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REPORT
HE – 434

AN ANALYSIS OF GENERAL MOTORS LATE MODEL YEAR VEHICLE CO EMISSIONS AS MEASURED BY REMOTE SENSING

ROBERT D. STEPHENS
Health & Environment Department

12 AUGUST, 1996

GM CONFIDENTIAL

NORTH AMERICAN OPERATIONS RESEARCH AND DEVELOPMENT CENTER

GENERAL MOTORS CORPORATION

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Intended Audience: **R&D Center, Corp Affairs, Environmental and Energy, Industry-Government Relations, GM Legal Staff, GM Powertrain, Hughes Santa Barbara Research Center**

Technology Category

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- ☐ Energy-Materials/Metals
- ☐ Energy-Materials/Polymers
- ☐ Energy-Powertrain/Alternative Systems
- ☐ Energy-Powertrain/Engines: Base Engine
- ☒ Energy Powertrain/Engines: Controls
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- ☐ Energy-Powertrain/Transmissions
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- ☒ Service Integrity
- ☐ Vehicle Communications/Information Systems
- ☐ Vehicle Safety-Crash Avoidance
- ☐ Vehicle Safety-Crashworthiness

Purpose

The purpose of this project was to utilize remote sensing measurements to evaluate, by model year and engine type, the in-use CO emissions from late model GM vehicles.

Summary

Remote sensing of vehicle exhaust emissions was conducted via several Hughes RES-100 instruments in May and June of 1995 in southern California. During this time, 40,237 valid CO readings were acquired, 8,570 of which were on GM vehicles. For 1990 through 1994 model years, 1,505 different vehicles were measured. Some of these vehicles were measured more than once, in which case the multiple readings were averaged. Further sorting of the vehicles was accomplished by decoding VIN numbers and sorting the measurements via engine type. A total of 29 different engine types were evaluated for each of the five model years. The number of measurements for each engine type and model year ranged from zero to 92. For a study to provide adequate numbers of measurements for statistically significant evaluations of all late model GM engine types, the number of remote sensing measurements must be increased substantially. For each model year and engine type, the mean and median CO was determined. The mean CO concentrations ranged from 0.04 (four measurements of 1990 5.0L FI engines) to 1.45 (two measurements of 1991 2.0L FI engines). Also, the number of vehicles with a given model year and engine type that emitted more than 1%, more than 2%, and more than 3% CO was determined. It was found that exceedance rates were substantially higher for freeway off-ramp sites than for surface street sites. Only three vehicles equipped with 1994 engines had any measurements that exceeded 3% CO. The engines in these vehicles included the 3.8L MFI engine (1 exceedance out of 25 measured), the 4.3L TBI engine (1 of 70), and the 5.7L TBI engine (3 of 92). All of these exceedances occurred at freeway off-ramp sites.

Significance

This study has identified some late model GM engine types that have excessive emissions of CO, as measured by remote sensors. Other engine types have been found to have zero exceedances of a CO high emission threshold. This study demonstrates that remote sensing measurements can be used to evaluate engine family emissions performance, but careful site selection for remote sensing data collection is crucial.

Introduction

Remote sensors have been used to identify high emitting vehicles in experimental programs with reasonable success since 1990[1-3]. Typically, these programs have been research studies conducted at surface street locations where vehicle operating modes consist primarily of mild acceleration. Also, during these programs, police have been present to stop the vehicles that have been identified as high emitters. The presence of the police might also serve to moderate driver behavior, i.e. reduce speeds and acceleration rates that might otherwise occur.

More recently, remote sensors have been employed by the Arizona Department of Environmental Quality as an adjunct to the state sponsored Inspection and Maintenance (I/M) program. In this program, police have not been present at the remote sensor sites, which have consisted of freeway off-ramps, and vehicles have not been pulled over and tested immediately after identification via remote sensors. Instead, this program is utilizing mail notifications to owners of high emitting vehicles. When a vehicle is first identified as a high emitter, the owner is informed that their vehicle might require repairs. If identified again, the owner is notified that their vehicle must be brought in for IM240 testing. During a pilot program of this type, a large proportion (60%) of a small fleet of vehicles (89) that failed a single remote sensor test subsequently passed an IM240 test (or steady state test for pre-1980 vehicles)[4]. Each of these vehicles was tested via remote sensors two additional times after the IM240 or steady state test. False failure rates in this program were reduced dramatically, to approximately 15%, when omitting the highest remote sensor reading and averaging the remainder of the readings. These data suggest that freeway off-ramp sites might not be appropriate for using remote sensors to identify high emitting vehicles, and if such sites are to be used, multiple measurements per vehicle are recommended.

The consensus of opinion of remote sensor experts is that remote sensing can be used to successfully identify high emitting vehicles if the remote sensor sites are carefully selected so as to minimize the frequency of (1) cold start operation, (2) heavy acceleration or high load operation that might give rise to fuel-enrichment, and (3) cruise or deceleration operation that give rise to high fuel-economy operation that results in low volumes of exhaust for the remote sensor to detect.

Efforts are underway to develop high emitter profiles, i.e. to identify specific vehicle models that have higher than average emission rates[5-6]. High emitter profiles are being developed based on IM240 based measurements, as well as remote sensing measurements. These studies have shown that there are vehicle models that have higher than average rates of emissions exceedances. GM should be aware that such profiling efforts are underway and actively participate to insure that GM vehicles are being properly evaluated. This study represents an effort to evaluate GM engine types.

Each year, EPA performs FTP tests on a limited number of in-use vehicles to determine if they are compliant with the 50,000 mile emissions standards. It is often difficult to determine, based upon the limited numbers of tests, if a vehicle recall is necessary. The remote sensing measurements presented in this report can help to determine if there are any gross emission failures in the engine families tested by EPA.

For 1990 through 1994 model year vehicles, we have analyzed separately each of 29 different engine types. We have reported a number of statistics for each engine type, including the mean and median CO concentrations emitted, and the frequency of high emitters observed. Data was also available for 1995 model year vehicles, but these vehicles were not included in the analysis because VIN decoding software was not available for this model year.

Experimental

In May and June of 1995, several Hughes RES-100 remote sensors were used in Orange County California to measure the CO and HC emissions of in-use vehicles. Most of the measurements were performed with vehicles driving under conditions of mild acceleration. A description of the sites, their locations, and the number of measurements on GM vehicles is shown in **Table I**. The numbers in parenthesis represent the numbers of 1990 through 1994 GM vehicles measured. All of the sites, except the last two listed, were freeway off-ramps. The last two sites were surface streets, where approximately 70% of all measurements were acquired. At the surface street locations, high emitters were identified by the remote sensors and immediately stopped by police that were present at the site. It is likely that the driving modes experienced at the surface street sites, i.e. speeds and acceleration rates, were within the range experienced during an FTP. For the off-ramp sites, it is more likely that some of the vehicles were operating with speed and acceleration rates that are outside of the range encountered during an FTP.

The remote sensing systems utilized automated license plate readers to acquire the license plate numbers of each vehicle measured. Registration data was acquired from the state of California for each vehicle. A total of 49,256 vehicle measurements were attempted. Of these, 40,237 yielded valid measurements of CO. From these measurements, 2,387 vehicles were identified by the registration information as having been manufactured by GM between 1990 and 1994. When an individual vehicle was measured more than once, the multiple readings were averaged. In total, 1,627 different 1990 through 1994 GM vehicles were measured at least once. These vehicles were separately analyzed. Software purchased from Radian Corporation[7] was used to decode VIN numbers to determine the engine type in each of these GM vehicles. The final analysis was performed on 29 separate fuel-injected engines from each model year, for which there were a total of 1,505 measurements.

Results

Although the remote sensors used in this study measured both HC and CO emissions, only the CO emissions were analyzed for this report, since previous research[8] has indicated that the HC measurement accuracy varies substantially with the speciation of HC in the exhaust.

In using remote sensors to identify vehicles with malfunctioning emission control systems, there are four major sources of misidentification. These are (1) measurement of a vehicle during cold-start operation, (2) measurement of a vehicle during a transient high emission period during warm-running, non-commanded fuel-enrichment operation, (3) measurement of a vehicle during a commanded fuel-enrichment episode, and (4) remote sensor measurement error.

Table I. Site Descriptions and GM Vehicle Measurements Obtained[a]

Site	Description	# Meas.	# Valid Meas.
E. Hwy 91 to N. Kraemer	Fast Cruise	64 (25)	43 (15)
N. Hwy 405 to Magnolia	Uphill	246 (74)	144 (48)
N. Hwy 405 to S. Beach	Uphill fast cruise	749 (298)	527 (215)
S. Hwy 405 to N. Brookhurst	Fast level cruise	144 (68)	63 (30)
S. Hwy 55 to Baker	Downhill	271 (100)	126 (44)
S. Hwy 5 to Broadway	Curved, uphill, medium speed	1069 (283)	938 (242)
S. Hwy 405 to Bolsa Chica	Uphill, medium speed cruise	290 (119)	181 (71)
W. Hwy 22 to N. Beach	Uphill cruise	372 (123)	282 (91)
Fair Drive, Costa Mesa[b]	Level accel	2419 (835)	2152 (733)
Fairview Rd., Santa Ana[b]	Level accel	4449 (979)	4115 (898)
Totals		10,073 (2904)	8571 (2387)

[a] Numbers in parenthesis are the number of 1990 through 1994 GM vehicles measured.
[b] Police were present at each of these sites.

Previous research has shown that emissions from properly functioning late model GM vehicles during FTP operation exceed 3% CO during less than 0.1% of warm-running operating time and exceed this limit during approximately 8% of cold-start operating time[9]. A study of 118 FTP tests conducted on 70 1985 and later model GM, Ford, and Chrysler vehicles demonstrated that 50% of high emitting vehicles (i.e. vehicles that emit greater than 20 gram/mile CO during the FTP) emit under 3% CO during a typical acceleration event[10]. Of the vehicles that emitted under 20 gram/mile CO in this study, only 1% emitted more than 3% CO during a typical acceleration. These data suggest that transient high emissions from warm-running, non-commanded fuel-rich operation should not result in a high rate of false failures of low emitting vehicles.

Studies have indicated that the frequency of fuel-enrichment operation during on-road driving is approximately 1-2% of overall vehicle operating time[11]. The frequency of remote sensor measurement errors is not known, however the conditions that are likely to cause these errors are understood and will be discussed more later in this report. Although the frequency of misidentification of normally operating vehicles as high emitters is probably low, the frequency of high emitters is also low, hence misidentification rates might be a significant cause of remote sensor false failures.

To reduce remote sensor measurement errors, the Hughes sensors have an algorithm that checks the validity of each measurement. This is accomplished primarily by assessing the signal to noise ratio of the measurement of the exhaust gases. Since remote sensors attempt to measure the exhaust gas concentrations in the atmosphere, after the exhaust leaves the tailpipe, the exhaust gases can sometimes be too dilute to measure. The algorithms are designed to invalidate measurements performed on extremely dilute exhaust mixtures, or measurements performed on vehicles that have low exhaust volumes. However this is difficult in practice because the dilution rates vary dramatically, even during the fraction of a second that the measurement is made. As a result, the remote sensor algorithms that invalidate measurements on highly dilute exhaust mixtures are not perfect and it should be noted that remote sensor measurement errors can occur for vehicles operating under conditions that give rise to dilute exhaust mixtures.

These considerations have an impact upon the site selection for remote sensing measurements. Rapid exhaust dilution occurs preferentially under conditions of fast driving; whereas low exhaust volume occurs preferentially during high fuel economy driving, e.g. deceleration events or cruise (particularly downhill cruise) operation. As can be seen in **Table I**, the fraction of measurements that are valid (i.e. not rejected due to low signal to noise ratio) increases for those sites where vehicle operation primarily requires acceleration and/or uphill driving, i.e. conditions that avoid low exhaust volumes. These sites are also likely to have the lowest rate of remote sensor measurement errors. It should also be noted that sites where high speed driving is typical, such as freeway interchanges and off-ramps to highways, might also give rise to higher frequencies of fuel-enriched operation. However, these same freeway off-ramp sites probably have no vehicles that are operating in a cold-start mode. The surface street sites probably have near zero rates of fuel-enriched operation and very low rates of measurement errors, but might have a low frequency of cold start operation. However, driver interviews at the surface street sites helped to identify those vehicles that had not been driven far prior to the remote sensing. Hence, the contribution to remote sensor false failures due to cold start operation at the surface street sites is probably very low. For the sites studied, we believe that the various types of high emitter misidentifications are most likely to occur at the freeway off-ramp sites, and that the surface street data is most reliable.

Because of the potential impact of sites on high emitter identifications employed in this study, and the vehicle operating modes prevalent at those sites, we will report statistics for the entire set of measurements obtained, and separately report statistics for the measurements performed at the surface street sites.

Table II shows the breakdown of the number of measurements performed on each engine type as a function of model year. As can be seen from this table, with a few exceptions, after sorting by model year and engine type, there are not a lot of measurements within any given engine category. For those engine categories where there are at least twenty measurements (an arbitrarily chosen number), the numbers have been bolded. In this, and all subsequent tables, the numbers in parenthesis show values obtained at the surface street sites.

Tables III and IV show the mean and median percent CO measured for each engine, respectively, as a function of model year. Again, in this table the values are bolded if the calculation has been performed on at least twenty measurements. For engine types where there are at least twenty vehicles that have been measured, the means ranged from a low of 0.18% CO for the 1993 3.8L MFI engine to 0.73% CO for the 1990 4.3L FI engine and the 1990 4.5L FI engine. Overall, the mean CO tends to gradually increase with vehicle age, ranging from 0.34% for all 1994 engines to 0.64% for all 1990 engines. The median CO values ranged from 0.02% for the 1994 3.8L MFI engine to 0.52% for the 1992 3.1L MFI engine. On a model year basis, generally the medians gradually increased from 0.14% for all 1994 engines to 0.23% for all 1990 engines, although the 1992 model year was slightly higher at 0.24%. Typically, the means and medians were lower for the surface street sites than were obtained for the entire data set. The overall trends in means and medians as a function of model year do not show up when examining data obtained for individual engines. This is probably the result of the small numbers of measurements obtained on each individual engine.

Table II. Number of Vehicles Measured With Each Engine[a]

Engine	1994	1993	1992	1991	1990
1.0 MFI	0	0	0	1 (1)	4 (2)
1.6 FI	0	1 (1)	2 (1)	1 (0)	3 (2)
1.6 MFI	0	0	1 (0)	9 (4)	18 (11)
2.0 FI	0	0	0	2 (0)	2 (1)
2.0 MFI	3 (1)	2 (1)	2 (1)	0	0
2.2 FI	0	0	0	15 (7)	10 (6)
2.2 MFI	**32** (18)	13 (10)	5 (4)	0	0
2.3 FI	0	1 (1)	0	4 (3)	6 (6)
2.3 MFI	13 (7)	6 (5)	8 (4)	1 (1)	1 (1)
2.5 FI	0	0	1 (1)	10 (9)	15 (7)
2.8 FI	0	6 (5)	3 (0)	6 (4)	0
3.1 FI	2 (1)	0	2 (1)	5 (4)	14 (10)
3.1 MFI	19 (11)	**24** (10)	**24** (14)	**34** (19)	**29** (13)
3.3 MFI	0	**26** (17)	**20** (13)	10 (7)	18 (9)
3.4 MFI	**27** (17)	4 (2)	1 (0)	3 (2)	0
3.8 FI	0	0	0	9 (7)	**31** (13)
3.8 MFI	**25** (10)	**27** (18)	**28** (15)	19 (12)	1 (1)
4.3 FI	0	0	**53 (33)**	**92 (59)**	**50 (25)**
4.3 CPI	**52 (34)**	**23** (11)	8 (4)	0	0
4.3 MFI	2 (1)	0	0	0	0
4.3 TBI	**70 (32)**	**45 (26)**	0	0	0
4.5 FI	0	0	2 (1)	0	**24** (12)
4.6 MFI	16 (8)	0	0	0	0
4.9 MFI	3 (1)	12 (7)	11 (3)	**22** (12)	0
5.0 FI	0	0	8 (3)	17 (9)	4 (3)
5.0 TBI	5 (3)	1 (1)	0	0	0
5.7 MFI	11 (3)	5 (2)	4 (2)	5 (2)	3 (3)
5.7 TBI	**92 (49)**	**58 (26)**	**49 (24)**	**46 (23)**	**49 (25)**
7.4 TBI	13 (6)	**22** (14)	7 (2)	7 (2)	7 (4)
Totals	**383 (202)**	**276 (157)**	**239 (127)**	**319 (187)**	**289 (154)**

[a] Numbers in parenthesis are the numbers of measurements performed at the two surface street sites. Engine types that have at least 20 measurements have been bolded.

Table III. Mean CO Concentrations For Each Engine[a]

Engine	1994	1993	1992	1991	1990
1.0 MFI	na	na	na	na	1.19 (1.18)
1.6 FI	na	na	0.45 (na)	na	1.44 (2.07)
1.6 MFI	na	na	na	0.46 (0.25)	0.30 (0.43)
2.0 FI	na	na	na	1.45 (na)	0.75 (na)
2.0 MFI	0.65 (na)	1.22 (na)	0.10 (na)	na	na
2.2 FI	na	na	na	0.22 (0.19)	0.60 (0.70)
2.2 MFI	**0.39** (0.38)	0.36 (0.44)	0.44 (0.52)	na	na
2.3 FI	na	na	na	0.08 (0.10)	0.60 (0.60)
2.3 MFI	0.32 (0.23)	0.23 (0.27)	0.15 (0.11)	na	na
2.5 FI	na	na	na	1.01 (1.10)	1.19 (1.15)
2.8 FI	na	0.15 (0.17)	0.26 (na)	0.26 (0.04)	na
3.1 FI	0.06 (na)	na	0.25 (na)	1.58 (0.33)	0.39 (0.21)
3.1 MFI	0.34 (0.35)	**0.30** (0.20)	**0.70** (0.67)	**0.63** (0.46)	**0.55** (0.37)
3.3 MFI	na	**0.44** (0.52)	**0.52** (0.70)	0.24 (0.20)	0.58 (0.31)
3.4 MFI	**0.39** (0.33)	0.56 (0.04)	na	0.37 (0.08)	na
3.8 FI	na	na	na	0.15 (0.07	**0.55** (0.26)
3.8 MFI	**0.29** (0.06)	**0.18** (0.07)	**0.37** (0.22)	0.67 (0.36)	na
4.3 FI	na	na	**0.67 (0.48)**	**0.61 (0.65)**	**0.73 (0.78)**
4.3 CPI	**0.21 (0.23)**	**0.33** (0.36)	0.89 (0.20)	na	na
4.3 MFI	0.18 (na)	na	na	na	na
4.3 TBI	**0.35 (0.24)**	**0.42 (0.35)**	na	na	na
4.5 FI	na	na	0.14 (na)	na	**0.73** (0.38)
4.6 MFI	0.32 (0.32)	na	na	na	na
4.9 MFI	0.28 (na)	0.34 (0.34)	1.25 (0.26)	**0.43** (0.24)	na
5.0 FI	na	na	0.16 (0.03)	0.18	0.04 (0.05)
5.0 TBI	0.06 (0.10)	na	na	na	na
5.7 MFI	0.11 (0.01)	0.07 (0.09)	0.05 (0.01)	0.89 (0.05)	0.78 (0.78)
5.7 TBI	**0.45 (0.31)**	**0.37 (0.30)**	**0.59 (0.61)**	**0.41 (0.33)**	**0.69 (0.86)**
7.4 TBI	0.20 (0.10)	**0.41** (0.31)	0.14 (0.23)	0.37 (0.23)	0.14 (0.11)
Totals	**0.34 (0.27)**	**0.35 (0.30)**	**0.55 (0.46)**	**0.53 (0.45)**	**0.64 (0.59)**

[a] Numbers in parenthesis represent the measurements made at the surface street sites. Numbers printed in bold where at least twenty measurements were available.

Table IV. Median CO Concentrations For Each Engine[a]

Engine	1994	1993	1992	1991	1990
1.0 MFI	na	na	na	na	1.18 (1.18)
1.6 FI	na	na	0.45 (na)	na	0.89 (2.07)
1.6 MFI	na	na	na	0.18 (0.19)	0.11 (0.40)
2.0 FI	na	na	na	1.45 (na)	0.75 (na)
2.0 MFI	0.70 (na)	1.22 (na)	0.10 (na)	na	na
2.2 FI	na	na	na	0.11 (0.03)	0.29 (0.33)
2.2 MFI	**0.28** (0.24)	0.20 (0.24)	0.22 (0.48)	na	na
2.3 FI	na	na	na	0.07 (0.09)	0.51 (0.51)
2.3 MFI	0.23 (0.10)	0.21 (0.29)	0.09 (0.08)	na	na
2.5 FI	na	na	na	0.35 (0.37)	0.63 (0.63)
2.8 FI	na	0.16 (0.18)	0.13 (na)	0.08 (0.03)	na
3.1 FI	0.06 (na)	na	0.25 (na)	0.27 (0.21)	0.23 (0.23)
3.1 MFI	0.17 (0.17)	**0.31** (0.08)	**0.52** (0.50)	**0.37** (0.36)	**0.31** (0.21)
3.3 MFI	na	**0.17** (0.13)	**0.09** (0.03)	0.06 (0.03)	0.12 (0.07)
3.4 MFI	**0.20** (0.18)	0.54 (0.04)	na	0.12 (0.08)	na
3.8 FI	na	na	na	0.06 (0.03)	**0.16** (0.07)
3.8 MFI	**0.02** (0.04)	**0.09** (0.06)	**0.25** (0.15)	0.22 (0.12)	na
4.3 FI	na	na	**0.25 (0.22)**	**0.28 (0.29)**	**0.43 (0.30)**
4.3 CPI	**0.09 (0.09)**	**0.31** (0.35)	0.60 (0.12)	na	na
4.3 MFI	0.18 (na)	na	na	na	na
4.3 TBI	**0.18 (0.22)**	**0.20 (0.09)**	na	na	na
4.5 FI	na	na	0.14 (na)	na	**0.14** (0.08)
4.6 MFI	0.26 (0.260	na	na	na	na
4.9 MFI	0.11 (na)	0.22 (0.23)	0.70 (0.04)	**0.14 (0.12)**	na
5.0 FI	na	na	0.05 (0.00)	0.09 (0.08)	0.04 (0.06)
5.0 TBI	0.09 (0.09)	na	na	na	na
5.7 MFI	0.00 (0.00)	0.08 (0.09)	0.01 (0.01)	0.22 (0.05)	0.03 (0.03)
5.7 TBI	**0.18 (0.17)**	**0.19 (0.17)**	**0.37 (0.39)**	**0.24 (0.28)**	**0.25 (0.18)**
7.4 TBI	0.13 (0.10)	**0.15** (0.23)	0.08 (0.23)	0.26 (0.23)	0.06 (0.07)
Totals	**0.14 (0.13)**	**0.18 (0.14)**	**0.24 (0.18)**	**0.23 (0.20)**	**0.23 (0.20)**

[a] Numbers in parenthesis represent the measurements made at the surface street sites. Numbers are printed in bold where at least twenty measurements were available.

terms of three definitions of high emitters, exceedances of 1%, 2%, and 3% CO. A typical definition of a high emitter based on remote sensing measurements is 3% CO. Again, where at least twenty measurements were acquired, these values have been highlighted in the tables. Also, any engine for which there was an exceedance of 3% CO has also been highlighted.

Of the 32 1990 through 1994 GM vehicles that had emissions in excess of 3% CO, 20 (62.5%) were measured at freeway off-ramps, whereas only 12 (37.5%) were measured at the surface street sites. These numbers are disproportionate to the numbers of measurements performed at the various sites. Overall, only 31.2% of the total number of valid measurements were obtained at the off-ramp sites. In addition to the higher possibility of measurement errors and fuel-enrichment operation at the freeway sites, the identification of 3% CO high emitters at the surface street sites can be considered more reliable in some cases because multiple measurements on the same vehicle were often acquired, as indicated by the footnotes in Tables V through IX. This occurred because each of the surface street sites were monitored for an entire week, hence there was a higher probability of measuring the same vehicle more than once. None of the vehicles identified as 3% CO high emitters at the off-ramp sites were measured more than once. A summary of all of the 3% CO high emitters identified is shown as **Table X.**

For 1994 vehicles, three engine types had exceedances of 3% CO. These engines were the 3.8L MFI (1 of 25), the 4.3L TBI (1 of 70), and the 5.7L TBI (3 of 92). None of these exceedances occurred at the surface street sites. In contrast, for engine types for which at least twenty measurements were available, no exceedances were observed for the 2.2L MFI engine (32 measured), the 3.4L MFI engine (27 measured), or the 4.3L CPI engine (52 measured).

For 1993 vehicles, only the 3.3L MFI (1 of 26) and the 4.3L TBI (1 of 45) engine had exceedances of 3% CO. Both of these exceedances occurred at the surface street sites. The vehicle equipped with a 4.3L TBI engine had been measured twice, once at 7.6% CO and once at 0% CO. For engines that had been measured at least 20 times, zero exceedances were observed for the 3.1L MFI (24 measured), the 3.3L MFI(26 measured), the 3.8L MFI (27 measured), the 4.3L CPI (23 measured), the 5.7L TBI (58 measured), or the 7.4L TBI (22 measured).

For 1992 vehicles, the 3.3L MFI (1 of 20), the 4.3L FI (2 of 53), the 4.9L MFI (2 of 11), and the 5.7L TBI (1 of 49) had exceedances of 3% CO. The 3.3L MFI and 5.7L TBI engines were each measured twice at the surface street sites. For engines that had at least 20 measurements, the 3.1L MFI (24 measured) and the 3.8L MFI (28 measured) had zero exceedances.

1991 vehicles had exceedances with the 1.0L MFI (1 of 1), the 2.5L FI (1 of 10), the 3.1L FI (1 of 5), the 3.4L MFI (1 of 34), the 3.8L MFI (1 of 19), the 4.3L FI (3 of 92), the 5.7L MFI (1 of 5), and the 5.7L TBI (1 of 46). The 1.0L MFI, the 2.5L FI, and two of the 4.3L FI engines had exceedances at the surface street sites. The two 4.3L FI engines with exceedances at the surface street site were each measured twice. For engine types for which at least 20 measurements were available, the 4.9L MFI had zero exceedances (22 measurements).

Exceedances in 1990 vehicles occurred with the 1.6L FI (1 of 3), the 2.5L FI (2 of 15), the 3.1L MFI (1 of 29), the 3.8L FI (1 of 31), the 4.5L FI (2 of 24), and the

Tables V through IX show the high emitter frequencies observed for each engine type for 1994 through 1990 model years, respectively. The frequencies have been listed in

Table V. High Emitter Frequencies for 1994 Engines[a]

Engine	# Measured	# > 1% CO	# > 2% CO	# > 3% CO
1.0 MFI	0	0	0	0
1.6 FI	0	0	0	0
1.6 MFI	0	0	0	0
2.0 FI	0	0	0	0
2.0 MFI	3 (1)	1 (0)	0	0
2.2 FI	0	0	0	0
2.2 MFI	**32** (18)	**3** (2)	**0**	**0**
2.3 FI	0	0	0	0
2.3 MFI	13 (7)	0	0	0
2.5 FI	0	0	0	0
2.8 FI	0	0	0	0
3.1 FI	2 (1)	0	0	0
3.1 MFI	19 (11)	0	0	0
3.3 MFI	0	0	0	0
3.4 MFI	**27** (17)	**3** (2)	**0**	**0**
3.8 FI	0	0	0	0
3.8 MFI	**25** (10)	**2** (0)	**1** (0)	**1** (0)
4.3 FI	0	0	0	0
4.3 CPI	**52 (34)**	**2 (2)**	**1 (1)**	**0**
4.3 MFI	2 (1)	0	0	0
4.3 TBI	**70 (32)**	**4 (0)**	**2 (0)**	**1 (0)**
4.5 FI	0	0	0	0
4.6 MFI	16 (8)	1 (1)	0	0
4.9 MFI	3 (1)	0	0	0
5.0 FI	0	0	0	0
5.0 TBI	5 (3)	0	0	0
5.7 MFI	11 (3)	0	0	0
5.7 TBI	**92 (49)**	**9 (3)**	**6 (2)**	**3 (0)**
7.4 TBI	13	0	0	0
Totals	**383 (202)**	**25 (10)**	**10 (3)**	**5 (0)**

[a] Numbers in parenthesis represent the measurements made at the surface street sites.

Table VI. High Emitter Frequencies for 1993 Engines[a]

Engine	# Measured	# > 1% CO	# > 2% CO	# > 3% CO
1.0 MFI	0	0	0	0
1.6 FI	1 (1)	0	0	0
1.6 MFI	0	0	0	0
2.0 FI	0	0	0	0
2.0 MFI	2 (1)	1 (0)	1 (0)	0
2.2 FI	0	0	0	0
2.2 MFI	13 (10)	1 (1)	1 (1)	0
2.3 FI	1 (1)	0	0	0
2.3 MFI	6 (5)	0	0	0
2.5 FI	0	0	0	0
2.8 FI	6 (5)	0	0	0
3.1 FI	0	0	0	0
3.1 MFI	**24** (10)	**0**	**0**	**0**
3.3 MFI	**26** (17)	2 (2)	**1** (1)	**1** (1)
3.4 MFI	4 (2)	1 (0)	0	0
3.8 FI	0	0	0	0
3.8 MFI	**27** (18)	**0**	**0**	**0**
4.3 FI	0	0	0	0
4.3 CPI	**23** (11)	**0**	**0**	**0**
4.3 TBI	**45 (26)**	**3 (1)**	**1 (1)**	**1 (1)[b]**
4.5 FI	0	0	0	0
4.6 MFI	0	0	0	0
4.9 MFI	12 (7)	1 (0)	0	0
5.0 FI	0	0	0	0
5.0 TBI	1 (1)	0	0	0
5.0 MFI	0	0	0	0
5.7 MFI	5 (2)	0	0	0
5.7 TBI	**58 (26)**	**7 (2)**	**1 (1)**	**0**
7.4 TBI	**22** (14)	**2** (0)	**1** (0)	**0**
Totals	**276 (157)**	**18 (6)**	**6 (4)**	**2 (2)**

[a] Numbers in parentheses are the numbers of measurements performed at the surface street sites.
[b] The emissions from this vehicle represented the average of two readings.

Table VII. High Emitter Frequencies for 1992 Engines[a]

Engine	# Measured	# > 1% CO	# > 2% CO	# > 3% CO
1.0 MFI	0	0	0	0
1.6 FI	2 (1)	0	0	0
1.6 MFI	1 (0)	0	0	0
2.0 FI	0	0	0	0
2.0 MFI	2 (1)	0	0	0
2.2 FI	0	0	0	0
2.2 MFI	5 (4)	0	0	0
2.3 FI	0	0	0	0
2.3 MFI	8 (4)	0	0	0
2.5 FI	1 (1)	0	0	0
2.8 FI	3 (0)	0	0	0
3.1 FI	2 (1)	0	0	0
3.1 MFI	**24** (14)	**5** (3)	**2** (1)	**0**
3.3 MFI	**20 (13)**	**1 (1)**	**1 (1)**	**1 (1)**[b]
3.4 MFI	1 (0)	0	0	0
3.8 FI	0	0	0	0
3.8 MFI	**28** (15)	**2** (0)	**0**	**0**
4.3 FI	**53 (33)**	**11 (6)**	**5 (1)**	**2 (0)**
4.3 CPI	8 (4)	2 (0)	1 (0)	0
4.3 TBI	0	0	0	0
4.5 FI	2 (1)	0	0	0
4.6 MFI	0	0	0	0
4.9 MFI	**11** (3)	**4** (0)	**4** (0)	**2** (0)
5.0 FI	8 (4)	0	0	0
5.0 TBI	0	0	0	0
5.0 MFI	0	0	0	0
5.7 MFI	4 (2)	0	0	0
5.7 TBI	**49 (24)**	**9 (5)**	**4 (2)**	**1 (1)**[b]
7.4 TBI	7 (2)	0	0	0
Totals	**239 (126)**	**34 (15)**	**17 (5)**	**6 (2)**

[a] Numbers in parentheses represent the numbers of measurements performed at the surface street sites.
[b] The emissions from these vehicles represented the average of two readings.

Table VIII. High Emitter Frequencies for 1991 Engines[a]

Engine	# Measured	# > 1% CO	# > 2% CO	# > 3% CO
1.0 MFI	**1 (1)**	**1 (1)**	**1 (1)**	**1 (1)**
1.6 FI	1 (0)	0	0	0
1.6 MFI	9 (4)	1 (0)	1 (0)	0
2.0 FI	2 (0)	1 (0)	0	0
2.0 MFI	0	0	0	0
2.2 FI	15 (7)	1 (1)	0	0
2.2 MFI	0	0	0	0
2.3 FI	4 (3)	0	0	0
2.3 MFI	1 (1)	0	0	0
2.5 FI	**10 (9)**	**2 (2)**	**2 (2)**	**1 (1)**
2.8 FI	6 (4)	0	0	0
3.1 FI	**5** (4)	**1** (0)	**1** (0)	**1** (0)
3.1 MFI	**34** (19)	**3** (1)	**2** (0)	**1** (0)
3.3 MFI	10 (7)	1 (1)	0	0
3.4 MFI	3 (2)	0	0	0
3.8 FI	9 (7)	0	0	0
3.8 MFI	**19** (12)	**4** (1)	**2** (0)	**1** (0)
4.3 FI	**92 (59)**	**11 (9)**	**5 (3)**	**3 (2)**[b]
4.3 CPI	0	0	0	0
4.3 TBI	0	0	0	0
4.5 FI	0	0	0	0
4.6 MFI	0	0	0	0
4.9 MFI	**22** (12)	**3** (1)	**1** (0)	**0**
5.0 FI	17 (9)	0	0	0
5.0 TBI	0	0	0	0
5.0 MFI	1 (0)	0	0	0
5.7 MFI	**5** (2)	**1** (0)	**1** (0)	**1** (0)
5.7 TBI	**46 (23)**	**3 (1)**	**2 (1)**	**1 (0)**
7.4 TBI	7 (2)	0	0	0
Totals	**319 (187)**	**33 (18)**	**18 (7)**	**10 (4)**

[a] Numbers in parentheses represent the numbers of measurements performed at the surface street sites.
[b] The emissions from one of these vehicles represents the average of three readings.

Table IX. High Emitter Frequencies for 1990 Engines[a]

Engine	# Measured	# > 1% CO	# > 2% CO	# > 3% CO
1.0 MFI	4 (2)	2 (1)	2 (1)	0
1.6 FI	**3 (2)**	**1 (1)**	**1 (1)**	**1 (1)**
1.6 MFI	18 (11)	1 (1)	1 (1)	0
2.0 FI	2 (1)	1 (0)	0	0
2.0 MFI	0	0	0	0
2.2 FI	10 (6)	2 (1)	1 (1)	0
2.2 MFI	0	0	0	0
2.3 FI	6 (6)	1 (1)	0	0
2.3 MFI	1 (1)	0	0	0
2.5 FI	**15 (7)**	**5 (2)**	**3 (1)**	**2 (1)**
2.8 FI	0	0	0	0
3.1 FI	14 (10)	1 (0)	1 (0)	0
3.1 MFI	**29** (13)	**4** (1)	**2** (0)	**1** (0)
3.3 MFI	18 (9)	4 (1)	2 (0)	0
3.4 MFI	0	0	0	0
3.8 FI	**31** (13)	**3** (1)	**1** (0)	**1** (0)
3.8 MFI	1 (1)	0	0	0
4.3 FI	**50 (25)**	**15 (7)**	**2 (2)**	**0**
4.3 CPI	0	0	0	0
4.3 TBI	0	0	0	0
4.5 FI	**24 (12)**	**6 (1)**	**4 (1)**	**2 (1)**[b]
4.6 MFI	0	0	0	0
4.9 MFI	0	0	0	0
5.0 FI	4 (3)	0	0	0
5.0 TBI	0	0	0	0
5.0 MFI	0	0	0	0
5.7 MFI	3 (3)	1 (1)	1 (1)	0
5.7 TBI	**49 (25)**	**6 (4)**	**3 (2)**	**3 (2)**[c]
7.4 TBI	7 (4)	0	0	0
Totals	**288 (160)**	**53 (22)**	**24 (12)**	**10 (5)**

[a] Numbers in parentheses represent the numbers of measurements performed at the surface street sites.
[b] The emissions from this vehicle represents the average of two readings.
[c] The emissions from one of these vehicles represents the average of two readings.

Table X. Summary of High Emitters[a]

Engine	Model Year	Total # Measured	# 3% High Emitters
3.8 MFI	1994	25 (10)	1 (0)
4.3 TBI	1994	70 (32)	1 (0)
5.7 TBI	1994	92 (49)	3 (0)
3.3 MFI	1993	26 (17)	1 (1)
4.3 TBI	1993	45 (26)	1 (1)[b]
3.3 MFI	1992	20 (13)	1 (1)[b]
4.3 FI	1992	53 (33)	2 (0)
4.9 MFI	1992	11 (3)	2 (0)
5.7 TBI	1992	49 (24)	1 (1)[b]
1.0 MFI	1991	1 (1)	1 (1)
2.5 FI	1991	10 (9)	1 (1)
3.1 FI	1991	5 (4)	1 (0)
3.1 MFI	1991	34 (19)	1 (0)
3.8 MFI	1991	19 (12)	1 (0)
4.3 FI	1991	92 (59)	3 (2)[c]
5.7 TBI	1991	46 (23)	1 (0)
5.7 MFI	1991	5 (2)	1 (0)
1.6 FI	1990	3 (2)	1 (1)
2.5 FI	1990	15 (7)	2 (1)
3.1 MFI	1990	29 (13)	1 (0)
3.8 FI	1990	31 (13)	1 (0)
4.5 FI	1990	24 (12)	2 (1)[b]
5.7 TBI	1990	49 (25)	3 (2)[c]

[a] Numbers in parentheses represent the numbers of measurements performed at the surface street sites.
[b] The emissions from this vehicle represents the average of two readings.
[c] The emissions from one of these vehicles represents the average of two readings.

5.7L TBI (3 of 49). The 1.6L FI, 2.5L FI, one of the two 4.5L FI, and two of the three 5.7L TBI engines had exceedances at the surface street sites. The 4.5L FI engine that had the exceedance at the surface street site was measured twice. The two 5.7L TBI engines that had exceedances at the surface street sites were also each measured twice. The 4.3L FI engine had zero exceedances out of 50 vehicles measured.

To demonstrate contrasts in engine performance, **Figure 1** shows all of the measurements that were obtained for the 1990 4.3L FI engine and the 1990 5.7L TBI engine. A similar trend exists when plotting only the data obtained at surface street sites. The 5.7L engine had three exceedances (two at the surface street sites) out of a total of 49 measurements. The 4.3L engine had zero exceedances out of 50 measurements. It is interesting to note that, although the 5.7L engine has a higher frequency of exceedances, the 4.3L engine has, on average, higher emissions than the 5.7L engine. This difference might indicate a difference in engine calibrations or overall fuel control, as opposed to durability of emission control components.

Figure 2 shows the difference in the distributions of CO measurements obtained at the surface street sites for the 1990 and 1994 5.7L TBI engine. Not surprisingly, the 1990 engines show higher emissions on average, as well as a higher frequency of exceedances.

A summary of all the vehicles with engine types that were measured at least twenty times without a 3% CO exceedance is shown in **Table XI**. Engine types that were measured to have exceedances at the off-ramp sites but no exceedances at the surface street sites are listed in both Table X and Table XI, if at least 20 measurements of that engine type were obtained at the surface street sites.

Table XI. Summary of Low Emitters[a]

Engine	Model Year	Total # Measured
2.2 MFI	1994	32 (18)
3.4 MFI	1994	27 (17)
4.3 TBI	1994	(32)[b]
5.7 TBI	1994	(49)[b]
3.1 MFI	1993	24 (10)
3.8 MFI	1993	27 (18)
4.3 CPI	1993	23 (11)
5.7 TBI	1993	58 (26)
3.1 MFI	1992	24 (14)
4.3 FI	1992	(33)[b]
4.9 MFI	1991	22 (12)
5.7 TBI	1991	(23)[b]
4.3 FI	1990	50 (25)

[a] Engine types are listed only if 20 or more measurements were obtained without a 3% CO exceedance. Numbers in parentheses represent the number of measurements performed at the surface street sites.

[b] These engine types had one or more 3% CO exceedances at the off-ramp sites.

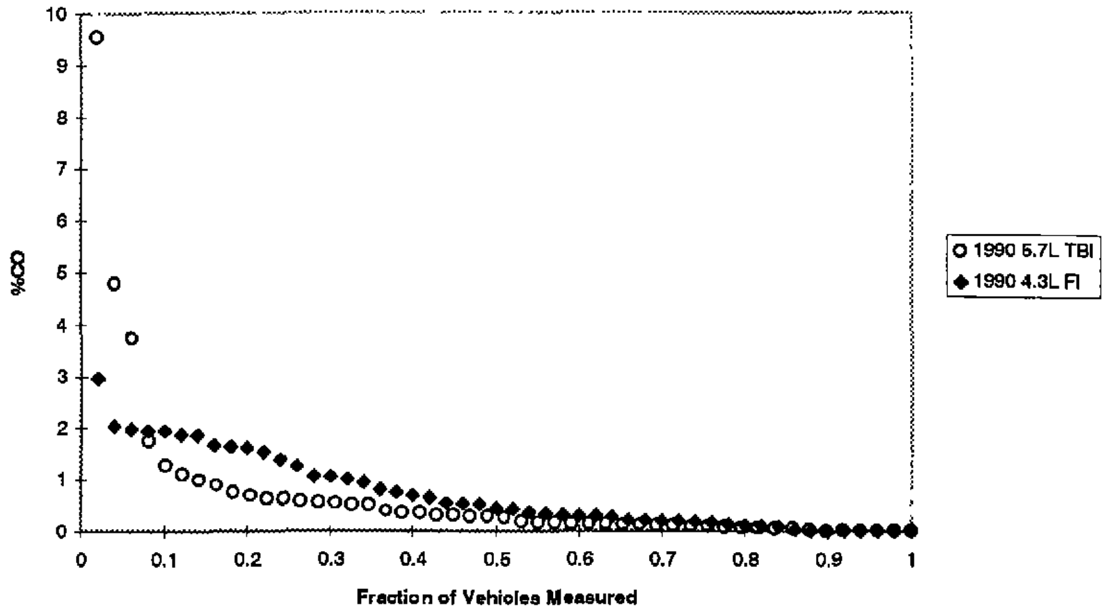

Figure 1. Distribution of CO emissions from 1990 4.3L FI and 1990 5.7L TBI engines as measured at all sites.

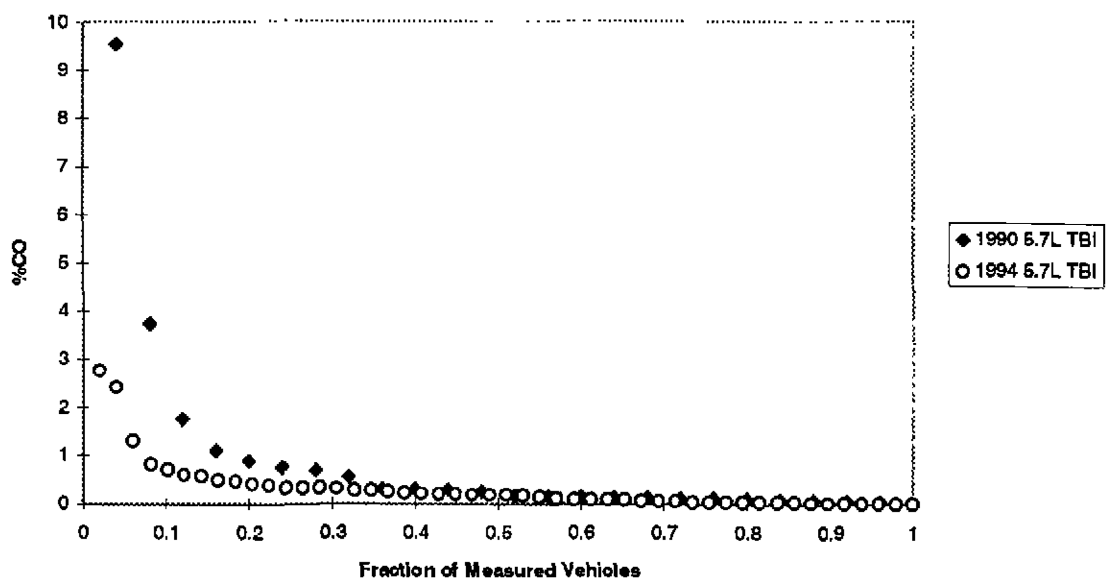

Figure 2. Distribution of CO emissions from 1990 and 1994 5.7L TBI engines as measured at the surface street sites.

Conclusions

The identification of high emitting, late model GM vehicles from data obtained in this study is ambiguous. A majority of the high emitters, as defined by an exceedance of 3% CO, were identified at freeway off-ramp sites despite the fact that the majority of measurements were obtained at surface street sites. This fact, in conjunction with the higher probability of power enrichment and remote sensor measurement errors at the freeway off-ramp sites make the identification of high emitters at the off-ramp sites suspect. Additionally, the low numbers of late model GM vehicles measured in this study makes the significance of high emitter identification unclear.

However, there were a number of late model GM engine types that were measured at least 20 times that had no CO exceedances. These data provide good evidence that these engine types do not have significant emission control system failure rates.

Future remote sensor studies aimed at identifying late model GM engine types should be conducted with the following considerations: (1) Sites should be selected in which vehicles are operated under slight acceleration conditions (within the range experienced during the FTP) and moderate speeds, e.g. 25 to 45 miles-per-hour. Such operating conditions should minimize the frequency of power enrichment and remote sensor measurement errors. (2) Measurements should be conducted repeatedly at the same site with the goal being to obtain multiple measurements per vehicle. Multiple measurements per vehicle should minimize the rate of false failures. (3) Larger numbers of measurements than were obtained in this study are required to obtain significant numbers of measurements for each engine type.

1) Lawson. D. R., Groblicki, P. J.. Stedman. D. H., Bishop, G. A., Guenther. P. L., "Emissions from In-use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program", J. Air and Waste Manage. Assoc.,40(8). 1096-1105, 1990.

2) Stephens, R. D.. "Remote Sensing Data and a Potential Model of Vehicle Exhaust Emissions", J. Air and Waste Manage. Assoc., 44. 1284-1292, 1994.

3) Stephens, R. D., Liberty, T. F., Groblicki, P. J., Gorse, R. A., McAlinden, K. J., Hoffman, D. B., James. R., Smith. S., "The Michigan Remote Sensing Study: A Preliminary Review of Repair Induced Emissions Reductions", Air and Waste Manage. Assoc./California Air Resources Board Conference "The Emissions Inventory: Perception and Reality", Pasadena. CA, October 18-20, 1993.

4) Cox. F. W., Arizona Department of Environmental Quality, 600 N. 40th St., Phoenix, AZ. 85008. Private Communication. November. 1995.

5) Kishan. S., Amlin, D., Klausmeier, R. "Profiling Vehicle Emissions: Identifying High Emitters and Screening-Out Low Emitters". 6th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, March 18-20, 1996.

6) Wenzel. T., "Relationship Between Vehicle Attributes and Malfunction of Emissions Control Systems". 6th CRC On-Road Vehicle Emissions Workshop. San Diego, CA, March 18-20. 1996.

7) VIN Decoder Version 94.1, August 4, 1994, Radian Corporation, P.O. Box 201088, Austin, TX.

8) Stephens, R. D., Mulawa, P. A., Giles, M. T., Kennedy, K. G., Groblicki, P. J., Cadle, S. H., Knapp, K. T., "An Experimental Evaluation of Remote Sensing Based Hydrocarbon Measurements: A Comparison to FID Measurements", J. Air and Waste Manage. Assoc. 46: 148-158, 1996.

9) Stephens, R. D., Cadle, S. H., and Qian, T. Z., "Analysis of Remote Sensing Errors of Omission and Commission Under FTP Conditions", CRC Final Report, Contract VE-11-4, April, 1994.

10) Stephens, R. D., Hoffman, D., McAlinden, K., "Errors of Omission and Commission For the Detection of High Emitters During Well Defined FTP Operating Conditions", Presentation at the Fifth CRC-APRAC On-Road Vehicle Emissions Workshop, April 3-5. 1995, San Diego, CA.

11) Kelly, N. A., Groblicki, P. J., "Real-World Emissions From a Modern Production Vehicle Driven in Los Angeles", GMR-7858, December 9, 1992.

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