Temperature(B)	SSB	2	MSB = SSB/2
Fuel (C)	SSC	2	MSC = SSC/2
Vehicle (D)	SSD	10	MSD = SSD/10
Interaction Effect			
Speed*Temp (A*B)	SSAB	18	MSAB = SSAB/18
Temp*Fuel (B*C)	SSBC	4	MSBC = SSBC/4
Fuel*Speed (C*A)	SSCA	18	MSCA = SSSCA/18
Speed*Temp*Fuel (A*B*C)	SSABC	36	MSABC = SSABC/36
Total	TSS	99	

*Based on the SAS program
HC CO NOx = Veh Speed Temp Fuel Speed* Fuel Speed *Temp Fuel*Temp Fuel*Speed*Temp

Since the data matrix does not include all the data, an unbalanced ANOVA was employed.

Table 3.4.1 outlines the three-way ANOVA table. This analysis was performed on each technology group and all eleven vehicles combined to explore the relative contribution of speed, temperature, fuel, and their interaction terms on the emission rates.

This complete database was analyzed with Statistical Application System (SAS) software and based on the PROC GLM from SAS:

HC CO NOx = Veh Speed Temp Fuel Speed*Fuel Speed*Temp Fuel*Temp Speed*Temp*Fuel

where HC, CO and NOx were dependent variables while vehicle, speed, cycle, temperature, fuel, speed*fuel, speed*temp, fuel*temp, and speed*temp*fuel were independent variables or factors. The test hypotheses were as follows:

Ho: The effect due to each factor = 0

Ha: The effect due to each factor $\neq 0$

where α=0.05

For example,

$$Ho : \text{All (speed*temp)ij} = 0$$

$$Ha : \text{All (speed*temp)ij} \neq 0$$

Emissions data were analyzed using ANOVA by technology group as well as all vehicles as an aggregate. Table 3.4.2 summarizes the p-values with respect to the major and interaction terms. In the MPFI group, speed and vehicle were the significant factors for HC, CO, and NOx, while fuel was significant for NOx. Moreover, it was observed that the interaction term temp*fuel was significant for HC and CO. It was found that in the TBI group, vehicle and cycle were the significant factors for HC, CO, and NOx, while temperature was a significant factor for NOx. When CARBU was examined, it was concluded that speed was the significant factor for HC, CO, and NOx while vehicle was the significant factor for HC and CO, and fuel was a significant factor for CO.

When all 11 vehicles were considered, it became clear that speed and vehicle were the significant factors for HC, CO and NOx emissions, while fuel was a significant factor for NOx only. In summary, all interaction terms in three technology groups as well as all eleven vehicles as an aggregate were not statistically significant, except in the MPFI group where the temp*fuel term was significant for HC and CO.

The effect of ambient temperature on tailpipe exhaust emissions appeared to be negligible. This may be due to the vehicles being preconditioned or "warmed up"

Table 3.4.2 The following summarizes the level of significance (p-value) based on analysis of variance on vehicle, speed, fuel, temperature, and interaction terms.

MPFI

Source	HC p-value	CO p-value	NOx p-value
TEMP	0.8595	0.8021	0.0975
SPEED	0.0001	0.0002	0.0001
FUEL	0.7803	0.4431	0.0055
VEH	0.0001	0.0001	0.0001
TEMP*SPEED	0.9998	0.9416	0.7180
TEMP*FUEL	0.1828	0.0440	0.0803
SPEED*FUEL	0.9990	0.8388	0.7001
TEMP*SPEED*FUEL	0.9982	0.3619	0.9697

TBI

Source	HC p-value	CO p-value	NOx p-value
TEMP	0.7926	0.5496	0.0112
SPEED	0.0001	0.0001	0.0001
FUEL	0.2279	0.3466	0.2700
VEH	0.0001	0.0001	0.0001
TEMP*SPEED	0.9942	0.9787	0.9469
TEMP*FUEL	0.8496	0.7344	0.0631
SPEED*FUEL	0.8024	0.9941	0.9996
TEMP*SPEED*FUEL	1.0000	0.9999	0.9396

CARBU

Source	HC p-value	CO p-value	NOx p-value
TEMP	0.6068	0.1013	0.8847
SPEED	0.0001	0.0001	0.0001
FUEL	0.6040	0.0022	0.8019
VEH	0.0001	0.0001	0.0772
TEMP*SPEED	1.0000	0.8521	0.8452
TEMP*FUEL	0.7187	0.5124	0.6844
SPEED*FUEL	0.9998	0.9800	0.8838
TEMP*SPEED*FUEL	1.0000	1.0000	0.9996

ALL VEHICLES

Source	HC p-value	CO p-value	NOx p-value
TEMP	0.7691	0.4867	0.3603
SPEED	0.0001	0.0001	0.0001
FUEL	0.2609	0.5059	0.0267
VEH	0.0001	0.0001	0.0001
TEMP*SPEED	1.0000	1.0000	0.8477
TEMP*FUEL	0.9646	0.9277	0.6235
SPEED*FUEL	0.9758	1.0000	0.4342
TEMP*SPEED*FUEL	1.0000	1.0000	0.9999

prior to each test, thus enabling the catalyst to attain operating temperature. In general, if the vehicles were tested without preconditioning (cold-start), the ambient temperature was likely to have an impact during the cold-start emissions since the catalyst is temperature sensitive as discussed in Sections 3.1.7 and 3.1.9 above. Moreover, ambient temperature has a greater impact on running and evaporative HC losses from the fuel delivery system.

Speed and vehicle are clearly the dominant factors in exhaust emissions modeling. Each vehicle has its unique fuel delivery system, mileage, engine design, and maintenance/repair record, as well as other factors. All these factors may affect the emissions from vehicles to a certain degree. The LOW1 and LOW3 cycles comprise many abrupt stops with sharp accelerations and decelerations. Conversely, cycles such as UHWY, HHWY, WHWY, and XHWY simulate highway driving conditions characterized by relatively high speeds. Rich open-loop or "off-cycle" operations take place in the region of high acceleration, deceleration, and speed. This is a probable explanation for the observation that HC, CO, and NOx emissions tended to increase at the low and high ends of the average speed domain.

To summarize the overall temperature, fuel, and speed effects on exhaust emissions, they were plotted in the following figures. Figure 3.4.1 presents the population means of HC, CO, and NOx emissions based on all tests conducted at 50 F, 75 F, and 100 F, respectively. It indicates that the effect of temperature on exhaust emissions is minimal. Similarly, Figure 3.4.2 illustrates the population means of HC, CO, and NOx emissions based on all tests conducted with Phase 1, Phase 2,

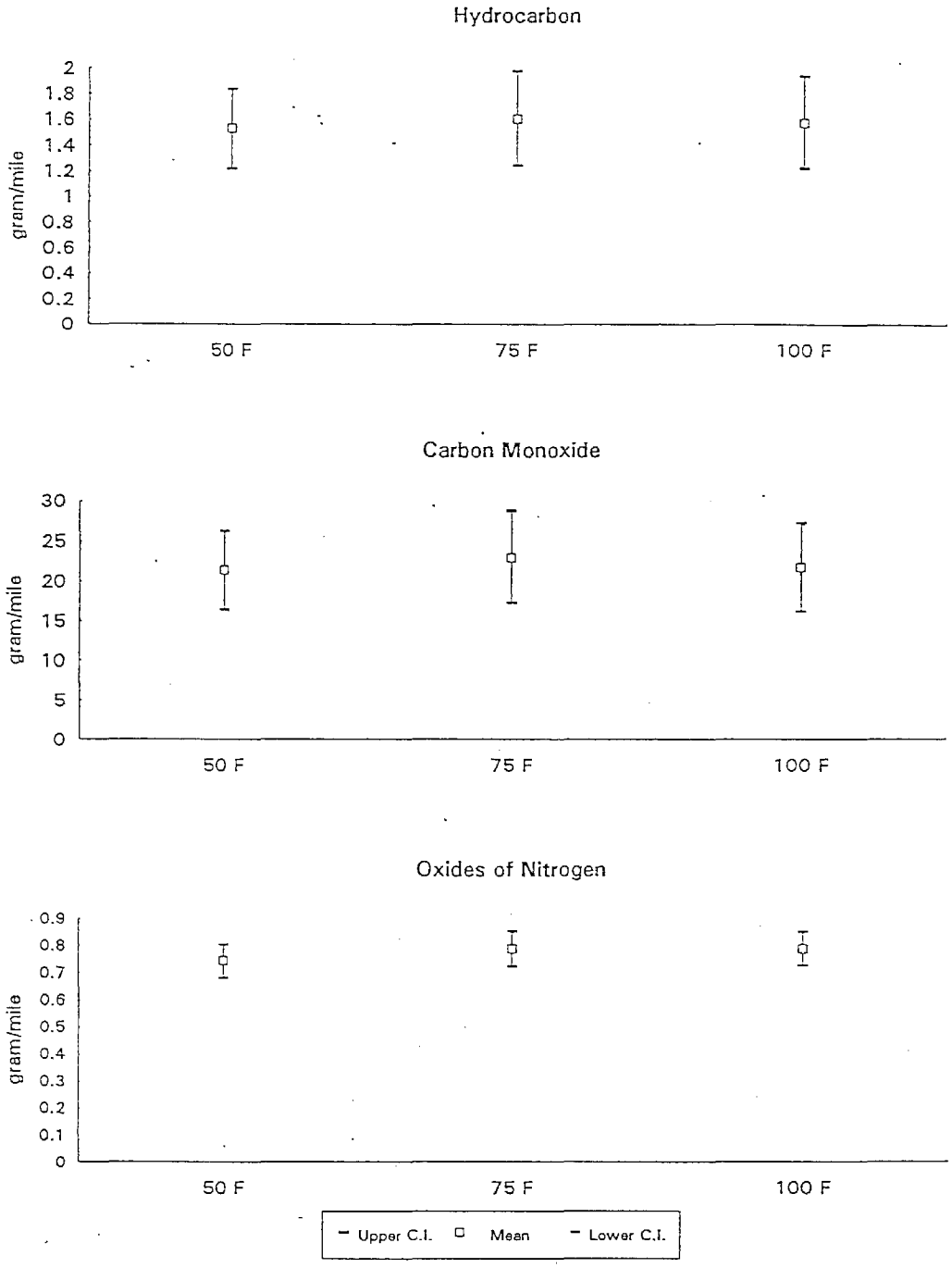

Figure 3.4.1 Comparison of temperature effects on exhaust emissions. Each interval represents 95% confidence interval of the population mean.

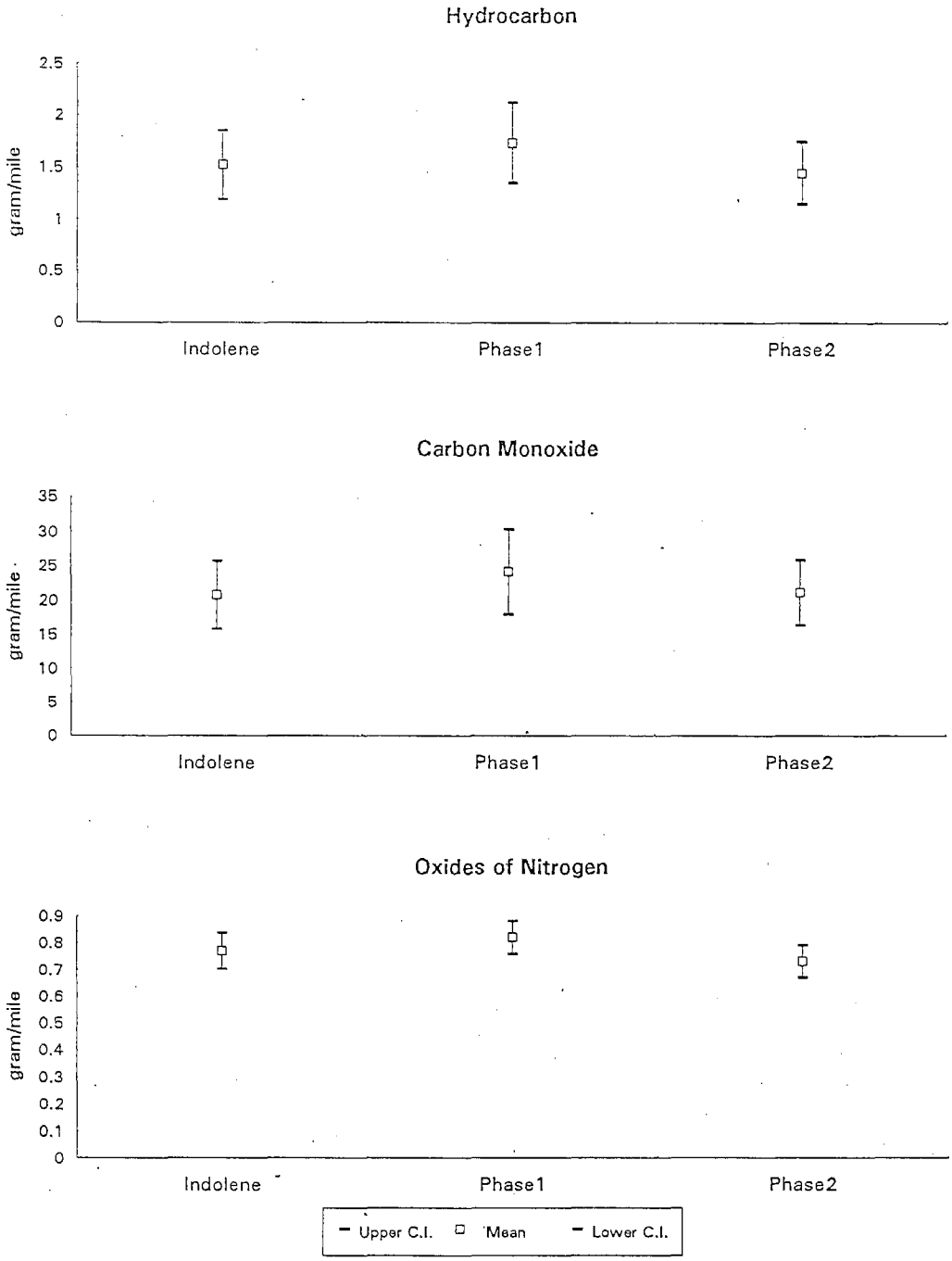

Figure 3.4.2 Comparison of fuel effects on exhaust emissions.
Each interval represents 95% confidence interval of the population mean.

and Indolene. It suggests the population mean of Phase 1 fuel is higher than both Indolene and Phase 2 fuels. Finally, Figure 3.4.3 displays the population mean of HC, CO, and NOx emissions based on all tests conducted at the ten speed cycles. It indicates that HC and CO emissions have high variation at lower speeds because of the wider confidence interval. More importantly, it is clear that HC, CO, and NOx exhaust emissions are strong functions of the average speed of the cycle.

As discussed more fully in the next section, two main drawbacks of this study were the small sample size and lack of repeat tests. Since the test-to-test error and vehicle-to-vehicle variation constituted a large fraction of the overall uncertainty, it requires a large sample size to detect subtle interactive effects. Therefore, in the present study, it was difficult to detect subtle interactive effects hidden in the "noise." Despite the small sample size and lack of repeat tests, this present study demonstrated the importance of speed and vehicle type in exhaust emissions modeling.

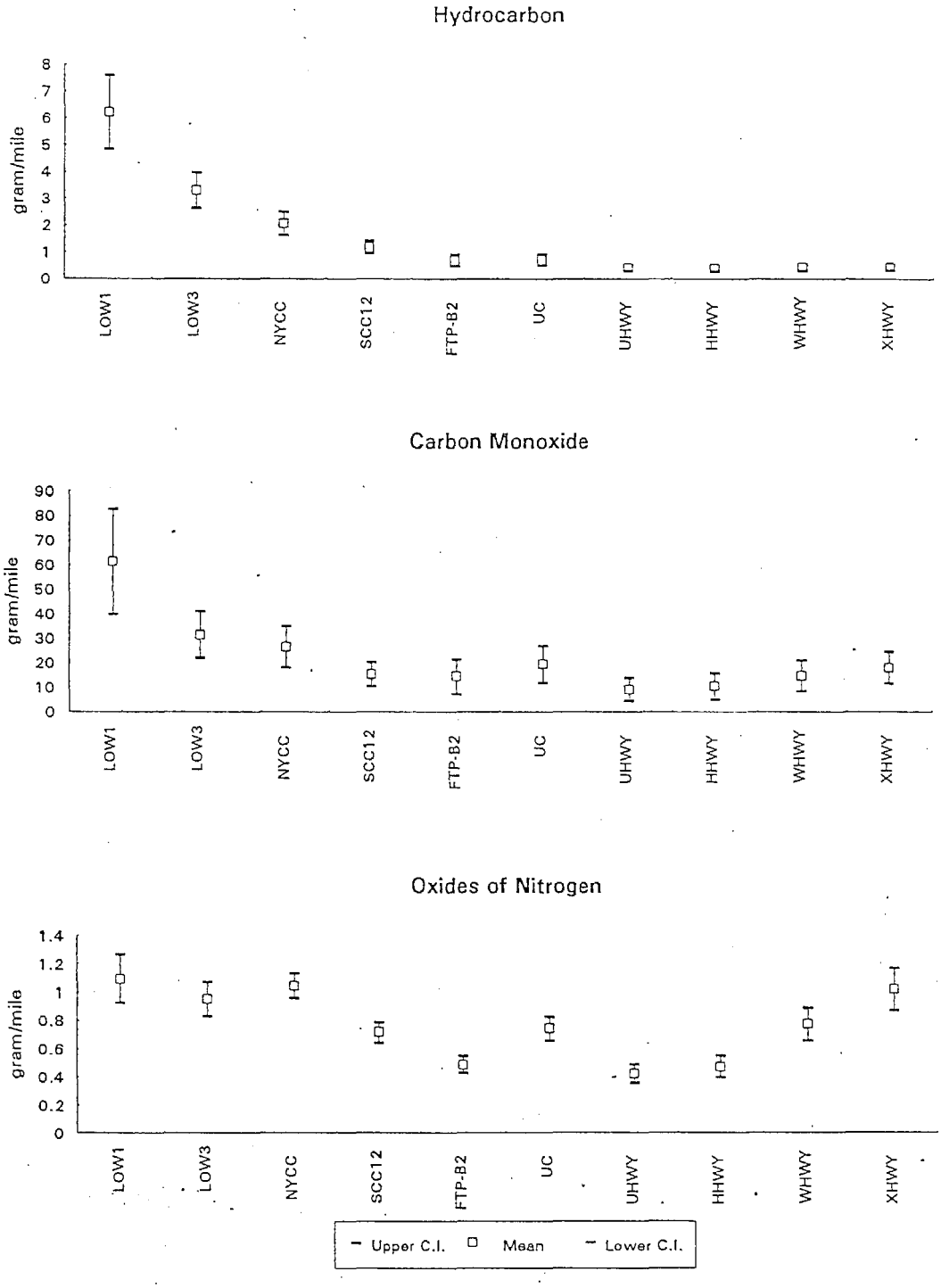

Figure 3.4.3 Comparison of speed effects on exhaust emissions.
Each interval represents 95% confidence interval of the population mean.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Limitations on the Scope of the Study

While mobile source emissions models (e.g. EMFAC, BURDEN, WEIGHT) are developed in attempt to understand and predict the complexities of the mobile source emission inventory, there are limitations in modeling. In particular, these models tend to define a dynamic open-system as a discrete closed-system. In addition, these models are based on the available research findings from vehicles, and they are refined as new information arises. Thus, these models can be viewed primarily as a learning tool to investigate and resolve the problem as opposed to a "solution" to the problem. Nevertheless, emissions models provide a basis for estimating emissions inventories which are routinely used by agencies for critical emission control strategy decisions.

The present study offers an unprecedented and comprehensive approach to examining the effects of speed, temperature, and fuel on exhaust emissions. The major limitation of this study was the small sample size (n=11). Questions can be raised about the fleet representativeness because of such a small sample size, however, it was the optimum sample size given the funding constraints. In the original project plan, ten vehicles were proposed to be tested. Later, with careful budget management and the elimination of redundant tasks, funding was available to add an eleventh vehicle (a 1992 Ford Taurus). The fuels used in the present study were summer grade Phase 1 (without oxygenates), Phase 2 (with oxygenates) and Indolene. Note that the complete

fuel speciation analysis is provided in the Appendix. While this study demonstrates there is a net benefit in using Phase 2 instead of Phase 1 fuels, there is a need to confirm the results by assessing commercial grade fuels. That is, will the commercial grade Phase 2 exhibit the same benefit over commercial Phase 1 fuel? Though all commercial grade fuels meet the specified fuel standards, exhaust emissions could be affected by the unique fuel composition of each fuel. In particular, the fuel additives and oxygenates in the commercial grade Phase 1 and Phase 2 fuels are likely to vary both in quality and quantity. To address this issue, a spectrum of commercial grade fuels must be tested, but this was beyond the scope of the present study. In fact, an in-depth study such as the Auto/Oil Air Quality Improvement Research Program has already investigated the relationship of fuel properties to exhaust emissions (SAE, 1993). In addition, CARB (1994b) has developed a predictive model to estimate exhaust emissions based on specific gasoline properties (e.g., RVP, sulfur, oxygenates, benzene, aromatic hydrocarbons, olefins, T_{90}, and T_{50}).

The basis for selecting the range of ambient temperatures (50 F, 75 F, 100 F) was that it approximates the full range of California's climate apart from a few special conditions (e.g. high elevation winter temperature). Results from Chapter 3 indicated that temperature has a limited effect on exhaust emissions during hot-stabilized operating mode and temperature effects were significant only for cold start conditions. In addition, high ambient temperature could affect evaporative HC emissions for resting vehicles. Thus, it is imperative to quantify hydrocarbons from both exhaust and evaporative sources. To address this issue HC emissions must be measured from

both exhaust and evaporative sources during testing, but this was beyond the scope of this study.

Another issue the present study did not address adequately was test-to-test variation or test error, for example errors caused by instruments and the driver. Even though drivers may record no violations in following the speed trace during the tests, none of the drivers could follow an identical speed trace, even when the same driver repeated the test, because there was a margin of $\pm$ 2 mph in following the speed trace on the monitor. Thus, a driver effect could be one major source of test error and this issue was not addressed in the present study.

4.2 Conclusions

Based on the eleven vehicles investigated in the present study, it was found that more recent model year vehicles were "cleaner" than older model year vehicles and the exhaust emissions increased in the order of MPFI, TBI and CARBU. In other words, exhaust emissions were affected by the fuel delivery technology and model year of the vehicle.

Because of high vehicle-to-vehicle and cycle-to-cycle variation, the effects of temperature and fuel on exhaust emissions could not be observed, which in turn suggested that both vehicle and speed were relatively more important than temperature and fuel factors. In general, all HC, CO, and NOx emissions were strong functions of speed. Both HC and CO emissions increased sharply at lower speed while NOx tended to increase slightly both at low and high speed. Besides, CO exhibited a

higher variability than HC and NOx emissions across all speeds.

Temperature has a limited influence on hot-stabilized exhaust emissions since the catalyst was "warmed-up" during hot-stabilized operating mode. However, the temperature effects on exhaust emissions were more pronounced during the cold start mode the test cycle as indicated from the comparison study of UC Bag 1 and Bag 3 (both bags were hot start) versus FTP Bag 1 (cold start) and Bag 3 (hot start). There was no statistical significant difference between Bag 1 and Bag 3 of UC, while the FTP Bag 1 exhaust emissions were statistical significant higher than Bag 3. In short, the temperature affect the conversion efficiency of the catalyst, which in turn caused high exhaust emissions during the cold start mode of the FTP.

Furthermore, when comparing the exhaust emissions difference due to Phase 2 and Phase 1 fuels based on all vehicles, cycles and temperatures, it was found that the average exhaust emissions benefits of Phase 2 over Phase 1 fuel on HC, CO, and NOx were 17%, 13% (statistically insignificant), and 11%, respectively. Note that studies from CARB estimated emissions reduction between Phase 2 and Phase 1 fuel for HC (including evaporative and exhaust emissions), CO and NOx were 17%, 11%, and 11%, respectively based on 1996 calendar year. Nevertheless, the findings from the present study were in good agreements with the predictions from CARB.

The best fuel economy for MPFI, TBI, and CARBU were 33, 30, and 28 miles per gallon, respectively, at the optimum speed of 45 mph. In general, the fuel economy increased in the order of CARBU, TBI and MPFI, which was probably due to better fuel delivery system leading to improved engine combustion, as well as

improved aerodynamics.

The catalyst efficiency test for each vehicle was conducted under FTP (Indolene and 75 F). It was found that all vehicles in the CARBU group (with average model year greater than 12 years) characteristically possessed a "dead" catalyst. This could partially explain why vehicles from CARBU were generally high emitters. It was also observed that catalyst efficiency was extremely temperature sensitive. Based on the vehicles from the MPFI and TBI groups, the average Bag 1 (cold start) catalyst efficiencies of HC, CO, and NOx were only 88%, 77%, 90% relative to the average composite catalyst efficiency. Thus, it is imperative to quantify the frequency of cold starts in a fleet in order to have a good emissions estimate from cold starts.

The test repeatability was examined based on the two test sequences (Indolene and 75 F), and it was concluded that the 1989 Mercury Topaz and 1982 Buick Regal were not repeatable for HC, CO, and NOx emissions. In addition, NOx emissions from the 1992 Toyota Paseo and CO emissions from the 1983 Honda Accord were also found not to be repeatable. This inconsistency of test data could be caused by prolonged non-use between the 9th and repeated (10th) sequences as well as test-to-test error. In general, the baselines (or FTPs) for HC and NOx were relatively stable for all vehicles during the course of first nine sequences, whereas the baseline for CO exhibited greater variability than HC and NOx. One of the drawbacks from the present study was that vehicles often idled for an unknown period of time between tests. It was expected that such test-to-test variation could be minimized if the vehicle

non-use time could be reduced.

The principal component analysis (PCA) was employed to explore the interrelationships among fuel (as Reid Vapor Pressure), temperature, speed, the number of cylinders, mileage, model year, engine displacement, HC, CO, and NOx emissions on all eleven vehicles. Based on the first principal component, it was concluded that HC, CO, and NOx emissions were inversely related to the speed. No other meaningful conclusion can be derived from the second principal component and beyond. Despite the limitation of PCA for the data, the results highlight the importance of speed factor to HC, CO, and NOx emissions.

One of the key assumptions in the CARB mobile source emissions model (EMFAC) is that there are no interactions or synergistic effects among speed, temperature and fuel correction factors. This fundamental assumption has never been challenged or investigated. Based on the analysis of variance (ANOVA), it was concluded that speed and vehicle type were the dominant factors affecting exhaust emissions. More importantly, the interaction or synergistic effects between fuel, temperature, and cycle were found to be statistically insignificant. Thus, the EMFAC assumption that speed, temperature, and fuel are independent was confirmed at least for the population of vehicles investigated.

4.3 Recommendations for Future Research

The results from the present study help to establish strategies and priorities in future mobile source emissions research, especially when many issues need to be addressed under a limited research budget. Based on the present study, the relative significance of speed, temperature, and fuel factors on exhaust emissions were established. It was evident that additional studies are needed on cycle-related research since speed is the dominant factor in determining the HC, CO and NOx exhaust emissions. In particular, we need to assess exhaust emissions from cycles with extremely low speed (idling) and high speed (above 75 mph). There is a need to incorporate these findings into the current EMFAC model. In addition, there is a need to assess other parameters that are related with exhaust emissions such as grade, high load, and air conditioning. All these issues need to be addressed in order to improve our current MVEI model.

There is also a need to assess the test-to-test variability caused by driver behavior. While the error margin for the driver to follow the speed trace is $\pm$ 2 mph, it is possible such small difference when accumulated over the entire cycle could cause major differences in the test results. Thus, in order to sharpen our tools on motor vehicle emissions research, it is crucial to evaluate and assess sources of test error especially due to the driver-to-driver variability.

From the vehicles investigated in the present study, high emitters were generally found in older vehicles (more than 12 years old) with "dead" catalysts. There is a need to assess the impact of "high" exhaust emissions from such group on

the total mobile source emissions. Since catalyst is a critical component on exhaust emission control, there is a definite need for research on how to prolong the operating life of the catalyst.

There were 1100 modal data files (about 250 Megabytes) collected from this study and each test file, ranges from approximately 350 to 1400 seconds depending on the length of the cycle, contains second-by-second instantaneous reading of HC, CO, NOx, CO_2, exhaust oxygen content, vehicle actual speed, catalyst temperature, and engine rpm. The next phase of the present study need to access the exhaust emissions dynamics based on the modal data collected.

As each cycle comprises a mix proportion of idle, acceleration, deceleration, and cruise, it is of interest to find out what is the real-time exhaust emissions under different combinations of speed and acceleration. Will the fuel and temperature make any difference during the real-time emissions? How is catalyst temperature related to HC, CO, and NOx exhaust emissions on a real-time basis? Does the technology group make any difference on exhaust emissions? At what speed and acceleration domains will excursion of exhaust emissions occur? Can real-time exhaust emissions be modeled? What are the important parameters to model real-time exhaust emissions? Obviously, many questions need to be answered thorough the modal data analysis. Perhaps with the modal data analysis, it will shed new light on motor vehicle emissions modeling.

A.1 Summary of Catalyst Efficiency

A.1 Catalyst efficiency for all vehicles based on FTP (Indolene, 75 F)

Vehicles	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx	CO2-B1	CO2-B2	CO2-B3	CO2
1990 Lincoln Town Car	90.90	97.59	96.11	96.11	91.30	97.03	96.59	95.70	62.84	75.51	72.95	71.33	-5.77	6.14	-2.34	1.52
1992 GM Oldsmobile	71.61	99.03	93.37	91.30	64.60	97.35	85.31	86.56	92.54	99.51	94.92	96.63	-12.53	-11.42	-11.60	-11.70
1992 Toyota Paseo	71.77	98.68	97.11	92.40	60.83	99.43	96.04	87.93	81.42	85.85	83.07	84.15	-15.57	-13.29	-16.61	-14.57
1989 Mercury Topaz	69.34	97.86	95.20	90.30	58.45	90.65	89.68	80.38	62.23	70.12	67.00	66.83	-8.64	-7.39	-11.96	-8.78
1992 Ford Taurus	90.4	74.50	92.90	90.38	58.55	87.83	92.25	90.38	81.37	89.21	90.52	87.7	-16.58	-18.08	-17.61	-17.64
1985 Continental MRK V	75.32	91.88	86.10	87.48	74.85	96.76	95.58	91.13	35.58	38.38	39.26	37.98	1.80	2.86	2.68	2.58
1986 Cadillac De Ville	83.50	96.00	94.96	93.44	75.79	99.34	96.26	91.23	43.92	58.31	41.24	49.14	4.41	15.61	8.31	11.66
1988 Dodge Daytona	80.40	98.25	91.59	93.94	63.92	88.45	82.07	80.91	65.25	70.91	71.48	65.58	8.44	13.21	9.26	9.60
1979 Chevrolet Impala	4.14	4.22	5.70	4.56	-9.14	1.70	-10.06	-4.16	-15.19	-17.88	-16.41	-16.92	-7.60	-5.96	-7.43	-6.66
1982 Buick Regal	10.34	11.32	12.81	11.47	-5.99	-1.55	-6.40	-4.80	-5.61	3.17	-0.92	-0.07	-5.39	-2.13	-4.59	-3.43
1983 Honda Accord*	n.a.															

* Unable to measure meaningful data, catalyst is functionally "dead".

A.2 Fuel Speciation Data

Fuel Type: Phase 1

Detailed Hydrocarbon Analysis (DHAX)
California Air Resources Board
Southern Laboratory Branch, Inorganic Analysis Section

File: DHA074.RUN Analyzed: 13-SEP-94 3:50 PM
Sample: PH1, S326,090294 Reported: 09-20-1994 07:29:42
Method: DHA074.MTH DHA DBase File: RI_PONVA.DBF
Processed 433 Peaks Normalized to 100.00%
Analyst: Rose P. Papa
Analysis requested by David Chou, MSD

Composite Report
Totals by Group Type & Carbon Number
(in Weight Percent)

	Paraffins:	I-paraffins:	Aromatics:	Naphthenes:	Olefins:	Total:
C1:	0	0	0	0	0	0
C2:	0	0	0	0	0	0
C3:	0	0	0	0	0	0
C4:	2.201	0.063	0	0	0.201	2.466
C5:	1.936	11.262	0	0.089	2.336	15.624
C6:	1.307	5.061	2.171	0.931	2.541	12.011
C7:	1.037	7.976	8.823	1.383	2.275	21.495
C8:	0.802	11.644	16.86	1.628	0.322	31.256
C9:	0.141	2.707	5.709	0.542	0.157	9.256
C10:	0.05	0.675	3.555	0.154	0.017	4.452
C11:	0.03	0.235	0.896	0.034	0.014	1.208
C12:	0.027	0.228	0.435	0	0.006	0.696
C13:	0.022	0.008	0	0	0	0.03
Total	7.552	39.861	38.449	4.762	7.869	98.493

Oxygenates: 0.099 Total C14+: 0.31 Total Unknowns: 1.098
Grand Total: 100

Composite Report
Totals by Group Type & Carbon Number
(in Volume Percent)

	Paraffins:	I-paraffins:	Aromatics:	Naphthenes:	Olefins:	Total:
C1:	0	0	0	0	0	0
C2:	0	0	0	0	0	0
C3:	0	0	0	0	0	0
C4:	2.819	0.084	0	0	0.244	3.147
C5:	2.291	13.474	0	0.089	2.63	18.484
C6:	1.469	5.701	1.831	0.918	2.687	12.605
C7:	1.125	8.621	7.543	1.36	2.379	21.027
C8:	0.846	12.29	14.414	1.564	0.328	29.442
C9:	0.146	2.787	4.862	0.514	0.165	8.474
C10:	0.051	0.682	2.944	0.143	0.018	3.838
C11:	0.03	0.235	0.682	0.032	0.013	0.992
C12:	0.026	0.225	0.363	0	0.006	0.619
C13:	0.021	0.008	0	0	0	0.029
Total	8.823	44.106	32.639	4.619	8.47	98.657

Oxygenate 0.099 Total C14 0.301 Total Unknowns: 0.943
Grand Total: 100

Fuel Type: Phase 2

Detailed Hydrocarbon Analysis (DHAX)
California Air Resources Board
Southern Lab Branch/ Inorganic Analysis Section

File: DHA075.RUN
Sample: PH2,R857,090294
Method: DHA075.MTH
Processed 391 Peaks
Analyst: Rose P. Papa
Analysis requested by David Chou, MSD

Analyzed: 13-SEP-94 6:49 PM
Reported: 09-21-1994 07:32:59
DHA DBase File: RI_PONVA.DBF
Normalized to 100.00%

Composite Report
Totals by Group Type & Carbon Number
(in Weight Percent)

	Paraffins:	I-paraffins:	Aromatics:	Naphthenes:	Olefins:	Total:
C1:	0	0	0	0	0	0
C2:	0	0	0	0	0	0
C3:	0.003	0	0	0	0	0.003
C4:	1.513	0.08	0	0	0.051	1.644
C5:	1.086	7.223	0	0.051	1.289	9.649
C6:	1.054	8.912	1.232	0.403	1.196	12.798
C7:	0.991	9.966	9.157	0.604	1.09	21.808
C8:	0.498	18.736	9.583	0.718	0.156	29.691
C9:	0.084	2.381	5.506	0.3	0.095	8.366
C10:	0.036	0.693	2.411	0.105	0.009	3.255
C11:	0.017	0.149	0.423	0.017	0.01	0.616
C12:	0.014	0.123	0.238	0	0	0.374
C13:	0.012	0.004	0	0	0	0.016
Total	5.308	48.267	28.55	2.199	3.896	88.22

Oxygenates: 11.092 Total C14+ 0.086 Total Unknowns: 0.602
Grand Total: 100

Composite Report
Totals by Group Type & Carbon Number
(in Volume Percent)

	Paraffins:	I-paraffins:	Aromatics:	Naphthenes:	Olefins:	Total:
C1:	0	0	0	0	0	0
C2:	0	0	0	0	0	0
C3:	0.005	0	0	0	0	0.005
C4:	1.914	0.105	0	0	0.061	2.08
C5:	1.269	8.534	0	0.05	1.43	11.283
C6:	1.17	9.931	1.026	0.392	1.247	13.766
C7:	1.061	10.634	7.73	0.587	1.125	21.137
C8:	0.519	19.542	8.088	0.681	0.157	28.987
C9:	0.086	2.421	4.629	0.281	0.099	7.515
C10:	0.036	0.69	1.982	0.096	0.009	2.815
C11:	0.016	0.147	0.321	0.016	0.01	0.509
C12:	0.014	0.119	0.196	0	0	0.328
C13:	0.012	0.004	0	0	0	0.016
Total	6.101	52.127	23.972	2.103	4.139	88.44

Oxygenate 10.96 Total C14+: 0.083 Total Unknowns: 0.517
Grand Total: 100

Fuel Type: Indolene

Detailed Hydrocarbon Analysis (DHAX)
California Air Resources Board
Southern Lab Branch / Inorganic Analysis Section

File: DHA079 Sample: IND,425,090294 Analyzed: 14-SEP-94 6:49 AM
Method: DHA079.MTH Processed 348 Peaks Reported: 12-14-1994 08:20:53
DHA DBase File: RI_DHA4.CSV Normalized to 100.00%
Analyst: R.P.Papa
Analysis requested by David Chou, MSD

Composite Report
Totals by Group Type & Carbon Number
(in Weight Percent)

	Paraffins:	I-paraffins:	Aromatics:	Naphthenes:	Olefins:	Total:
C1:	0	0	0	0	0	0
C2:	0.003	0	0	0	0	0.003
C3:	0.033	0	0	0	0	0.033
C4:	1.848	1.612	0	0	0.061	3.521
C5:	1.946	11.05	0	0.283	1.756	15.034
C6:	2.075	8.542	0.232	1.17	1.262	13.281
C7:	0.279	5.682	17.721	0.647	13.887	38.216
C8:	0.141	6.494	4.547	0.401	0.117	11.7
C9:	0.042	0.724	11.374	0.169	0.025	12.334
C10:	0.026	0.187	4.051	0.031	0.003	4.298
C11:	0.021	0.074	0.354	0.006	0.01	0.463
C12:	0.01	0.073	0.282	0	0	0.364
C13:	0.005	0	0	0	0	0.005
Total	6.428	34.437	38.56	2.707	17.121	99.253

Oxygenates: 0 Total C14+: 0.149 Total Unknowns: 0.599
Grand Total: 100

Composite Report
Totals by Group Type & Carbon Number
(in Volume Percent)

	Paraffins:	I-paraffins:	Aromatics:	Naphthenes:	Olefins:	Total:
C1:	0	0	0	0	0	0
C2:	0.007	0	0	0	0	0.007
C3:	0.048	0	0	0	0	0.048
C4:	2.342	2.123	0	0	0.074	4.539
C5:	2.28	13.087	0	0.278	1.961	17.605
C6:	2.309	9.531	0.194	1.141	1.328	14.502
C7:	0.3	6.092	14.998	0.631	14.603	36.623
C8:	0.147	6.691	3.842	0.381	0.118	11.179
C9:	0.043	0.739	9.576	0.159	0.025	10.542
C10:	0.026	0.187	3.356	0.029	0.003	3.601
C11:	0.02	0.073	0.269	0.005	0.009	0.377
C12:	0.01	0.071	0.232	0	0	0.313
C13:	0.005	0	0	0	0	0.005
Total	7.537	38.594	32.467	2.624	18.12	99.342

Oxygenates: 0 Total C14+: 0.143 Total Unknowns: 0.515
Grand Total: 100

A.3 Raw Data (Units are in gram/mile uncless otherwise noted)

1990 LINCOLN TOWN CAR

		Phase 1			Phase 2			Indolene			Indolene*		
Temp	Cycle	HC	CO	NOX	HC	CO	NOX	HC	CO	NOX	HC	CO	NOX
	FTP	0.216	1.039	0.425	0.198	1.045	0.357	0.214	1.260	0.482			
	HHWY	0.114	0.658	0.152	0.124	0.705	0.122	0.108	0.622	0.140			
	LA92	0.1	0.495	0.548	0.114	0.551	0.488	0.115	0.754	0.635			
	LOW1	0.727	0.143	0.441	0.723	0.057	0.396	0.824	0.093	0.323			
50 F	LOW3	0.466	0.131	0.472	0.290	0.008	0.383	0.409	0.034	0.344			
	NYCC	0.3	0.129	0.806	0.252	0.081	0.846	0.364	0.240	1.021			
	SCC12	0.193	0.284	0.574	0.156	0.074	0.406	0.490	0.372	1.274			
	UHWY	0.136	0.768	0.101	0.138	0.717	0.092	0.131	0.848	0.104			
	WHWY	0.051	0.279	0.628	0.048	0.252	0.373	0.060	0.399	0.368			
	XHWY	0.037	0.168	0.917	0.045	0.182	0.699	0.048	0.292	0.727			
	FTP	0.311	1.678	0.552	0.173	1.008	0.374	0.364	1.41	0.588	0.153	0.683	0.604
	HHWY	0.126	0.697	0.212	0.091	0.565	0.205	0.083	0.218	1.063	0.06	0.046	1.442
	LA92	0.152	1.012	0.648	0.096	0.519	0.524	0.093	0.439	1.083	0.103	0.411	1.174
	LOW1	1.082	0.495	0.331	0.950	0.065	0.389	1.187	0.59	0.736	1.468	0.512	0.35
75 F	LOW3	0.827	2.129	0.306	0.524	0.340	0.429	0.79	0.549	0.927	0.828	0.576	0.774
	NYCC	0.459	0.873	1.155	0.282	0.226	0.777	1.949	2.268	1.349	1.17	2.101	1.209
	SCC12	0.275	0.819	0.594	0.139	0.169	0.460	1.777	9.265	1.265	0.868	1.03	1.202
	UHWY	0.154	0.902	0.141	0.129	0.775	0.087	0.082	0.195	1.349	0.089	0.175	1.565
	WHWY	0.082	0.51	0.522	0.079	0.328	0.664	0.089	0.198	2.095	0.09	0.033	3.38
	XHWY	0.058	0.332	1.004	0.042	0.310	0.742	0.042	0.011	4.583	0.058	0.004	6.821
	FTP	0.382	1.42	0.52	0.18	1.306	0.428	0.202	1.085	0.429			
	HHWY	0.161	1.094	0.202	0.113	0.854	0.116	0.136	0.966	0.127			
	LA92	0.16	1.465	0.665	0.109	1.473	0.544	0.114	0.804	0.552			
	LOW1	1.331	1.482	0.342	0.712	0.277	0.387	0.93	0.539	0.388			
100 F	LOW3	1.084	5.758	0.466	0.503	0.742	0.569	0.369	0.222	0.572			
	NYCC	0.624	1.978	0.992	0.287	0.347	1.057	0.525	2.433	1.295			
	SCC12	0.459	2.371	0.627	0.108	0.248	0.552	0.187	0.322	0.576			
	UHWY	0.134	0.528	1.095	0.122	1.062	0.102	0.123	1.064	0.153			
	WHWY	0.082	0.723	0.422	0.07	0.617	0.23	0.061	0.56	0.371			
	XHWY	0.044	0.259	0.788	0.036	0.306	0.491	0.047	0.396	0.507			

* Repeated sequence

1990 Lincoln Town Car

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	0.446	0.137	0.182	0.214	3.631	0.515	0.866	1.260	0.715	0.390	0.478	0.482
FTP	Indolene	75	1.370	0.091	0.121	0.364	4.765	0.621	0.370	1.41	0.955	0.351	0.760	0.588
FTP	Indolene	100	0.429	0.128	0.170	0.202	2.500	0.671	0.796	1.085	0.573	0.332	0.503	0.429
FTP	Phase1	50	0.397	0.157	0.189	0.216	1.942	0.744	0.913	1.039	0.616	0.33	0.459	0.425
FTP	Phase1	75	0.718	0.191	0.23	0.311	3.909	1.039	1.206	1.678	0.922	0.404	0.552	0.552
FTP	Phase1	100	1.107	0.174	0.227	0.382	3.204	0.711	1.408	1.42	0.902	0.388	0.48	0.52
FTP	Phase2	50	0.435	0.110	0.185	0.198	2.681	0.503	0.835	1.045	0.546	0.279	0.360	0.357
FTP	Phase2	75	0.398	0.093	0.154	0.173	2.744	0.391	0.863	1.008	0.530	0.325	0.348	0.374
FTP	Phase2	100	0.448	0.09	0.148	0.18	4.341	0.38	0.762	1.306	0.541	0.366	0.46	0.428
FTP*	Indolene	75	0.323	0.1	0.125	0.153	1.441	0.524	0.412	0.683	1.027	0.368	0.729	0.604
LA92	Indolene	50	0.230	0.098	0.246	0.115	0.716	0.729	1.102	0.754	1.046	0.598	0.809	0.635
LA92	Indolene	75	0.506	0.060	0.209	0.093	0.658	0.414	0.592	0.439	1.317	1.081	0.932	1.083
LA92	Indolene	100	0.186	0.103	0.193	0.114	0.657	0.824	0.660	0.804	0.827	0.507	0.915	0.552
LA92	Phase1	50	0.203	0.087	0.178	0.1	0.57	0.479	0.644	0.495	0.847	0.515	0.747	0.548
LA92	Phase1	75	0.333	0.131	0.281	0.152	1.325	0.988	1.087	1.012	0.849	0.617	0.889	0.648
LA92	Phase1	100	0.358	0.139	0.284	0.16	2.477	1.313	2.651	1.465	0.869	0.53	2.397	0.865
LA92	Phase2	50	0.219	0.094	0.285	0.114	0.598	0.564	0.349	0.551	0.670	0.451	0.822	0.488
LA92	Phase2	75	0.205	0.084	0.162	0.096	0.463	0.540	0.297	0.519	0.617	0.487	0.930	0.524
LA92	Phase2	100	0.209	0.095	0.216	0.109	1.707	1.486	1.132	1.473	0.947	0.486	0.987	0.544
LA92*	Indolene	75	0.551	0.068	0.205	0.103	0.893	0.375	0.514	0.411	1.515	1.165	1.038	1.174

*repeat

1992 OLDSMOBILE DELTA 88

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	3.372	131.452	0.478	3.468	145.104	0.143	2.151	80.441	0.106			
	HHWY	1.673	96.377	0.211	1.849	105.524	0.027	1.922	117.664	0.042			
	LA92	2.76	134.546	0.413	2.853	138.2	0.128	2.371	116.879	0.17			
	LOW1	14.101	318.441	1.859	13.33	285.989	0.526	7.454	71.601	0.063			
50 F	LOW3	8.897	187.894	1.07	5.166	81.846	0.099	4.492	75.764	0.108			
	NYCC	5.49	126.063	1.963	4.468	121.955	0.594	7.051	244.246	0.26			
	SCC12	2.943	86.084	1.404	2.848	77.943	0.69	2.325	72.913	0.109			
	UHWY	1.633	80.448	0.426	1.185	50.802	0.228	1.855	108.12	0.035			
	WHWY	1.742	105.447	0.253	1.771	105.701	0.067	1.867	126.815	0.034			
	XHWY	1.451	75.474	0.405	1.999	135.435	0.027	1.641	103.282	0.081			
	FTP	0.582	16.204	0.362	1.997	64.293	0.136	3.731	151.66	0.216	0.166	1.88	0.11
	HHWY	1.765	111.448	0.265	1.325	74.615	0.043	2.057	120.99	0.091	0.023	0.454	0.093
	LA92	2.503	132.785	0.483	3.253	160.999	0.165	2.859	131.883	0.253	0.06	1.776	0.049
	LOW1	1.089	10.026	1.678	12.511	235.051	0.431	12.093	239.176	0.458	0.287	1.062	0.23
75 F	LOW3	3.231	37.382	0.74	7.09	128.577	0.758	6.826	104.917	1.033	0.173	0.759	0.045
	NYCC	4.737	142.145	0.928	4.86	134.841	0.955	5.67	169.154	0.243	0.073	0.84	0.138
	SCC12	2.495	71.832	1.258	2.945	92.442	0.955	3.38	121.062	0.438	0.055	0.688	0.15
	UHWY	1.652	101.606	0.18	1.245	62.993	0.088	1.789	101.902	0.153	0.124	0.762	0.356
	WHWY	1.766	126.075	0.313	1.85	120.094	0.149	1.835	111.915	0.216	0.018	0.844	0.011
	XHWY	0.759	49.442	0.388	1.634	111.305	0.081	2.104	142.778	0.106	0.063	2.342	0.555
	FTP	2.978	114.712	0.515	2.853	115.412	0.053	0.2	2.511	0.078			
	HHWY	1.729	103.144	0.225	1.151	50.779	0.024	0.059	1.643	0.175			
	LA92	3.606	163.122	0.467	2.951	145.279	0.078	0.154	6.758	0.115			
	LOW1	4.698	40.443	1.212	10.921	199.44	0.23	0.185	0.452	0.198			
100 F	LOW3	4.836	84.024	0.457	5.088	88.981	0.361	0.351	4.43	0.529			
	NYCC	4.783	139.247	0.735	3.567	83.466	0.996	0.479	11.16	0.487			
	SCC12	2.732	88.718	0.841	3.835	144.236	0.096	0.06	0.315	0.01			
	UHWY	1.08	49.734	0.37	1.916	108.347	0.024	0.095	3.474	0.453			
	WHWY	1.953	123.334	0.238	1.861	119.462	0.033	0.096	1.729	0.197			
	XHWY	2.079	141.743	0.232	1.957	134.253	0.033	0.055	1.968	0.062			

* Repeated sequence

1992 Oldsmobile Delta88

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	2.259	2.604	1.218	2.151	77.724	102.628	40.838	80.441	0.171	0.061	0.142	0.106
FTP	Indolene	75	3.344	4.493	2.59	3.731	131.697	178.604	115.996	151.08	0.334	0.207	0.145	0.218
FTP	Indolene	100	0.468	0.055	0.27	0.2	4.706	0.729	4.191	2.511	0.221	0.02	0.08	0.078
FTP	Phase1	50	3.441	3.982	2.173	3.372	135.427	146.755	99.644	131.452	0.595	0.531	0.289	0.478
FTP	Phase1	75	1.034	0.55	0.302	0.582	21.648	17.767	9.16	16.204	0.729	0.222	0.348	0.362
FTP	Phase1	100	2.869	3.688	1.725	2.978	86.089	151.272	67.599	114.712	0.877	0.401	0.454	0.515
FTP	Phase2	50	3.181	4.075	2.536	3.468	138.496	161.956	118.227	145.104	0.225	0.075	0.208	0.143
FTP	Phase2	75	2.486	2.126	1.387	1.997	65.175	69.229	54.388	64.293	0.433	0.027	0.114	0.136
FTP	Phase2	100	3.007	3.47	1.58	2.853	122.693	137.061	69.323	115.412	0.144	0.029	0.03	0.053
FTP*	Indolene	75	0.592	0.03	0.101	0.166	5.479	0.414	1.944	1.88	0.264	0.014	0.176	0.11
LA92	Indolene	50	4.542	2.352	0.96	2.371	206.412	118.966	22.301	116.879	0.212	0.173	0.1	0.17
LA92	Indolene	75	3.349	2.887	2.132	2.859	116.563	138.035	65.518	131.883	1.253	0.191	0.278	0.253
LA92	Indolene	100	0.074	0.08	1.166	0.154	1.046	3.793	49.055	6.758	0.126	0.091	0.416	0.115
LA92	Phase1	50	3.101	2.628	4.182	2.76	89.341	132.674	192.388	134.546	1.686	0.334	0.461	0.413
LA92	Phase1	75	3.707	2.444	2.276	2.503	185.626	133.627	81.942	132.785	0.949	0.457	0.463	0.483
LA92	Phase1	100	2.847	3.664	3.441	3.606	90.725	170.443	125.084	163.122	1.701	0.303	1.613	0.467
LA92	Phase2	50	3.655	2.808	2.815	2.853	130.711	140.158	118.683	138.2	0.621	0.063	0.588	0.128
LA92	Phase2	75	3.342	3.286	2.767	3.253	121.277	167.307	110.767	160.999	1.03	0.081	0.581	0.185
LA92	Phase2	100	4.309	2.92	2.325	2.951	207.081	145.99	89.821	145.279	0.106	0.066	0.222	0.078
LA92*	Indolene	75	0.039	0.043	0.296	0.06	0.481	1.388	7.752	1.776	0.075	0.044	0.099	0.049

*repeat

1992 TOYOTA PASEO

		Phase 1			Phase 2			Indolene			Indolene*		
Temp	Cycle	HC	CO	NOX	HC	CO	NOX	HC	CO	NOX	HC	CO	NOX
	FTP	0.250	1.768	0.226	0.198	1.803	0.197	0.207	1.978	0.312			
	HHWY	0.042	0.219	0.058	0.041	0.201	0.058	0.083	0.470	0.083			
	LA92	0.076	1.445	0.230	0.028	0.129	0.268	0.043	0.646	0.311			
	LOW1	0.205	0.067	1.372	0.238	0.104	1.123	0.158	0.032	1.125			
50 F	LOW3	0.126	0.006	1.351	0.128	0.266	0.899	0.098	0.154	0.708			
	NYCC	0.842	3.856	1.055	0.146	0.770	0.813	0.116	0.562	0.946			
	SCC12	0.406	2.173	0.435	0.105	0.623	0.346	0.111	0.256	0.579			
	UHWY	0.102	0.671	0.117	0.059	0.348	0.067	0.085	0.444	0.098			
	WHWY	0.258	1.410	0.221	0.042	0.286	0.085	0.059	0.439	0.074			
	XHWY	0.087	0.717	0.110	0.076	0.608	0.094	0.090	0.859	0.118			
	FTP	0.219	1.494	0.237	0.171	1.189	0.237	0.197	1.256	0.282	0.191	1.338	0.319
	HHWY	0.068	0.308	0.088	0.037	0.174	0.074	0.039	0.202	0.072	0.115	0.604	0.13
	LA92	0.033	0.241	0.255	0.041	0.165	0.296	0.042	0.648	0.232	0.112	1.07	0.325
	LOW1	0.173	0.065	2.407	0.161	0.087	0.802	2.36	77.347	0.202	0.35	4.054	0.642
75 F	LOW3	0.121	0.430	1.284	0.134	0.029	1.267	0.189	1.035	1.095	2.501	12.163	2.011
	NYCC	0.074	0.301	0.817	0.134	0.778	1.046	0.364	5.626	0.558	1.057	4.684	1
	SCC12	0.112	0.358	0.674	0.030	0.006	0.658	0.095	0.601	0.359	2.021	11.511	1.179
	UHWY	0.046	0.313	0.045	0.019	0.182	0.069	0.054	0.263	0.091	0.27	1.945	0.165
	WHWY	0.075	0.382	0.129	0.040	0.275	0.057	0.032	0.136	0.089	0.207	1.284	0.241
	XHWY	0.128	0.994	0.159	0.070	0.574	0.128	0.05	0.485	0.113	0.232	1.685	0.22
	FTP	0.207	1.110	0.220	0.195	2.149	0.287	0.134	0.935	0.287			
	HHWY	0.132	3.203	0.033	0.026	0.251	0.047	0.028	0.152	0.057			
	LA92	0.068	0.952	0.203	0.111	5.003	0.296	0.06	1.664	0.18			
	LOW1	1.428	23.535	0.308	0.850	17.642	0.375	0.249	6.115	0.311			
100 F	LOW3	1.397	34.329	0.215	0.294	2.341	0.607	0.819	17.45	0.382			
	NYCC	0.770	21.581	0.454	0.087	1.384	1.393	0.029	0.113	0.866			
	SCC12	0.756	19.080	0.275	0.033	0.431	0.479	0.379	13.893	0.1			
	UHWY	0.086	0.547	0.146	0.034	0.205	0.096	0.047	0.598	0.031			
	WHWY	0.136	0.637	0.169	0.056	1.224	0.077	0.026	0.155	0.155			
	XHWY	0.100	1.464	0.094	0.079	1.547	0.168	0.039	0.316	0.08			

* Repeated sequence

1992 Toyota Paseo

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	0.852	0.033	0.050	0.207	9.022	0.108	0.196	1.978	0.377	0.352	0.185	0.312
FTP	Indolene	75	0.827	0.031	0.035	0.197	5.839	0.024	0.119	1.256	0.3	0.312	0.211	0.282
FTP	Indolene	100	0.560	0.017	0.034	0.134	4.293	0.004	0.157	0.935	0.376	0.256	0.279	0.287
FTP	Phase1	50	1.055	0.029	0.057	0.250	7.564	0.173	0.395	1.768	0.373	0.187	0.187	0.226
FTP	Phase1	75	0.915	0.027	0.056	0.219	6.396	0.133	0.351	1.494	0.422	0.188	0.189	0.237
FTP	Phase1	100	0.839	0.032	0.057	0.207	4.517	0.088	0.463	1.110	0.412	0.153	0.200	0.220
FTP	Phase2	50	0.825	0.028	0.044	0.198	8.139	0.058	0.304	1.803	0.220	0.213	0.151	0.197
FTP	Phase2	75	0.710	0.028	0.036	0.171	5.493	0.032	0.121	1.189	0.249	0.222	0.254	0.237
FTP	Phase2	100	0.716	0.037	0.101	0.195	6.017	0.029	3.230	2.149	0.433	0.249	0.250	0.287
FTP*	Indolene	75	0.739	0.037	0.066	0.191	5.398	0.082	0.632	1.338	0.343	0.316	0.308	0.319
LA92	Indolene	50	0.042	0.040	0.078	0.043	0.080	0.696	0.430	0.646	0.530	0.280	0.546	0.311
LA92	Indolene	75	0.160	0.027	0.148	0.042	2.072	0.433	2.298	0.648	0.393	0.198	0.538	0.232
LA92	Indolene	100	0.024	0.026	0.513	0.06	0.031	0.467	18.037	1.664	0.517	0.159	0.206	0.18
LA92	Phase1	50	0.199	0.069	0.076	0.076	1.255	1.516	0.691	1.445	0.451	0.207	0.348	0.230
LA92	Phase1	75	0.077	0.030	0.044	0.033	0.759	0.212	0.213	0.241	0.442	0.226	0.481	0.255
LA92	Phase1	100	0.288	0.041	0.243	0.068	3.834	0.233	7.964	0.952	0.236	0.181	0.460	0.203
LA92	Phase2	50	0.077	0.023	0.056	0.028	0.542	0.105	0.126	0.129	0.499	0.242	0.429	0.268
LA92	Phase2	75	0.125	0.031	0.108	0.041	0.545	0.110	0.576	0.165	0.833	0.244	0.548	0.296
LA92	Phase2	100	0.113	0.085	0.438	0.111	6.407	3.984	16.909	5.003	0.481	0.265	0.556	0.296
LA92*	Indolene	75	1.216	0.048	0.114	0.112	7.584	0.664	1.462	1.07	1.441	0.254	0.404	0.325

*repeat

1989 MERCURY TOPAZ

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	0.388	6.208	0.669	0.156	1.709	0.619	0.383	7.238	0.504			
	HHWY	0.036	0.106	0.746	0.03	0.06	0.633	0.036	0.092	0.557			
	LA92	0.086	1.86	0.904	0.057	0.955	0.784	0.062	1.763	0.737			
	LOW1	1.668	15.19	0.443	1.423	8.974	0.437	1.244	12.785	0.271			
50 F	LOW3	0.811	13.096	0.758	0.897	5.7	0.584	0.926	6.999	0.562			
	NYCC	0.426	5.42	1.475	0.284	2.727	0.935	0.145	3.127	0.755			
	SCC12	0.163	1.344	0.741	0.143	1.031	0.584	0.163	1.257	0.388			
	UHWY	0.057	0.133	0.447	0.039	0.063	0.519	0.028	0.049	0.463			
	WHWY	0.058	0.148	1.291	0.036	0.017	1.091	0.028	0.221	0.836			
	XHWY	0.089	0.904	1.221	0.067	0.505	0.75	0.052	0.782	0.843			
	FTP	0.204	2.411	0.576	0.148	1.691	0.622	0.17	2.29	0.652	0.236	2.644	0.525
	HHWY	0.03	0.247	0.674	0.024	0.567	0.477	0.028	0.371	0.562	0.075	0.235	0.674
	LA92	0.097	5.682	0.867	0.079	3.482	0.768	0.127	7.228	0.735	0.118	4.02	0.758
	LOW1	1.468	13.816	0.483	0.782	12.499	0.369	1	14.635	0.373	1.785	7.882	0.572
75 F	LOW3	0.708	9.902	0.377	0.331	9.399	0.358	0.693	13.056	0.457	1.021	6.669	0.783
	NYCC	0.429	7.884	0.999	0.175	6.464	1.052	0.424	24.43	0.629	1.262	10.337	2.009
	SCC12	0.221	2.603	0.606	0.236	2.339	0.737	0.256	20.059	0.304	0.405	3.619	0.95
	UHWY	0.043	0.165	0.546	0.063	1.327	0.371	0.031	0.28	0.454	0.062	0.024	0.949
	WHWY	0.041	0.496	1.233	0.029	0.221	0.957	0.028	0.408	0.928	0.061	0.213	1.142
	XHWY	0.042	0.467	1.22	0.03	0.442	1.203	0.046	1.46	1.24	0.087	0.816	1.245
	FTP	0.152	1.861	0.672	0.13	1.778	0.67	0.119	1.746	0.799			
	HHWY	0.057	0.611	0.564	0.026	0.798	0.584	0.032	0.463	0.896			
	LA92	0.104	5.328	0.868	0.08	4.95	0.827	0.143	5.022	0.95			
	LOW1	0.958	9.726	0.476	1.927	22.061	0.45	5.313	34.155	0.408			
100 F	LOW3	1.086	25.887	0.33	0.465	17.767	0.352	2.908	17.911	1.395			
	NYCC	0.676	18.285	1.275	0.193	14.328	0.908	1.182	11.018	1.643			
	SCC12	0.346	11.21	0.517	0.512	20.911	0.519	0.463	3.14	1.149			
	UHWY	0.066	1.013	0.58	0.02	0.18	0.433	0.107	0.394	0.984			
	WHWY	0.035	0.043	1.41	0.022	0.3	1.078	0.036	0.062	1.507			
	XHWY	0.038	0.753	1.528	0.03	1.148	1.644	0.048	0.741	1.497			

* Repeated sequence

1989 Mercury Topaz

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	1.571	0.064	0.092	0.383	32.457	0.656	0.693	7.238	0.735	0.378	0.569	0.504
FTP	Indolene	75	0.513	0.059	0.119	0.17	5.419	1.466	1.477	2.29	1.203	0.399	0.712	0.652
FTP	Indolene	100	0.427	0.023	0.07	0.119	4.103	1.153	1.085	1.746	1.314	0.458	1.054	0.799
FTP	Phase1	50	1.581	0.064	0.098	0.388	25.391	1.379	0.817	6.208	1.031	0.452	0.804	0.669
FTP	Phase1	75	0.744	0.046	0.096	0.204	7.818	1.146	0.733	2.411	1.049	0.32	0.702	0.576
FTP	Phase1	100	0.527	0.045	0.07	0.152	5.733	0.922	0.703	1.861	1.07	0.418	0.848	0.672
FTP	Phase2	50	0.534	0.046	0.077	0.156	6.437	0.394	0.607	1.709	1.1	0.378	0.708	0.619
FTP	Phase2	75	0.479	0.046	0.087	0.148	5.562	0.666	0.685	1.691	1.005	0.443	0.667	0.622
FTP	Phase2	100	0.43	0.036	0.083	0.13	4.728	0.966	1.081	1.778	1.041	0.392	0.914	0.67
FTP*	Indolene	75	0.852	0.063	0.101	0.236	8.764	1.124	0.905	2.644	0.854	0.353	0.602	0.525
LA92	Indolene	50	0.078	0.051	0.184	0.062	1.315	1.826	1.29	1.763	0.665	0.725	0.935	0.737
LA92	Indolene	75	0.172	0.114	0.259	0.127	7.531	7.284	6.283	7.228	0.869	0.71	0.958	0.735
LA92	Indolene	100	1.053	0.086	0.19	0.143	8.864	4.829	4.616	5.022	2.382	0.827	1.436	0.95
LA92	Phase1	50	0.257	0.07	0.166	0.086	2.116	1.879	1.436	1.86	0.88	0.888	1.117	0.904
LA92	Phase1	75	0.344	0.08	0.135	0.097	12.188	5.516	2.91	5.682	0.712	0.847	1.237	0.867
LA92	Phase1	100	0.577	0.069	0.199	0.104	4.68	5.192	7.536	5.328	1.28	0.806	1.353	0.868
LA92	Phase2	50	0.148	0.04	0.2	0.057	0.775	0.904	1.747	0.955	0.736	0.776	0.926	0.784
LA92	Phase2	75	0.09	0.069	0.199	0.079	3.28	3.535	2.949	3.482	0.885	0.734	1.118	0.768
LA92	Phase2	100	0.107	0.074	0.135	0.08	6.562	4.807	5.564	4.95	0.954	0.794	1.156	0.827
LA92*	Indolene	75	0.906	0.064	0.228	0.118	5.002	3.92	4.561	4.02	1.626	0.671	1.217	0.758

*repeat

1992 FORD TAURUS

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	0.297	3.269	0.191	0.19	2.312	0.206	0.235	1.835	0.212			
	HHWY	0.068	0.653	0.054	0.024	0.306	0.036	0.037	0.443	0.022			
	LA92	0.119	1.117	0.197	0.054	0.563	0.215	0.075	1.304	0.251			
	LOW1	4.427	13.933	0.4	0.446	0.712	0.175	0.379	1.511	0.096			
50 F	LOW3	3.45	15.663	1.04	0.289	1.028	0.263	0.237	0.767	0.15			
	NYCC	0.195	2.281	0.215	0.211	1.456	0.42	0.179	1.451	0.346			
	SCC12	0.696	3.604	0.444	0.113	0.543	0.252	0.113	0.964	0.141			
	UHWY	0.097	1.236	0.091	0.022	0.227	0.041	0.047	0.606	0.023			
	WHWY	0.101	1.647	0.188	0.029	0.386	0.13	0.033	0.493	0.076			
	XHWY	0.065	0.946	0.123	0.024	0.437	0.2	0.046	0.651	0.152			
	FTP	0.253	3.052	0.209	0.173	1.52	0.316	0.208	2.266	0.239	0.202	2.132	0.275
	HHWY	0.097	0.685	0.126	0.066	0.372	0.09	0.069	1.542	0.05	0.054	1.071	0.037
	LA92	0.128	1.366	0.241	0.07	0.982	0.281	0.115	2.302	0.236	0.086	1.721	0.258
	LOW1	4.04	13.099	0.413	0.438	0.759	0.115	0.508	3.756	0.133	0.522	3.871	0.097
75 F	LOW3	2.644	11.271	0.893	0.296	2.385	0.295	0.312	0.918	0.172	0.566	11.705	0.264
	NYCC	0.386	2.83	0.409	0.209	2.192	0.44	0.401	6.68	0.542	0.435	7.739	0.587
	SCC12	0.731	3.362	0.656	0.095	0.441	0.221	0.218	3.901	0.203	0.207	4.575	0.363
	UHWY	0.08	0.718	0.092	0.022	0.145	0.037	0.058	0.996	0.057	0.062	0.876	0.055
	WHWY	0.101	1.111	0.184	0.028	0.271	0.128	0.061	1.28	0.097	0.039	0.554	0.102
	XHWY	0.123	1.078	0.389	0.038	0.423	0.258	0.046	0.554	0.225	0.04	0.479	0.234
	FTP	0.236	2.916	0.218	0.168	1.77	0.243	0.174	1.864	0.284			
	HHWY	0.064	0.617	0.091	0.033	0.461	0.066	0.05	1.021	0.058			
	LA92	0.152	1.585	0.305	0.089	2.099	0.384	0.086	1.557	0.344			
	LOW1	0.676	3.672	0.074	0.523	1.612	0.107	0.835	6.03	0.118			
100 F	LOW3	0.744	8.319	0.173	0.433	5.542	0.281	0.491	7.943	0.225			
	NYCC	0.332	2.633	0.424	0.47	9.775	0.667	0.373	4.97	0.521			
	SCC12	0.11	2.031	0.216	0.433	11.993	0.335	0.528	12.396	0.29			
	UHWY	0.104	0.779	0.218	0.026	0.181	0.056	0.096	1.865	0.044			
	WHWY	0.043	0.524	0.126	0.037	0.399	0.214	0.045	0.593	0.136			
	XHWY	0.082	1.006	0.281	0.045	0.589	0.272	0.056	0.818	0.221			

* Repeated sequence

1992 Ford Taurus

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	0.788	0.051	0.164	0.235	5.528	0.867	0.86	1.835	0.442	0.127	0.198	0.212
FTP	Indolene	75	0.628	0.07	0.148	0.208	6.425	1.322	0.897	2.266	0.433	0.18	0.202	0.239
FTP	Indolene	100	0.512	0.073	0.112	0.174	4.169	1.589	0.649	1.884	0.497	0.245	0.196	0.284
FTP	Phase1	50	0.969	0.065	0.225	0.297	11.992	0.843	1.252	3.269	0.484	0.064	0.21	0.191
FTP	Phase1	75	0.794	0.077	0.177	0.253	10.329	1.177	1.092	3.052	0.446	0.125	0.188	0.209
FTP	Phase1	100	0.768	0.072	0.14	0.236	8.991	1.461	1.055	2.916	0.421	0.137	0.214	0.218
FTP	Phase2	50	0.7	0.034	0.097	0.19	9.254	0.447	0.591	2.312	0.473	0.116	0.173	0.206
FTP	Phase2	75	0.523	0.062	0.118	0.173	4.629	0.814	0.5	1.52	0.497	0.282	0.243	0.316
FTP	Phase2	100	0.543	0.059	0.088	0.168	5.448	0.957	0.526	1.77	0.446	0.183	0.204	0.243
FTP*	Indolene	75	0.648	0.062	0.128	0.202	6.145	1.282	0.691	2.132	0.486	0.221	0.218	0.275
LA92	Indolene	50	0.232	0.058	0.165	0.075	5.309	1.114	0.697	1.304	0.424	0.228	0.408	0.251
LA92	Indolene	75	0.633	0.078	0.193	0.115	13.873	1.731	0.791	2.302	0.424	0.218	0.336	0.236
LA92	Indolene	100	0.128	0.076	0.174	0.086	2.102	1.6	0.608	1.557	0.524	0.329	0.403	0.344
LA92	Phase1	50	0.525	0.079	0.32	0.119	2.878	0.887	2.731	1.117	0.605	0.159	0.377	0.197
LA92	Phase1	75	0.487	0.091	0.325	0.128	2.497	1.246	2.051	1.306	0.625	0.205	0.41	0.241
LA92	Phase1	100	0.828	0.104	0.257	0.152	3.997	1.446	1.55	1.585	0.86	0.27	0.339	0.305
LA92	Phase2	50	0.117	0.042	0.161	0.054	0.713	0.552	0.584	0.563	0.302	0.197	0.379	0.215
LA92	Phase2	75	0.156	0.058	0.16	0.07	2.177	0.936	0.669	0.982	0.356	0.269	0.379	0.281
LA92	Phase2	100	0.362	0.064	0.2	0.089	10.111	1.727	0.855	2.099	0.53	0.366	0.504	0.384
LA92*	Indolene	75	0.354	0.064	0.164	0.086	7.968	1.42	0.771	1.721	0.42	0.235	0.429	0.258

*repeat

1985 CONTINENTAL MRKVII

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	1.051	20.307	0.709	0.545	3.549	0.564	0.51	4.515	0.63			
	HHWY	0.201	1.092	0.441	0.243	1.034	0.542	0.167	0.49	0.407			
	LA92	0.441	2.906	0.796	0.425	2.506	0.876	0.376	1.635	0.999			
	LOW1	8.643	34.81	1.461	14.509	230.828	0.733	13.294	260.649	0.788			
50 F	LOW3	4.727	79.61	0.623	8.834	118.89	0.688	5.038	89.497	0.716			
	NYCC	5.566	83.819	0.709	3.786	37.255	0.855	1.381	13.296	0.824			
	SCC12	2.465	27.989	0.484	1.166	4.101	0.572	0.52	2.144	0.572			
	UHWY	0.483	2.918	0.306	0.326	1.715	0.558	0.162	0.387	0.496			
	WHWY	0.317	2.671	0.744	0.268	2.07	0.952	0.156	0.364	1.317			
	XHWY	0.141	0.447	1.235	0.283	2.595	1.41	0.162	0.349	1.682			
	FTP	0.595	3.66	0.636	0.48	3.022	0.592	0.473	2.646	0.691	0.531	3.165	0.64
	HHWY	0.304	2.355	0.454	0.139	0.321	0.392	0.228	1.094	0.668	0.313	1.246	0.883
	LA92	0.555	5.221	1.014	0.321	1.615	0.827	0.37	2.081	1.012	0.533	3.307	1.041
	LOW1	29.303	547.988	0.695	13.779	260.612	0.894	10.957	217.546	1.371	21.793	334.283	0.96
75 F	LOW3	14.878	257.974	0.569	5.054	84.876	0.77	9.623	194.479	0.612	10.965	184.956	0.61
	NYCC	5.814	93.016	0.831	1.115	8.974	0.942	0.931	7.766	1.013	6.447	43.085	0.834
	SCC12	2.047	25.709	0.503	0.492	1.661	0.509	0.455	2.615	0.652	2.363	21.069	0.611
	UHWY	0.281	0.638	0.676	0.156	0.444	0.321	0.15	0.56	0.351	0.165	0.194	0.913
	WHWY	0.325	2.466	0.959	0.136	0.289	0.761	0.153	0.666	0.956	0.3	2.64	1.651
	XHWY	0.285	1.78	1.479	0.145	0.4	1.128	0.142	0.461	1.358	0.329	6.429	2.162
	FTP	0.575	2.649	0.639	0.505	2.273	0.644	0.536	2.602	0.648			
	HHWY	0.325	2.855	0.524	0.321	1.346	0.719	0.302	1.357	0.629			
	LA92	0.431	3.681	1.033	0.485	3.016	1.009	0.477	3.003	0.937			
	LOW1	30.318	538.057	0.723	13.642	233.49	0.897	20.493	374.038	0.802			
100 F	LOW3	13.602	214.397	0.557	6.149	93.039	0.768	5.986	107.226	0.662			
	NYCC	5.371	82.876	0.85	1.421	8.993	1.083	3.022	30.425	0.836			
	SCC12	2.263	28.179	0.566	1.369	8.458	0.692	1.343	5.657	0.66			
	UHWY	0.382	3.932	0.393	0.141	0.347	0.438	0.407	3.034	0.752			
	WHWY	0.289	2.258	1.056	0.272	2.662	1.027	0.264	2.396	1.073			
	XHWY	0.263	1.998	1.708	0.317	2.9	1.595	0.363	3.136	1.133			

* Repeated sequence

1985 Continental MRKVII

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	0.896	0.395	0.435	0.51	16.995	1.025	1.658	4.515	1.021	0.392	0.781	0.83
FTP	Indolene	75	0.766	0.394	0.401	0.473	7.031	1.194	2.078	2.646	0.998	0.48	0.859	0.691
FTP	Indolene	100	1.104	0.389	0.383	0.536	7.918	1.254	1.119	2.602	0.805	0.495	0.817	0.648
FTP	Phase1	50	3.641	0.369	0.385	1.051	93.383	1.142	1.314	20.307	1.471	0.375	0.764	0.709
FTP	Phase1	75	1.384	0.353	0.454	0.595	12.557	0.966	2.018	3.66	0.875	0.439	0.826	0.638
FTP	Phase1	100	1.401	0.33	0.411	0.575	8.064	0.904	1.838	2.649	0.834	0.452	0.842	0.639
FTP	Phase2	50	1.085	0.375	0.461	0.545	13.332	0.771	1.418	3.549	0.981	0.355	0.843	0.564
FTP	Phase2	75	0.82	0.39	0.39	0.48	10.481	1.068	1.05	3.022	0.823	0.419	0.742	0.592
FTP	Phase2	100	0.831	0.369	0.516	0.505	5.725	1.225	1.639	2.273	0.866	0.461	0.819	0.644
FTP*	Indolene	75	0.936	0.417	0.441	0.531	10.871	1.139	1.156	3.165	0.849	0.405	0.925	0.64
LA92	Indolene	50	0.631	0.301	1.142	0.376	2.073	1.488	3.163	1.635	1.211	0.997	0.857	0.999
LA92	Indolene	75	0.506	0.289	1.309	0.37	1.467	1.738	6.937	2.081	1.028	1.005	1.082	1.012
LA92	Indolene	100	1.648	0.329	1.486	0.477	11.79	2.177	6.98	3.003	0.866	0.94	0.954	0.937
LA92	Phase1	50	2.73	0.26	1.014	0.441	33.712	1.079	2.859	2.906	0.786	0.794	0.833	0.796
LA92	Phase1	75	2.62	0.293	2.308	0.555	35.289	1.426	30.523	5.221	0.988	1.023	0.93	1.014
LA92	Phase1	100	2.759	0.234	1.188	0.431	36.606	1.564	5.818	3.681	0.834	1.048	0.99	1.033
LA92	Phase2	50	2.784	0.254	0.817	0.425	30.184	0.825	3.07	2.506	0.849	0.884	0.785	0.876
LA92	Phase2	75	0.678	0.245	1.032	0.321	3.092	1.3	4.542	1.615	0.843	0.826	0.824	0.827
LA92	Phase2	100	3.208	0.28	1.073	0.485	28.288	1.399	4.824	3.016	0.989	0.998	1.166	1.009
LA92*	Indolene	75	3.546	0.301	1.244	0.533	29.369	1.458	7.45	3.307	1.035	1.058	0.83	1.041

*repeat

1988 CADILLAC DEVILLE

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	0.304	2.393	0.648	0.352	1.908	0.624	0.693	13.416	0.648			
	HHWY	0.151	0.704	0.458	0.187	1.325	0.569	0.161	0.886	0.503			
	LA92	0.244	4.631	0.981	0.229	3.996	0.879	0.256	4.752	0.887			
	LOW1	17.394	115.76	0.91	3.831	19.254	0.884	18.81	112.028	1.088			
50 F	LOW3	6.575	23.071	1.206	9.698	46.656	1.096	6.654	18.624	1.025			
	NYCC	2.038	11.009	1.424	2.459	11.307	1.36	2.572	12.919	1.267			
	SCC12	1.685	6.756	1.153	1.773	8.746	1.239	1.836	7.065	0.971			
	UHWY	0.229	1.594	0.588	0.264	1.582	0.443	0.228	1.258	0.488			
	WHWY	0.163	3.969	0.821	0.18	4.84	0.62	0.185	4.59	0.812			
	XHWY	0.178	5.486	1.822	0.16	5.553	1.385	0.169	4.505	1.737			
	FTP	0.309	2.472	0.807	0.343	1.925	0.784	0.326	1.661	0.773	0.319	1.839	0.746
	HHWY	0.137	0.514	0.584	0.172	0.918	0.751	0.163	1.045	0.764	0.143	0.978	0.65
	LA92	0.267	5.101	1.223	0.25	4.637	1.087	0.274	4.243	1.171	0.229	4.707	1.109
	LOW1	18.978	128.638	1.295	18.022	100.154	1.458	16.914	66.454	1.389	16.828	109.644	1.19
75 F	LOW3	5.085	18.394	1.176	5.648	20.671	1.229	6.355	21.889	1.292	1.161	0.632	0.876
	NYCC	2.415	13.091	1.45	2.199	9.492	1.653	2.165	10.273	1.553	2.192	10.567	1.49
	SCC12	1.395	4.926	0.976	1.516	4.9	1.051	1.554	7.369	0.984	1.33	5.581	0.892
	UHWY	0.221	1.089	0.626	0.24	1.144	0.648	0.22	1.042	0.54	0.217	2.658	0.987
	WHWY	0.207	4.593	0.963	0.194	3.461	0.961	0.213	3.806	0.951	0.179	4.945	1.008
	XHWY	0.161	4.619	1.6	0.16	4.008	2.022	0.213	5.372	2.404	0.16	4.205	2.233
	FTP	0.278	1.509	0.589	0.296	1.726	0.718	0.26	1.661	0.8			
	HHWY	0.107	0.519	0.872	0.161	0.602	0.61	0.064	0.227	0.685			
	LA92	0.174	4.213	1.378	0.216	3.401	1.512	0.237	5.167	1.231			
	LOW1	16.216	101.769	1.326	9.238	59.605	1.124	13.737	87.731	1.654			
100 F	LOW3	3.719	18.48	1.343	8.059	51.174	1.385	1.373	0.926	1.176			
	NYCC	2.111	11.636	1.684	2.151	7.883	1.602	2.045	10.754	2.028			
	SCC12	1.074	6.866	1.064	1.377	9.132	1.104	0.52	0.978	1.123			
	UHWY	0.208	0.747	0.652	0.221	1.376	0.627	0.117	0.554	0.66			
	WHWY	0.155	3.362	1.13	0.148	2.943	1.151	0.117	4.077	0.987			
	XHWY	0.138	5.304	1.579	0.169	5.001	2.455	0.399	19.813	0.963			

* Repeated sequence

1988 Cadillac De Ville

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	2.221	0.364	0.16	0.693	53.28	4.379	0.337	13.416	1.212	0.354	0.774	0.648
FTP	Indolene	75	0.742	0.229	0.194	0.326	7.027	0.181	0.395	1.661	1.026	0.482	1.129	0.773
FTP	Indolene	100	0.558	0.193	0.162	0.26	6.48	0.222	0.748	1.661	0.844	0.585	1.175	0.8
FTP	Phase1	50	0.778	0.175	0.192	0.304	10.621	0.136	0.435	2.393	0.806	0.439	0.923	0.648
FTP	Phase1	75	0.759	0.203	0.169	0.309	11.276	0.071	0.334	2.472	1.217	0.522	1.033	0.807
FTP	Phase1	100	0.681	0.184	0.153	0.278	6.899	0.045	0.208	1.509	0.733	0.411	0.819	0.589
FTP	Phase2	50	0.839	0.236	0.204	0.352	8.571	0.078	0.33	1.908	0.725	0.44	0.896	0.624
FTP	Phase2	75	0.823	0.219	0.211	0.343	8.57	0.089	0.359	1.925	1.049	0.513	1.092	0.784
FTP	Phase2	100	0.745	0.18	0.176	0.296	7.865	0.031	0.291	1.726	0.856	0.527	0.975	0.718
FTP*	Indolene	75	0.683	0.238	0.198	0.319	7.893	0.138	0.476	1.839	0.925	0.513	1.049	0.746
LA92	Indolene	50	1.65	0.163	0.395	0.256	9.625	4.778	0.753	4.752	1.297	0.837	1.212	0.887
LA92	Indolene	75	1.916	0.164	0.44	0.274	9.295	4.18	1.241	4.243	1.582	1.132	1.346	1.171
LA92	Indolene	100	1.815	0.137	0.334	0.237	6.831	5.399	0.955	5.167	1.665	1.177	1.589	1.231
LA92	Phase1	50	1.707	0.149	0.347	0.244	10.542	4.59	0.691	4.631	1.595	0.911	1.412	0.981
LA92	Phase1	75	1.979	0.163	0.301	0.267	11.798	5.057	0.617	5.101	1.819	1.169	1.47	1.223
LA92	Phase1	100	1.295	0.105	0.216	0.174	10.351	3.929	3.183	4.213	1.994	1.326	1.582	1.378
LA92	Phase2	50	1.606	0.131	0.444	0.229	6.541	4.104	0.693	3.996	1.363	0.826	1.191	0.879
LA92	Phase2	75	1.912	0.144	0.358	0.25	11.225	4.55	0.767	4.637	1.557	1.022	1.569	1.087
LA92	Phase2	100	1.661	0.118	0.377	0.216	10.086	3.14	1.691	3.401	2.252	1.422	2.094	1.512
LA92*	Indolene	75	1.616	0.137	0.349	0.229	8.873	4.736	1.204	4.707	1.488	1.054	1.521	1.109

*repeat

1988 DODGE DAYTONA

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	1.003	26.225	0.436	1.136	30.111	0.369	0.212	4.192	0.462			
	HHWY	0.063	0.846	0.525	0.049	3.48	0.268	0.054	1.465	0.376			
	LA92	0.164	4.444	0.826	0.171	4.468	0.679	0.133	4.058	0.683			
	LOW1	1.661	24.721	1.198	1.081	11.97	0.679	0.707	9.671	0.684			
50 F	LOW3	0.996	18.141	1.021	0.647	8.793	0.652	0.668	9.938	0.743			
	NYCC	0.508	9.984	1.258	0.344	6.911	0.687	1.128	9.834	1.023			
	SCC12	0.601	9.08	0.874	0.651	5.876	0.651	0.371	5.951	0.549			
	UHWY	0.055	0.773	0.444	0.049	0.887	0.355	0.462	3.831	0.511			
	WHWY	0.076	2.488	0.632	0.055	2.418	0.572	0.081	3.797	0.444			
	XHWY	0.089	3.541	0.836	0.096	2.971	0.554	1.478	35.968	0.668			
	FTP	0.826	13.016	0.791	0.305	3.813	0.474	0.251	3.747	0.432	0.223	3.331	0.472
	HHWY	0.034	0.844	0.472	0.069	0.532	0.297	0.03	0.546	0.281	0.024	0.276	0.292
	LA92	0.235	6.808	0.844	0.222	3.702	0.72	0.259	5.295	0.724	0.181	3.964	0.63
	LOW1	1.637	27.884	1.401	1.313	14.582	0.875	1.084	13.938	0.977	1.245	8.91	0.819
75 F	LOW3	1.032	13.336	0.866	0.632	7.264	0.629	0.322	6.342	0.554	1.909	12.807	0.843
	NYCC	0.703	11.67	1.388	0.713	8.962	1.018	0.344	8.156	0.843	0.377	6.844	0.913
	SCC12	0.824	9.24	0.661	0.313	3.494	0.628	0.109	3.316	0.43	0.184	3.475	0.557
	UHWY	0.123	1.323	0.396	0.062	0.559	0.341	0.029	0.649	0.252	0.031	0.344	0.24
	WHWY	0.096	2.984	0.628	0.05	1.817	0.398	0.059	1.951	0.412	0.045	1.431	0.544
	XHWY	0.064	3.781	0.805	0.13	3.36	0.58	0.08	3.029	0.568	0.051	2.27	0.611
	FTP	0.822	20.967	0.42	0.24	4.066	0.731	0.201	2.266	0.442			
	HHWY	0.07	1.168	0.43	0.089	4.111	0.435	0.019	0.376	0.288			
	LA92	0.47	9.057	0.873	0.564	13.096	1.346	0.376	7.051	0.704			
	LOW1	1.545	19.342	1.08	0.609	13.619	1.13	0.596	10.182	0.648			
100 F	LOW3	0.857	11.257	1.111	1.6	29.618	0.673	0.285	6.552	0.475			
	NYCC	0.384	7.701	1.097	1.213	45.152	1.634	0.296	6.317	0.757			
	SCC12	0.263	5.101	0.615	1.276	26.247	0.738	0.11	2.34	0.508			
	UHWY	0.074	3.133	0.319	0.19	10.628	0.341	0.016	0.203	0.201			
	WHWY	0.095	3.198	0.615	0.053	2.038	0.592	0.05	1.473	0.413			
	XHWY	0.194	5.318	1.142	0.114	4.675	0.872	0.063	2.812	0.509			

* Repeated sequence

1988 Dodge Daytona

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	0.592	0.074	0.187	0.212	7.858	3.612	2.523	4.192	0.628	0.377	0.497	0.462
FTP	Indolene	75	0.653	0.084	0.261	0.251	7.268	2.73	3.01	3.747	0.58	0.365	0.447	0.432
FTP	Indolene	100	0.496	0.064	0.238	0.201	4.419	1.453	2.173	2.266	0.603	0.347	0.499	0.442
FTP	Phase1	50	3.801	0.289	0.244	1.003	100.927	8.701	3.035	26.225	0.409	0.386	0.549	0.436
FTP	Phase1	75	3.077	0.179	0.35	0.826	41.498	5.557	5.627	13.016	1.348	0.548	0.831	0.791
FTP	Phase1	100	3.185	0.165	0.278	0.822	86.446	4.059	3.477	20.987	0.467	0.353	0.511	0.42
FTP	Phase2	50	3.956	0.506	0.205	1.136	100.723	16.424	2.834	30.111	0.302	0.295	0.56	0.369
FTP	Phase2	75	0.898	0.13	0.187	0.305	7.033	3.204	2.532	3.813	0.706	0.347	0.537	0.474
FTP	Phase2	100	0.738	0.077	0.174	0.24	6.714	3.66	2.837	4.066	1.013	0.587	0.792	0.731
FTP*	Indolene	75	0.62	0.064	0.223	0.223	6.757	2.313	2.671	3.331	0.655	0.387	0.494	0.472
LA92	Indolene	50	0.448	0.1	0.314	0.133	10.415	3.598	5.131	4.058	0.845	0.671	0.715	0.683
LA92	Indolene	75	0.208	0.156	1.602	0.259	3.691	3.047	34.941	5.295	0.869	0.724	0.615	0.724
LA92	Indolene	100	0.319	0.134	3.487	0.376	5.016	3.061	59.094	7.051	0.829	0.705	0.597	0.704
LA92	Phase1	50	0.524	0.118	0.478	0.164	9.869	4.001	6.008	4.444	1.096	0.803	0.925	0.826
LA92	Phase1	75	0.632	0.139	1.144	0.235	10.668	5.358	22.248	6.808	1.008	0.82	1.026	0.844
LA92	Phase1	100	0.482	0.212	3.733	0.47	9.346	5.264	57.01	9.057	1.184	0.857	0.836	0.873
LA92	Phase2	50	0.314	0.158	0.224	0.171	5.12	4.49	3.693	4.468	0.985	0.656	0.741	0.679
LA92	Phase2	75	0.463	0.147	0.993	0.222	4.797	3.137	10.073	3.702	0.839	0.693	0.975	0.72
LA92	Phase2	100	0.655	0.255	4.471	0.564	18.648	8.098	65.493	13.096	1.4	1.29	2.023	1.346
LA92*	Indolene	75	0.858	0.1	0.712	0.181	9.441	2.927	13.136	3.964	1.051	0.581	0.943	0.63

*repeat

1979 CHEVROLET IMPALA

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	2.341	23.66	0.789	2.413	26.336	0.686	2.462	35.094	0.697			
	HHWY	1.093	6.923	0.931	1.266	8.739	0.933	0.946	8.971	0.904			
	LA92	2.145	26.247	0.979	2.144	29.215	0.887	2.075	38.845	0.872			
	LOW1	12.301	36.76	1.943	13.483	65.817	1.24	12.202	61.906	1.72			
50 F	LOW3	7.81	41.259	1.452	8.526	36.791	1.16	7.162	63.35	1.248			
	NYCC	5.397	35.054	1.409	5.527	46.329	1.092	5.371	51.234	1.258			
	SCC12	3.051	14.573	1	3.198	21.261	0.8	2.915	30.289	0.863			
	UHWY	1.368	4.437	0.77	1.312	5.626	0.759	1.041	6.673	0.796			
	WHWY	1.029	20.166	1.281	1.219	25.064	1.189	0.9	21.678	1.242			
	XHWY	0.989	39.838	1.257	1.066	46.274	1.007	0.744	39.463	0.93			
	FTP	2.679	34.206	0.93	2.509	23.696	0.822	2.07	32.944	0.718	2.523	40.268	0.693
	HHWY	1.079	10.095	1.238	1.207	9.354	0.991	1.034	9.474	0.984	1.082	12.37	0.95
	LA92	2.295	38.126	1.179	2.461	35.549	0.907	2.229	40.03	0.935	2.319	44.452	0.855
	LOW1	15.172	67.589	1.915	14.459	26.94	1.682	13.473	54.353	1.65	12.948	39.564	1.725
75 F	LOW3	8.438	14.239	1.68	7.841	10.713	1.516	8.091	36.91	1.464	8.215	28.906	1.448
	NYCC	6.851	69.93	1.353	6.678	34.798	1.304	5.784	43.744	1.286	5.795	75.121	1.106
	SCC12	3.791	31.834	1.057	4.022	16.185	0.985	3.292	35.154	0.84	3.228	23.049	0.884
	UHWY	1.309	6.681	1.038	1.618	7.639	0.862	1.309	6.606	0.856	1.303	10.494	0.794
	WHWY	1.321	26.577	1.466	1.233	28.763	1.163	1.107	24.561	1.287	1.191	35.766	1.085
	XHWY	1.04	52.583	1.256	1.1	44.565	1.091	0.849	44.17	0.991	0.964	54.087	0.877
	FTP	2.643	31.169	0.808	2.566	28.488	1.053	2.382	32.062	0.677			
	HHWY	1.202	12.677	1.199	1.179	11.691	1.248	1.035	12.164	0.969			
	LA92	2.701	50.479	1.084	2.707	43.941	1.182	2.178	53.024	0.834			
	LOW1	12.378	29.369	2.146	14.64	33.107	2.085	11.281	37.097	1.7			
100 F	LOW3	8.089	22.215	1.723	7.83	25.56	2.027	7.591	39.62	1.4			
	NYCC	6.688	66.065	1.4	6.188	40.759	1.65	5.512	76.943	1.099			
	SCC12	3.457	29.542	0.948	4.217	19.971	1.164	2.77	21.076	0.978			
	UHWY	1.329	7.982	1.013	1.268	16.222	1.294	1.156	7.516	0.869			
	WHWY	1.154	32.048	1.434	1.283	34.68	1.414	1.084	36.861	1.141			
	XHWY	1.202	68.113	0.97	1.101	53.178	1.457	0.988	60.465	1.044			

* Repeated sequence

1979 Chevrolet Impala

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	3.125	2.407	2.065	2.462	53.63	31.534	27.826	35.094	0.668	0.635	0.835	0.697
FTP	Indolene	75	0.559	2.534	2.334	2.07	44.974	29.167	31.004	32.944	0.704	0.672	0.815	0.718
FTP	Indolene	100	2.664	2.399	2.138	2.382	43.628	26.368	34.091	32.062	0.636	0.642	0.773	0.677
FTP	Phase1	50	2.798	2.328	2.021	2.341	35.875	19.856	21.599	23.66	0.796	0.741	0.874	0.789
FTP	Phase1	75	3.142	2.571	2.53	2.679	51.325	30.634	27.906	34.206	0.917	0.863	1.004	0.93
FTP	Phase1	100	2.892	2.664	2.417	2.643	37.083	27.231	34.124	31.169	0.81	0.765	0.888	0.808
FTP	Phase2	50	2.675	2.472	2.189	2.413	32.757	25.307	23.42	26.336	0.709	0.625	0.786	0.686
FTP	Phase2	75	2.805	2.501	2.3	2.509	38.403	17.885	23.566	23.696	0.771	0.79	0.92	0.822
FTP	Phase2	100	2.943	2.587	2.24	2.566	39.004	19.576	37.28	28.488	0.946	1.058	1.123	1.053
FTP*	Indolene	75	3.145	2.461	2.192	2.523	64.968	34.789	31.959	40.268	0.622	0.662	0.806	0.693
LA92	Indolene	50	3.193	1.876	3.783	2.075	52.714	37.545	45.063	38.845	0.994	0.859	0.951	0.872
LA92	Indolene	75	3.396	2.019	4.079	2.229	41.449	39.049	51.805	40.03	1.06	0.921	1.02	0.935
LA92	Indolene	100	3.33	1.995	3.641	2.178	63.53	51.993	58.261	53.024	0.849	0.829	0.878	0.834
LA92	Phase1	50	3.351	1.948	3.779	2.145	26.537	26.105	27.86	26.247	1.057	0.967	1.069	0.979
LA92	Phase1	75	3.693	2.04	4.466	2.295	40.241	37.408	45.589	38.126	1.252	1.175	1.185	1.179
LA92	Phase1	100	3.985	2.318	6.585	2.701	43.22	50.958	49.867	50.479	1.255	1.063	1.222	1.084
LA92	Phase2	50	3.913	1.884	4.168	2.144	35.581	28.635	31.867	29.215	0.919	0.88	0.954	0.887
LA92	Phase2	75	7.809	1.984	4.578	2.461	39.141	35.403	34.703	35.549	1.007	0.888	1.08	0.907
LA92	Phase2	100	10.245	1.972	6.529	2.707	59.528	42.145	55.436	43.941	1.104	1.175	1.332	1.182
LA92*	Indolene	75	3.507	2.12	3.963	2.319	40.626	43.688	56.979	44.452	0.988	0.849	0.823	0.855

*repeat

1982 BUICK REGAL

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	0.495	4.606	1.051	0.402	3.478	1.031	0.497	4.578	0.897			
	HHWY	0.116	0.923	0.624	0.092	0.784	0.569	0.072	1.019	0.501			
	LA92	0.237	6.472	0.967	0.242	5.539	0.856	0.198	6.397	0.83			
	LOW1	4.233	4.028	3.707	2.581	2.354	3.214	0.468	0.353	3.021			
50 F	LOW3	1.66	2.16	2.486	1.768	2.557	2.246	0.352	1.441	2.255			
	NYCC	2.533	10.155	1.984	1.258	6.526	1.487	0.399	5.758	1.454			
	SCC12	0.434	2.669	1.074	1.824	5.624	1.405	0.168	2.542	0.94			
	UHWY	0.249	1.314	0.504	0.241	1.226	0.502	0.076	0.97	0.432			
	WHWY	0.147	1.1	1.208	0.231	1.331	1.101	0.081	1.343	1.043			
	XHWY	0.209	2.977	1.783	0.141	3.179	1.511	0.126	4.268	1.547			
	FTP	0.509	5.976	0.907	0.399	3.197	0.941	0.456	4.602	0.933	2.468	12.909	1.674
	HHWY	0.108	0.722	0.626	0.059	0.678	0.501	0.078	0.97	0.6	1.377	4.405	1.368
	LA92	0.367	6.87	1.051	0.175	5.725	0.797	0.211	6.256	0.954	2.33	14.386	1.841
	LOW1	4.16	4.987	3.873	0.386	0.178	3.363	0.398	0.495	3.138	14.255	8.128	2.177
75 F	LOW3	1.679	3.349	2.406	0.294	0.748	2.672	2.71	4.377	2.281	8.912	6.594	3.459
	NYCC	1.626	9.423	1.839	0.38	4.935	1.376	0.544	5.581	1.386	5.589	14.539	2.858
	SCC12	0.701	4.159	1.088	0.154	1.896	1.072	0.164	2.734	0.952	3.926	8.617	1.697
	UHWY	0.126	0.808	0.531	0.062	0.595	0.423	0.081	0.951	0.431	1.48	5.283	1.2
	WHWY	0.187	1.742	0.725	0.07	1.014	0.948	0.113	0.864	1.082	1.434	7.027	1.961
	XHWY	0.265	5.197	1.481	0.088	2.579	1.415	0.145	4.644	1.648	1.291	10.581	2.463
	FTP	0.402	3.754	1.014	0.375	3.752	0.801	0.434	4.476	0.801			
	HHWY	0.182	1.088	0.631	0.115	1.176	0.493	0.098	1.639	0.399			
	LA92	0.228	7.485	0.933	0.196	6.206	0.805	0.278	8.867	0.648			
	LOW1	1.492	0.923	3.254	1.473	1.091	2.323	0.52	0.308	1.96			
100 F	LOW3	1.47	2.437	2.516	1.713	2.606	1.957	0.454	2.111	1.751			
	NYCC	0.712	5.711	1.415	0.794	4.903	1.205	0.637	8.019	1.126			
	SCC12	0.282	1.412	0.993	0.503	2.202	0.728	0.205	2.65	0.878			
	UHWY	0.073	0.48	0.523	0.2	1.239	0.424	0.096	1.635	0.31			
	WHWY	0.105	0.956	1.186	0.112	1.918	1.002	0.109	1.149	0.816			
	XHWY	0.225	5.119	1.627	0.166	4.289	1.396	0.179	2.132	1.358			

* Repeated sequence

1982 Buick Regal

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	1.458	0.206	0.321	0.497	14.3	1.831	2.434	4.578	1.615	0.706	0.716	0.897
FTP	Indolene	75	1.222	0.214	0.336	0.456	11.876	2.259	3.54	4.602	1.858	0.701	0.676	0.933
FTP	Indolene	100	1.132	0.205	0.337	0.434	10.726	2.487	3.488	4.476	1.562	0.588	0.627	0.801
FTP	Phase1	50	1.491	0.184	0.326	0.495	16.38	1.33	1.858	4.606	1.917	0.769	0.927	1.051
FTP	Phase1	75	1.386	0.2	0.428	0.509	18.781	2.437	2.956	5.976	1.734	0.675	0.717	0.907
FTP	Phase1	100	1.18	0.147	0.295	0.402	11.34	1.388	2.481	3.754	2.004	0.725	0.808	1.014
FTP	Phase2	50	1.1	0.179	0.297	0.402	11.028	1.461	1.578	3.478	1.941	0.743	0.888	1.031
FTP	Phase2	75	1.12	0.173	0.28	0.399	8.862	1.419	2.275	3.197	1.733	0.743	0.717	0.941
FTP	Phase2	100	1.058	0.177	0.234	0.375	10.093	2.172	1.957	3.752	1.546	0.547	0.719	0.801
FTP*	Indolene	75	2.927	2.411	2.229	2.468	30.428	6.833	11.213	12.909	2.214	1.539	1.531	1.674
LA92	Indolene	50	0.249	0.182	0.366	0.198	3.624	6.822	3.041	6.397	0.892	0.794	1.248	0.83
LA92	Indolene	75	0.236	0.189	0.481	0.211	3.675	6.423	6.088	6.256	1.207	0.93	1.073	0.954
LA92	Indolene	100	0.352	0.239	0.72	0.278	4.574	8.817	12.772	8.867	0.809	0.62	0.877	0.648
LA92	Phase1	50	0.491	0.206	0.439	0.237	3.35	6.951	2.72	6.472	1.161	0.938	1.195	0.967
LA92	Phase1	75	2.47	0.225	0.573	0.367	14.111	6.556	5.369	6.87	3.428	0.894	1.247	1.051
LA92	Phase1	100	0.317	0.198	0.539	0.228	2.34	7.646	9.323	7.485	1.289	0.904	1.042	0.933
LA92	Phase2	50	0.96	0.191	0.343	0.242	4.3	5.874	2.19	5.539	1.156	0.817	1.131	0.856
LA92	Phase2	75	0.16	0.156	0.437	0.175	2.618	5.893	5.945	5.725	1.114	0.761	1.009	0.797
LA92	Phase2	100	0.408	0.168	0.385	0.196	3.675	6.508	4.284	6.206	1.105	0.772	0.99	0.805
LA92*	Indolene	75	3.806	2.152	3.5	2.33	14.165	14.487	13.264	14.386	2.117	1.804	2.108	1.841

*repeat

1983 HONDA ACCORD

Temp	Cycle	Phase 1 HC	Phase 1 CO	Phase 1 NOX	Phase 2 HC	Phase 2 CO	Phase 2 NOX	Indolene HC	Indolene CO	Indolene NOX	Indolene* HC	Indolene* CO	Indolene* NOX
	FTP	1.213	15.927	0.966	0.788	10.824	1.17	0.949	13.008	1.484			
	HHWY	0.806	13.667	1.18	0.339	5.343	1.887	0.568	9.137	1.875			
	LA92	1.045	19.116	0.66	0.448	10.512	0.454	1.032	18.71	1.471			
	LOW1	8.162	20.451	1.186	4.447	12.304	1.197	7.188	19.856	1.49			
50 F	LOW3	2.525	15.516	0.501	2.317	10.331	0.684	4.417	20.28	2.306			
	NYCC	1.972	18.756	0.552	1.91	9.273	0.692	2.194	13.097	2.771			
	SCC12	1.414	14.149	0.474	0.921	4.548	0.543	1.192	7.51	0.601			
	UHWY	0.73	10.745	0.373	0.167	2.295	0.502	0.373	5.902	0.476			
	WHWY	0.69	12.265	0.797	1.122	20.513	2.392	0.947	15.979	2.747			
	XHWY	1.252	25.517	1.271	0.647	16.858	1.098	0.765	19.267	1.079			
	FTP	1.19	15.825	1.108	0.725	9.235	1.147	1.483	19.239	1.161	2.15	25.729	1.416
	HHWY	0.837	11.425	0.635	0.46	7.832	0.358	0.78	11.276	0.6	0.733	9.171	0.469
	LA92	1.175	20.434	0.82	0.825	12.363	3.112	1.331	22.315	0.78	1.106	20.589	1.41
	LOW1	7.42	17.781	1.861	2.402	10.342	0.748	6.607	38.71	1.29	10.168	17.34	1.738
75 F	LOW3	1.773	9.399	0.825	1.87	11.111	0.555	4.353	17.725	1.163	4.584	11.066	1.24
	NYCC	2.314	17.232	1.078	1.795	14.682	0.494	3.509	25.635	0.671	2.248	18.937	0.597
	SCC12	1.498	9.603	0.674	0.852	6.778	0.607	2.477	24.292	0.408	1.104	6.629	0.489
	UHWY	0.672	10.401	0.467	0.423	6.76	0.37	0.977	16.517	0.323	0.515	6.379	0.407
	WHWY	0.93	15.96	0.93	0.519	10.679	0.721	1.07	18.248	1.092	0.771	11.999	0.672
	XHWY	1.056	23.322	1.589	0.82	18.082	1.495	1.163	30.058	1.632	1.189	25.036	2.834
	FTP	1.094	14.384	1.318	0.836	11.224	1.118	2.329	18.501	1.373			
	HHWY	0.807	13.273	0.615	0.447	7.826	0.469	1.091	13.606	0.506			
	LA92	1.289	22.67	0.898	0.833	17.05	0.57	2.342	26.571	1.321			
	LOW1	5.767	21.018	1.749	4.772	31.302	0.757	9.517	49.131	1.253			
100 F	LOW3	3.56	13.175	1.457	4.585	22.861	0.803	8.492	31.739	1.126			
	NYCC	2.26	21.323	0.745	2.351	27.584	0.413	11.27	17.404	0.573			
	SCC12	2.137	13.459	0.924	1.995	11.157	2.555	3.077	14.301	0.851			
	UHWY	0.874	12.348	0.664	0.581	5.502	1.965	1.286	16.253	0.478			
	WHWY	0.851	16.682	0.989	0.245	4.991	0.975	1.164	21.834	2.905			
	XHWY	1.083	24.937	1.57	0.711	16.918	1.262	1.217	34.054	3.756			

* Repeated sequence

1983 Honda Accord

Cycle	Fuel	Temp (F)	HC-B1	HC-B2	HC-B3	HC	CO-B1	CO-B2	CO-B3	CO	NOx-B1	NOx-B2	NOx-B3	NOx
FTP	Indolene	50	1.254	0.865	0.879	0.949	13.831	13.552	11.365	13.008	2.181	1.03	1.817	1.484
FTP	Indolene	75	2.471	1.222	1.225	1.483	29.499	16.63	16.379	19.239	1.866	1.214	0.528	1.161
FTP	Indolene	100	3.056	1.784	2.808	2.329	23.537	16.018	19.389	18.501	1.967	1.543	0.607	1.373
FTP	Phase1	50	2.413	0.788	1.109	1.213	28.419	11.231	15.328	15.927	1.518	1.034	0.42	0.966
FTP	Phase1	75	2.111	0.864	1.11	1.19	23.338	12.567	16.299	15.825	1.77	1.175	0.48	1.108
FTP	Phase1	100	1.667	0.869	1.086	1.094	17.361	12.817	15.101	14.384	2.152	1.36	0.61	1.318
FTP	Phase2	50	1.962	0.443	0.55	0.788	23.648	6.931	8.468	10.824	1.673	1.313	0.522	1.17
FTP	Phase2	75	1.489	0.427	0.708	0.725	15.756	6.311	9.819	9.235	1.796	1.253	0.458	1.147
FTP	Phase2	100	1.342	0.723	0.666	0.836	12.57	11.216	10.225	11.224	1.95	1.021	0.674	1.118
FTP*	Indolene	75	3.245	1.802	1.975	2.15	34.395	24.315	21.837	25.729	1.989	1.614	0.612	1.416
LA 92	Phase2	50	0.8	0.387	0.97	0.448	9.106	10.492	11.775	10.512	0.593	0.45	0.396	0.454
LA92	Indolene	50	1.657	0.975	1.287	1.032	11.981	19.284	16.452	18.71	3.088	1.452	0.5	1.471
LA92	Indolene	75	1.609	1.233	2.386	1.331	15.106	21.787	34.543	22.315	0.632	0.809	0.646	0.78
LA92	Indolene	100	6.29	1.822	6.006	2.342	21.15	24.716	54.462	26.571	0.911	1.389	0.753	1.321
LA92	Phase1	50	1.785	0.98	1.319	1.045	19.851	19.006	19.961	19.116	0.636	0.672	0.528	0.66
LA92	Phase1	75	2.324	1.069	1.649	1.175	18.579	20.36	22.794	20.434	1.012	0.824	0.622	0.82
LA92	Phase1	100	2.221	1.082	3.237	1.289	15.485	20.432	56.638	22.67	1.251	0.898	0.634	0.898
LA92	Phase2	75	1.785	0.765	0.859	0.825	6.96	12.947	9.066	12.363	2.823	2.167	0.867	3.112
LA92	Phase2	100	1.538	0.712	1.856	0.833	17.487	16.214	27.402	17.05	0.532	0.571	0.578	0.57
LA92*	Indolene	75	1.223	1.055	1.664	1.106	17.264	20.454	24.811	20.589	1.728	1.45	0.658	1.41

*repeat

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