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Guidance on Data Handling And Analyses In An Inspection/ Maintenance Program

FINAL REPORT

1 December 1981

Prepared for:

U.S. Environmental Protection Agency
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RADIAN
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ABSTRACT

Under contract with the Inspection/Maintenance (I/M) Staff of the U.S. Environmental Protection Agency, Radian provided guidance on the establishment of a data handling and analyses system for an I/M program. The report first discusses various uses of data in an I/M program. Details are then presented on statistical analysis and sampling techniques along with ways of presenting the data. The report also contains a discussion of data collection and handling techniques, including provisions for quality control.

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1.0 INTRODUCTION

An inspection/maintenance program is a system and like many other systems it depends on feedback. In an I/M program, data provide the feedback. Although many I/M options exist, the proper operation of any program depends upon knowledge of how the program is actually operating. This is accomplished through the timely and accurate collection and reporting of data to measure the effectiveness of the program. This document is intended to serve as a reference on the use of data in an I/M program.

There are two main purposes for this document. One is to describe specific techniques to analyze I/M data in order to generate the maximum amount of useful information. The other purpose is to provide guidance on the establishment of a data collection and handling system. Since an I/M program could generate massive quantitites of data, it is important to identify the key data elements. This document recommends data items which should be collected and offers suggestions on specific techniques to do so. These techniques include data collection forms that could be used and the method of data transcription and storage.

The following section discusses how data can be used to perform a variety of tasks in an I/M program. These tasks vary from revising the cut points to evaluating the performance of the inspection facilities. Analysis techniques and a list of data elements are provided for each task or objective, and it is noted which tasks require computers. Section 3 provides details on statistical analysis and sampling techniques along with ways of presenting the data. A detailed discussion of data collection and handling techniques, including provision for quality control, is provided in Section 4. The Appendix contains comprehensive lists of data that can be recorded in an I/M program.

2.0 THE USE OF DATA IN AN I/M PROGRAM

Many objectives can be met by analyzing data from an I/M program. Some of these objectives are basic to the day-to-day operation of the program. For example, data analyses can be used to evaluate the performance of inspection facilities in order to identify the facilities which are performing improper inspections or are recommending too many waivers. Data analyses can also be used to revise the program cutpoints (the emissions standards used to fail the vehicles). The effectiveness of the enforcement activities can be determined by data analyses, and an accurate accounting can be made on the issuance of the inspection stickers or certificates. Data analyses can also be used to evaluate the vehicle waiver system to determine if waiver policies need to be revised. Finally, it can serve the basic function of providing reports for the public, legislative agencies, service industries and special interest groups.

Aside from the basic objectives of data analyses there are additional objectives that could enhance operation of the program. For example, it may be useful to evaluate the effectiveness of different types of repairs in order to enhance the mechanics training program. It may also be useful to evaluate the performance of the individual inspectors as well as the inspection facilities.

Consumer protection would be highlighted if data analyses were used to evaluate the performance of the individual repair facilities. Facilities charging excessively or performing inadequate repairs could be identified. The performance of the individual emissions analyzers can also be determined by data analysis, as could the quality of the calibration gases that are used in these analyzers. Finally, data analyses could help determine the effectiveness of a public awareness program.

2.1 Evaluating the Performance of the Inspection Facilities

It is important to determine if accurate emission inspections are being performed. This is particularly true for decentralized programs, since there are many possibilities for error in the inspection. In these programs, the training of the inspectors varies considerably, as does the quality of the emission analyzers that are used. In centralized programs, high quality emissions analyzers generally are used, and there is much more consistency in the training of the inspectors. Consequently, data analyses play a greater role in the quality control of decentralized programs. However, the techniques used to evaluate the performance of the decentralized inspection facilities are also applicable to centralized programs, particularly the supervision of fleet inspections.

Considerable data analysis is required to determine if correct inspections are being performed. There is no single parameter that will identify stations that are performing inaccurate or fraudulent inspections. Furthermore, data analysis in itself will not be sufficient to suspend a station's license to inspect. However, it should be sufficient to identify likely candidates for frequent audits, spot checks, or training. Essentially, the I/M program manager must observe trends to determine stations with possible quality control problems.

2.1.1 Data Required

The I/M manager needs to analyze several different pieces of data in order to identify stations that may have quality control problems. Table 1 presents the specific data that are needed for such an analysis. The basic data items shown on this table will

TABLE 1. DATA REQUIRED TO EVALUATE THE PERFORMANCE OF THE INSPECTION FACILITIES

BASIC DATA

Vehicle Inspection Records

- Facility ID (2.1.2)*
- Test sequence (initial, after garage repair, after outside repair) (2.1.2)
- Pass/Fail status (including waivers issued) (2.1.2)

Facility Audit Data (2.1.6)

- Date of check
- Results of analyzer calibration checks
- Results of record checks
- Make and model of analyzer
- Results of inspector proficiency checks

SUGGESTED ADDITIONAL DATA

Vehicle Inspection Records

- Odometer (2.1.2)
- Type of repair (items replaced or repaired) (2.1.3)
- Vehicle type (LDV, LDT, HDG, etc.) or gross vehicle weight (2.1.2)
- Date of inspection (2.1.7)
- Repair cost (2.1.3)
- HC reading (before and after repairs) (2.1.4)
- CO reading (before and after repairs) (2.1.4)
- License or VIN (2.1.7)
- Model year (or cutpoint category) (2.1.2)
- Make (2.1.2)

Vehicle Registration Records (2.1.2)

- License or VIN
- Model year (and/or make)
- Vehicle type or gvw

Roadside or Challenge Check Data (2.1.7)

- Date of check
- License or VIN
- HC reading
- CO reading
- P/F
- Inspection facility (if indicated on sticker) or sticker serial number to trace back to the facility

Complaints (2.1.7)

- Type
- Facility

*Numbers in parentheses refer to sections that describe how the data are used.

be sufficient for most analyses, although the suggested additional items will enhance the results. (The Appendix contains detailed lists of data.)

Important data for determining the quality of the inspections are contained on the inspection records; consequently, it is extremely important that these data be accurately recorded. Another very important source of data are the results of facility audit checks. Data from roadside or challenge checks may also give an indication of the quality of the inspection, as could a tally of complaints. The following sections discuss the analyses that may be performed to identify stations that may have quality control problems.

2.1.2 Analysis of Failure Rates

A key indication of the performance of any inspection facility is the reported failure rate. A simple method to identify stations with questionable failure rates is to first determine the overall failure rate by facility. The stations could then be sorted by failure rate, and those with extremely high or low failure rates could be more frequently audited by the administrating agency.

Some of the outliers may be correctly inspecting vehicles; therefore additional analysis will be useful. Failure rates may vary by model year and cutpoint category; thus, if these data are collected, a breakdown by such categories would be very useful. These breakdowns can be performed manually if each station provides tabulated results of the inspection (see Section 3.2.1).

If computers and automated data collection equipment are available, the following analysis can be performed.

- It is advantageous to be able to isolate vehicles that are known to have low failure rates. These vehicles include the 1979 and later General Motors light duty vehicles and the 1981 and later (three-way catalysts) vehicles. Therefore, the failure rates could be broken down further by make and possibly gross vehicle weight or vehicle type. (This latter breakdown is not necessary if the program only applies to light duty vehicles.)

- Calculation of the average odometer reading for each group of vehicles may provide additional insight, since the higher mileage vehicles stand a greater chance of failing the test.

- The administrating agency may find it useful to standardize the failure rate. In order to arrive at a standardized failure rate for each facility, it is best to determine the failure rates for the different groups of vehicles (e.g., similar model years) and then use a standard weight factor for each group to determine standardized failure rate (see Table 2.) The standard weighting factors could be determined by tabulating registration data.

TABLE 2. SAMPLE CALCULATION OF A STANDARDIZED FAILURE RATE

CATEGORY (1)	MODEL YEAR (2)	FAILURE RATE (3)	WEIGHTING[1] FACTOR (4)	3 x 4
1	Pre 68	30%	.10	3
2	68-69	25%	.20	5
3	70-74	35%	.20	7
4	75-79	20%	.40	8
5	80 +	10%	.10	1
			Standardized Failure Rate	= 24%

[1]From vehicle registration records.

2.1.3 Analysis of Repair Data in Decentralized Programs

In decentralized programs, an analysis of repair data will greatly aid surveillance efforts. This is particularly true of stations that have higher than average failure rates, since they may actually be performing accurate inspections. Computers play an important role in the collection and analysis of repair data. Without computers, the analysis of repair data are largely limited to spot checking and qualitative review of repair costs or invoices.

If repair cost data are collected automatically, the average costs for each station can be calculated. Those stations with extremely high or low costs could be investigated.

Information on the type of repair can help determine if facilities are charging excessive costs for simple repairs. In addition, the type of repair data will help to determine whether or not adequate repairs are being performed. For example, if the repair facility only adjusts the idle mixture and never performs more extensive repairs, then that facility may not be achieving adequate HC emission reductions.

2.1.4 Analysis of Emission Levels

A further screening technique for those facilities identified as outliers is to analyze the emission levels that are recorded during the inspection. Although the available analysis is limited, the following techniques can be used to determine if the station is falsifying the emission levels recorded on forms. Like the preceding analysis, this analysis would require some form of automated data collection.

- One method to check on the quality of the recorded levels would be to calculate the means and standard deviations of the emission levels (by model year and possibly by make and model year groupings). These calculations should be made for each test facility and for the entire population. Facilities that vary greatly from the entire population could be suspect.

- Another approach to determine expected means and standard deviations would be to identify certain high volume stations that appear to be performing accurate inspections as indicated by failure rate, facility audits, discussions with owners, the inspection equipment, and so forth. Emission levels from these stations could be a more accurate representation of the vehicle population.

2.1.5 Analysis of Waiver Rates

Another basic means of measuring facility performance is to tally the number of waivers that are issued by each facility. Those stations with extremely high waiver rates (as a percentage of the failed vehicles) may be performing inadequate repairs and those with low waiver rates may be performing inadequate inspections.

Additional analysis can help to determine if the outliers (with respect to waivers) may actually be performing adequate inspections and repairs. Waiver rates may vary for different model year vehicles or cutpoint categories. Facilities which inspect primarily newer vehicles, such as new car dealerships, may have significantly different waiver rates than the average facility. Thus, if model year data were collected along with the waiver data, the differences (if any) in waiver rates for different groups of vehicles could be determined. These differences could be considered when waiver rates for different inspection facilities (especially the outliers) are being analyzed.

2.1.6 Analysis of Data From Facility Audits

Facility audits are excellent sources of data on the performance of a test facility. In fact, these checks plus unannounced spot checks probably are the only solid legal basis for station suspension. These checks mainly address two facets of the emission inspection:

- The accuracy of the emissions analyzer; and
- The proficiency of the inspectors to perform emission tests and other duties, such as recording data and analyzer maintenance.

A considerable amount of data can be generated from audits; however, the bottom line is the overall accuracy of the inspection facility. This is determined by reviewing both the results of the analyzer accuracy check and the proficiency check. The raw audit data are specific to each facility; therefore, it is not appropriate to statistically analyze these data.

Radian is preparing guidelines to perform these audits and review the data. Consequently, the handling of the raw data generated during the audits will not be addressed in this report. However, there are many uses for the audit results after they are technically evaluated. For example, they can be used to establish performance trends for different analyzers. And as previously mentioned, the audit checks can be used to identify stations that appear to be performing accurate inspections and thus, can be used to establish expected trends in emission levels.

In particular, the following data are very useful:

- The results of the analyzer calibration and leak checks (including make of analyzer);

- o The results of the inspector proficiency checks; and
- o The results of the record checks (to check for proper completion).

2.1.7 Other Analyses to Evaluate the Performance of Inspection Facilities

The previous analyses provide the major indications of the performance of an inspection facility. However, there are other data that can be analyzed. If roadside and challenge checks are performed, then it may be possible to cross-reference these checks with the I/M inspection (via the license number or VIN) to provide a gross indication of the accuracy of the inspection and repair. (The serial number of the inspection sticker may also be used to identify the original inspection facility.) Because there would be many reasons for discrepancy between roadside checks and the initial inspection, it would be difficult to use these checks to determine the precision of the initial inspection. However, if gross emitters are found in the field and these vehicles were recently inspected and passed, there is a high probability that the inspection facility improperly passed the vehicle.

Another possible way to check on the inspection facility would be to review complaints that are filed by motorists. In fact, program officials may want to encourage motorists to provide feedback on the inspection through some form of complaint handling process (or consumer hot line.) All complaints should be investigated, if possible, however if resources are limited, facilities with repetitive complaints should receive a high priority for investigation.

2.2 Revising Cutpoints

Data can be used to identify and support the need for changes in program cutpoints. Cutpoints may need to be revised for some of the following reasons:

- To adjust the average failure rate within cutpoint categories (e.g. to reduce excessively high failure rates for certain vehicle categories);
- To control the overall failure rate at the level desired for emission reductions (if the cutpoints are not changed, the failure rate, and accordingly, the program effectiveness, could drop); and
- To revise waiver rates.

Generally, at least one year should pass before cutpoints are revised.

The general analysis techniques to revise cutpoints are similar for each of the above reasons. They essentially involve collecting data from the vehicle inspection records (see Table 3) in order to tighten (increasing stringency) or loosen the emissions standards. Several approaches can be used to adjust the standards. One approach is trial and error. The CO and/or HC standards could be adjusted up or down until the desired failure rate is observed. A FORTRAN program for efficient trial and error selection of cutpoints is available from EPA.

A more straightforward approach may be to construct cumulative distributions of HC and CO idle emission levels. These distributions would show the percent of vehicles falling below certain emission levels and could be developed for different groups of model years and/or vehicle types. By observing these distributions, the analyst could pick cutpoints that will fail a greater or lesser number of vehicles. However, these distributions do not give a definitive indication of the number of vehicles that would fail both the HC and CO standard. Consequently, there is also some trial and error with this approach.

If the program handles and processes data manually, then a sample of the population should provide enough data to revise cutpoints (sampling techniques to revise cutpoints are discussed in Section 3.4). And as previously discussed, the program could also depend upon data collected from high volume stations that appear to be performing accurate inspections (see Section 2.1.3).

Procedures and recommendations to revise cutpoints are presented in a recent EPA report (Recommendations Regarding the Selection of Idle Emission Inspection Cutpoints for Inspection and Maintenance Programs, EPA-AA-IMS/81-1, January 1981.) This report addresses idle hydrocarbon (HC) and carbon monoxide (CO) cutpoints and expected resulting failure rates in an I/M program.

TABLE 3. DATA REQUIRED TO REVISE CUTPOINTS

BASIC DATA

Vehicle Inspection Records

- Test Sequence (initial or retest)
- P/F status (including if waiver issued)
- HC reading (before and after repair)
- CO reading (before and after repair)
- Model year

SUGGESTED ADDITIONAL DATA

Vehicle Inspection Records

- Odometer
- Make
- Vehicle type (LDV, LDT, HDG, etc.) or gross vehicle weight

Recommended cutpoints are included for various failure rates both in the first year of an I/M program and in its second year. The analysis applies to both centralized and decentralized programs.

2.3 Evaluating and Enhancing the Effectiveness of Sticker Enforcement

With a sticker enforcement system, there is a greater possibility of non-compliance than with a registration enforcement system. In the latter case, the inspection is a prerequisite to vehicle registration; and thus the enforcement is almost automatic (unless motorists register their vehicles outside the program area). A sticker system depends upon local or state police to stop and ticket vehicles which lack or have expired stickers. Consequently the effectiveness of sticker enforcement depends upon adequate police staffing, the vigilance of police in stopping and questioning apparent violators, the severity of penalties imposed by local courts and the visibility and publicity associated with the enforcement efforts. Operating I/M programs that have used stickers for enforcement have reported problems with program circumvention, especially when the program was implemented on a regional rather than a statewide basis. Consequently, there is a need for the program to use data analysis to evaluate the effectiveness of sticker enforcement. In addition, data analysis can be used to enhance the effectiveness of the enforcement program.

2.3.1 Data Required

As shown in Table 4, the data required to evaluate enforcement can be found on the vehicle inspection records, as well as the registration records. In addition, the maintenance of a data base that indicates the I/M compliance status of each registered vehicle would greatly aid the enforcement efforts.

TABLE 4. DATA REQUIRED TO EVALUATE STICKER ENFORCEMENT

BASIC DATA

Vehicle Inspection Records	Vehicle Registration Records
- P/F status (including waiver issued) (2.3.2)	- Vehicle type (LDV, LDT, HDG, etc.) or gross vehicle weight (2.3.2)

SUGGESTED ADDITIONAL DATA

Vehicle Registration Data Base[1] (2.3.3)

- License or VIN (from both vehicle inspection and vehicle registration records)
- Registration date (from vehicle registration records)
- I/M compliance status (yes/no) (from vehicle inspection record)
- I/M test date (from vehicle inspection record)
- Sticker number (from vehicle inspection record)

Data on Citations Issued for Non-compliance (2.3.2)

[1]Developed by combining the Vehicle Inspection Record with the Vehicle Registration Records

2.3.2 Calculating the Compliance Coefficient

A simple indication of the effectiveness of the enforcement efforts can be determined by calculating the compliance coefficient. The compliance coefficient is the percentage of registered vehicles that have complied with the inspection requirements. It can be determined by the following formula where the number of stickers equals the number of passed (or waived) vehicles:

$$\text{Compliance Coefficient} = \frac{\text{Number of stickers (including waivers)}}{\text{Number of vehicles registered - exempt vehicles}}$$

In a well enforced program the compliance coefficient should be close to 1.0. Therefore, if the calculated compliance coefficient is much below 1.0, then enforcement efforts may need to be enhanced. Program officials may want to consider adding additional police or stepping up the public awareness efforts.

Another useful piece of data would be the number of citations for noncompliance. This number needs to be evaluated in light of the compliance coefficient. If both numbers were low, then the program could have serious problems.

2.3.3 Identifying Non-Complying Vehicles

If enforcement continues to be a problem despite increased public awareness or policing, then it may be advantageous to set up a new system to identify non-complying vehicles. Essentially this would involve maintaining a data base on the I/M status of the registered vehicles, and currently registered vehicles that have not been inspected could be identified.

In a centralized program this form of data base could be easily maintained by entering compliance data directly at the inspection lanes. These data could then be correlated with the vehicle registration data via the license plate or the vehicle identification number (VIN), and vehicles needing inspection could be identified. If the registration data are in a real time data base management system (DBMS), registration files could be updated continuously as the inspection is performed. Otherwise the files could be updated in batches via data tapes.

There are several options available to identify non-complying vehicles in a decentralized I/M program. If machine readable forms or data tapes are used for the inspection, then it should be relatively easy to input data on the I/M status (see Section

4.1.1). The inspection data could be correlated with the registration data via license number or VIN, and printouts could be generated of non-complying vehicles. However, if the forms are not machine readable, then it would be necessary to keypunch the I/M status data along with the license or VIN.

With all of these approaches, except for possibly entering data into a real time DBMS, there could be accuracy problems with entering the license number or VIN. This could result in some vehicles being falsely identified as not complying with the I/M requirements. However, the presence of the sticker on the vehicle should quickly alleviate these problems.

2.4 Determine Sticker Accountability

In programs which use inspection stickers for compliance enforcement, it is necessary to account for them to ensure that large numbers of unauthorized stickers are not getting into the hands of the public. In order to account for stickers, the following data need to be collected.

1. The serial numbers of stickers issued to each inspection facility;
2. Data from audits on the serial number of stickers on hand; and
3. Vehicle inspection data, specifically the number of passed or waived vehicles.

Sticker accounting should be performed for each inspection facility (instead of all the facilities collectively) since this will allow for discrepancies to be immediately tracked down.

Stickers could be accounted for as part of the periodic facility quality control audits. The agency responsible for issuing stickers could supply auditors with lists of facilities and serial numbers. When the auditors inspect the facilities, they could check the serial numbers of the stickers on hand. Then, from the inspection data, the number of passed or waived vehicles could be tallied. The number of stickers on hand plus the number of passed or waived vehicles should equal the total number issued. In addition, the auditors could encourage stations to return expired stickers for credit, and thus help prevent "hot stickers."

2.5 Determine Fee Accountability (for Contractor Operated Programs)

The administrating agency for the I/M program should be responsible for the accountability of the inspection fees. In most centralized contractor run I/M programs, the inspection fee is collected by the contractor, who then transmits a portion to the administrating agency to cover its costs. It may be possible for a contractor to understate the number of inspections and thus withhold funds from the State.

Conversely, the administrating agency could pay the contractor a specific amount for each test or retest. (The inspection fee could be part of the registration fee.) In this case, it may be possible for the contractor to overstate the number of inspections, thereby causing the administrating agency to pay for a greater number of inspections than actually occurred. (This has potential for serious cash flow problems or fraud; therefore, I/M programs may opt to have the contractor collect the fee at the inspection lanes.)

It should be noted that agencies in Arizona and California do account for fees in their contractor-operated I/M programs, and they have not reported problems with fee accountability or fraud. The data required to account for fees is shown in Table 5.

TABLE 5. DATA REQUIRED TO ACCOUNT FOR FEES

Vehicle Inspection Records	Contractors Financial Data
BASIC DATA (2.5.1)	
- Date of inspection - Test sequence - P/F status - Facility ID	Money collected: - Amount due to contractor - Amount due to administrating agency
SUGGESTED ADDITIONAL DATA (2.5.2)	
Vehicle Registration Data	
- License or VIN - Registration date	
Vehicle Inspection Records	
- License or VIN	

2.5.1 Basic Accounting Methodology

When accounting for the fees, it is necessary to first determine the number of tests (including retests). This number can be determined by tallying the vehicle inspection records. The amount of money collected by the contractor depends upon the billing mechanism. If the motorist only pays for a certificate of compliance or a sticker, then the total funds collected should equal the number of stickers or certificates times the inspection fee. However, in some programs motorists pay for each test, whether or not it is an initial test or retest. In this instance, it is necessary to keep track of each inspection to determine whether the correct amount of money was collected.

2.5.2 Validating the Number of Inspections

If the contractor is suspected of understating or overstating the number of inspections for the reasons that were previously discussed, it may be necessary to validate the number of inspections. For the case where the number of inspections was understated and registration was used for the enforcement mechanism, then registration data should provide an accurate number of certificates issued.

In a contractor operated program using a sticker enforcement system, checking for an understatement of the number of inspections can be accomplished by holding the contractor accountable for the number of unused stickers. A contractor would have to show that he possesses the appropriate number of stickers to account for the difference between the total number of stickers initially issued to him, and the number issued to motorists after being inspected.

For a case where the number of inspections are overstated (for purposes of obtaining additional funds from the administrative agency) similar checks can be made. If registration is the enforcement mechanism, again the number of vehicles registered should correspond with the number of certificates issued. If sticker enforcement is used, a check could be made that a valid license number or vehicle identification number was entered onto the inspection form. This can be done by cross-referencing the inspection records with registration data (via the license number of VIN). Although this latter method is not foolproof, it will help to identify fraudulent records.

2.6 Evaluate the Vehicle Waiver System

Another important function of data analysis is to evaluate the vehicle waiver system. The effectiveness of an I/M program in achieving emission reductions would be significantly reduced if a large number or high percentage of the failed vehicles received waivers. Generally, an excessive waiver rate indicates that there are problems within the mechanic sector. Since most vehicles should be able to pass an I/M test, a high waiver rate may also indicate that there are a large number of illegitimate waivers. It also suggests that people are obtaining certificates of compliance or inspection stickers without really attempting to have their vehicles repaired. The data required to review waivers are shown on Table 6.

TABLE 6. DATA REQUIRED TO REVIEW WAIVERS

BASIC DATA

Vehicle Inspection Records (2.6.1)

- Test sequence (initial or retest)
- Facility ID
- P/F status (including waiver issued)

SUGGESTED ADDITIONAL DATA

Vehicle Inspection Records

- Type of repair (parts required or replaced) (2.6.2)
- Mechanics ID (2.6.2)
- Repair facility ID (2.6.2)
- HC reading (before and after repair) (2.6.2)
- CO reading (before and after repair) (2.6.2)
- Repair cost (2.6.2)
- Model year (2.6.3)
- Make (2.6.3)
- Odometer (2.6.3)

2.6.1 Determining the Basic Waiver Rate

The basic approach to analyzing the waiver system is to tally the overall number of waivers and determine the percentage of failed vehicles that are being waived from compliance. In addition, as mentioned earlier, the administrative agency can also determine if individual repair facilities or mechanics are abusing waiver policies. By tallying the number and percent of waivers issued by the decentralized inspection facilities, the program could identify facilities suspected of performing inadequate repairs or inspections. (In centralized I/M programs this analysis will require the use of licensed repair facilities or mechanics.)

2.6.2 Determining Legitimacy of Waivers

The following data analysis with the aid of automated data processing can help determine the legitimacy of the waivers issued.

- A review of the inspection records can be made to determine if repair costs of waived vehicles coincide with the repair cost limits established by the waiver policy.

- In addition, if the program requires that a licensed mechanic or garage perform the necessary repairs prior to obtaining a waiver, a check could be made to insure that a valid mechanic's ID number was entered onto the vehicle inspection records.

- Also, if the vehicle inspection record contains data on the type of repair, i.e., the parts repaired or replaced, verification could be made that the necessary repairs were made on the vehicle to qualify for a waiver. In most cases these repairs are the equivalent of a low emission tune-up.

- Another way of determining if waiver policies are being abused would be to calculate the idle emission reductions of the waived vehicles. Facilities that show very low idle emission reductions should be suspected of performing incorrect or inadequate repairs.

2.6.3 Characterizing Vehicles Receiving Waivers

It may also be useful to characterize the vehicles that are waived. This would involve tallying the number of waivers by make, model year and possibly odometer reading. If a relatively large number of waivers are issued for a certain make and model year vehicle, then the manufacturer may need to be consulted to determine why these vehicles are having difficulty complying with the emissions inspection. A revision of cutpoints may be required for such a case.

2.7 Quantify Idle Emission Reductions

Since the purpose of inspection/maintenance is to reduce emissions from motor vehicles, program officials may want to calculate the idle emission reductions that have resulted from the repairs. It should be noted, however, that idle emission reductions are indicative, but not necessarily definitive of actual emission reductions (measured by the Federal Test Procedure (FTP)). The vehicle inspection record provides the necessary data to calculate the reductions (see Table 7.) However, random surveys of idle emission levels in non-I/M areas provide additional input into the effectiveness of the I/M program. Of course, if the I/M program encompasses the entire state, then it would be impossible for state officials to conduct these surveys.

TABLE 7. DATA REQUIRED TO EVALUATE IDLE EMISSION REDUCTIONS

BASIC DATA

Vehicle Inspection Record (2.7.1)

- Test sequence (initial or retest)
- P/F status (including waiver issued)
- HC reading (before and after repair)
- CO reading (before and after repair)

SUGGESTED ADDITIONAL DATA

Vehicle Inspection Record (2.7.2)

- Odometer
- Model year
- Make

Random Surveys in Non-I/M Areas (2.7.2)

- HC reading
- CO reading
- Odometer
- Make
- Model year

2.7.1 Idle Emission Reductions from Repairs

A simple indication of the effectiveness of the program would be the idle emission reductions from repairs. Essentially, this is determined by calculating the average emission levels before and after the repairs. The percent difference is calculated by dividing the reduction in emission levels by the before repair levels. If the program handles data manually, then the above calculations may be performed on a sample of the vehicle population (see Section 3.4).

2.7.2 Comparing I/M Areas with Non-I/M Areas

If data handling were computer assisted, a comparison can also be made of the idle emission levels within the program area with a non-I/M population. One method to do this would be to collect data at the start of the program before repairs are performed. The data obtained from the initial emission test could be characterized by make, model year, and odometer reading.

The overall trends in average idle emissions, as a function of odometer reading, should vary for different technology categories. For instance, the increase in emissions from catalyst and non-catalyst vehicles as related to mileage would differ due to the particular deterioration rate associated with the type of technology. Thus model year groupings can be developed for the different technologies (i.e., non-catalyst, pre 1975; oxidation catalyst, 1975-1980; threeway catalyst, 1981 and later.)

As the program proceeds, the same characterizations can be performed with the I/M population. That is, the average idle emissions (both before and after repair) could be calculated and the overall trends in emissions as a function of odometer and model year group could be determined. These trends could then be compared to the extrapolations of data collected at the start of the program.

The data from the I/M population can also be compared with data from non-I/M populations. As previously discussed, this would involve conducting random surveys of idle emission levels in bordering areas that do not have I/M. The emission levels could be standardized by model year group and odometer reading and comparisons could be noted.

2.8 Reporting

Aside from using data analyses to help run the I/M program, they can also be used to generate reports about the operation and effectiveness of the program. Essentially, these reports would be compiled from the results of the previously described analyses. They should be prepared for different groups, such as the legislature, the public, special interest groups, agencies, and the service industry.

2.8.1 Reports to the Legislature

Different types of reports should be prepared for the legislature. Probably the most useful report would be a summary of the program data. These reports would give the legislature information such as:

- The number of vehicles inspected,
- Failure rates,
- Emission reductions, and
- Repair costs.

Certain members of the legislature will probably want to see a comprehensive compilation of I/M program data. Consequently, data should be analyzed to present specific details on the program. Essentially all available data should be analyzed to prepare such a report. As a minimum, these reports should include tabulations and averages of the basic items shown in Table 8, i.e., the inspection records, the results of field investigation and enforcement activities. In addition, a summary should be provided of the results of the following analysis:

- The performance of the inspection facility,
- Revision to the cutpoints,

- o Effectiveness of the enforcement activities,
- o Accountability of the fee and stickers,
- o Effectiveness of the waiver system,
- o Idle emission reductions, and
- o The public's perception of the program.

2.8.2 Reports to the Public

Like the legislature, the public is involved with the I/M program. Various public sectors may want to know information such as failure rate and average repair costs, along with reductions in idle emission levels. In addition, information on the use of warranty repairs would be informative to the public. Consequently, program officials should prepare a report similar to the summary report to the legislature. This report can be compiled from the data presented in Table 8. The public should also be kept informed of the availability of more comprehensive reports on the program.

TABLE 8. DATA REQUIRED FOR REPORTING

Summary data of the following:

BASIC DATA (2.8)

- Vehicle inspection records
- Facility audit data
- Vehicle registration records
- Contractor financial data
- Field enforcement activities

SUGGESTED ADDITIONAL DATA (2.8)

- Roadside or challenge check data
- Vehicle Registration Data Base (indicating I/M status to determine non-complying vehicles)
- Random surveys in non-I/M areas

2.8.3 Reports to Other Groups and Agencies

Other groups and agencies may be interested in the operation of the program. Consequently, program officials should be ready to generate reports as needed. For example, the Better Business Bureau may want information on emission related repairs, and in particular, repair costs. Another example would be requests by the automobile manufacturers for information on the failure rates of their vehicles. As discussed, these requests may be easily met if the inspection records are compiled into a well managed data handling system.

2.9 Additional Objectives of I/M Data Analysis

The previous analysis techniques addressed functions that are necessary to operate an inspection/maintenance program. However, as mentioned earlier, data analysis can perform additional functions that would enhance the operation of the program, although these functions are not crucial to the day-to-day activities.

2.9.1 Evaluating the Repair Process

Obviously the quality of the repairs plays an important role in success of an I/M program. Although mere compliance with the emission standards is likely to achieve significant emission reductions, much greater reductions are possible if repairs are performed carefully and in accordance with the manufacturer's specifications. Therefore, it is useful for program officials to use data analysis to evaluate repair performance. This evaluation should address both the individual repair facilities (or mechanics) and the overall effectiveness of repairs. In both cases, the results are useful in providing direction for mechanic training programs operated by the administrating agency. Data required to evaluate repairs are shown in Table 9.

TABLE 9. DATA REQUIRED TO REVIEW REPAIRS

BASIC DATA

Vehicle Inspection Record (2.9.1)

- Test Sequence (initial or retest)
- P/F status (including waivers issued)
- Repair cost
- HC reading (before and after repair)
- CO reading (before and after repair)

SUGGESTED ADDITIONAL DATA

Vehicle Inspection Record

- Type of repair (2.9.1.2)
- Repair facility ID (2.9.1.1)
- Model year (2.9.1.2)
- Make (2.9.1.2)

Repair Invoices from Waived Vehicles (2.9.1.1)

2.9.1.1 Evaluating the Repair Performance in Centralized Programs

For centralized programs, considerable analysis can be performed if some form of repair garage licensing or registration is used. The ID of the repair facilities could be included on the inspection records, thus allowing the administrating agency to determine the emission test performance. Specifically the agency could determine:

- o The percent passing on retest,
- o The average cost,

- o The average emission reductions, and
- o The number of waivers issued.

Without licensing or registration of the repair facilities in centralized programs, there are limitations to the analyses that can be performed. One possible method is to audit records and repair invoices on waived vehicles. Although this is a time consuming method, it can identify candidates for mechanic training or further surveillance activities. Program officials might look at the repair records and examine vehicles to determine if the repairs were correctly performed. In some cases, program officials could actually contact the repair facility. Arizona has successfully used such a program (which they term the "waiver surveillance program") to reduce the number of waivers. However, they do report that it is manpower intensive.

In decentralized programs the repairs are often performed at the inspection facility. Thus, analysis techniques that were previously discussed may be used to evaluate the repair performance (see Sections 2.1.3 and 2.6).

2.9.1.2 Evaluating the Effectiveness of Different Types of Repairs

If the type of repair is included on the inspection records, then program officials could tally the repairs that are performed for different type of failures (i.e., HC, CO, tampering.) The results of the tally should be compared with the repairs that would be expected as a result of engineering judgment or studies such as EPA's FTP Testing Programs. For example, if a vehicle fails only for CO, then it is unlikely that a complete engine tune-up should have been performed. Discrepancies found would provide feedback into mechanic training programs.

It may also be useful to calculate the idle emission reductions by type of repair to determine if certain types of repairs appear to be more effective. It should be noted, however, that although the idle emission reductions are indicative of the repair performance, they do not necessarily indicate that the vehicle will be achieving low emissions in actual use.

To provide additional input into mechanic training programs and public awareness programs, calculations could be made on the cost of repairs by the following parameters:

- Type of vehicle,
- Age and mileage of vehicle,
- Make of vehicle, and
- Geographic area.

Again, most of these calculations would probably require computer assistance.

2.9.2 Evaluating Inspector Performance

In decentralized programs, it may be advantageous to review vehicle inspection records in order to evaluate the performance of the inspectors. The items to investigate would be errors in following the test procedures or errors in filling out the forms. Procedural errors such as the use of the wrong emission standards could be picked up by a computer. In order to do this, the inspector ID needs to be included in the vehicle inspection record. A check could then be made to determine if the emission standards were appropriate for the model year reported on the inspection record.

It is more difficult, however, to determine if the forms are properly filled out. If computer readable forms are used, then the computer should be able to flag forms that have missing or absurd information on them. Techniques to flag these forms will be discussed in Section 4. However, in some cases it will be necessary to manually scan the forms to see if they were filled out correctly. If the forms that are not correctly filled out were separated by the inspector ID, then it should be easy to identify some of the inspectors who have problems filling out the forms.

In centralized programs, several inspectors may be involved with each vehicle that comes through the lanes. Consequently, it is not appropriate to use data analyses to evaluate inspector performance since it is difficult to actually pinpoint which inspector was responsible for which data.

Even with decentralized programs, it may not be appropriate for the administrating agency to concern itself with the performance of each inspector unless they are trying to track down problems in outlying inspection facilities (those with questionable data). It will take considerable manpower for the agencies to adequately monitor the performance of each test facility, regardless of the inspectors themselves.

2.9.3 Evaluate the Performance of Test Equipment

The results of the facility audits can be used to determine performance trends for different emissions analyzers. Therefore, auditors should collect data on the type and model of the analyzers that the stations use. These data can then be correlated with the results of gas calibration checks made by the auditors. Analyzers that consistently show good performance could be identified by the administrating agency, while the agency may want to restrict the sale of analyzers that show poor performance. In a centralized program, an analysis of the data could identify analyzers with frequent and/ or major problems. These analyzers could be singled out for major repairs or replacement.

Data from the facility audits can also be used to evaluate the accuracy of the calibration gases that are used by the inspection stations. When the auditors are at the stations, they could perform a gas calibration with their gas and with the station's gas. If discrepancies are found, then the auditors could track down the source of error in the calibration gas. The vendor of the calibration gas could also be noted on the audit data. This would allow trends to be investigated for the different specialty gas manufacturers.

2.9.4 Determine the Effectiveness of the Public Awareness Programs

Public awareness programs are different for various phases of the implementation of an I/M program. Early in the program, general air pollution and automobile-related air pollution would be emphasized; later, just prior to implementation, specific details of the program would be presented to the public; and finally, after implementation, current operating information would be provided to the public on an on-going basis. An evaluation of public awareness should deal with each phase separately.

There are two general sources of data to assess the effectiveness of public awareness programs. Data are available from inside the program such as the number and subject of complaints, and from outside the program through surveys and/or consumer "hotlines."

The program could encourage the use of consumer hotlines to report complaints or comments about the program. The operators of the hotline could record each phone call and periodically tally them. The I/M program in the South Coast Area Basin of California reports that it receives an average of 300 calls per day. Officials there categorize each call and prepare a summary report that quantifies the motorist feedback on the program (see Table 10.) This form of feedback can then be used to direct the public awareness activities and program modifications.

As mentioned, a major source of public awareness data are public opinion surveys. To ensure valid results from these surveys it is extremely important that they are properly designed. In the near future, EPA expects to release a technical report entitled, "Public Opinion Polls for Inspection and Maintenance Programs: Some Technical Considerations." This report will provide details on the design and uses of public opinion polls.

If the program uses sticker enforcement, then the previous analysis on the effectivenss of enforcement (see Section 2.3) will provide much input into the public awareness program.

2.10 Summary of Data Requirements

A listing of the data elements that are required to support the different objectives of I/M data analysis is presented in Table 11. The basic data elements are the data required to meet most of the major objectives, whereas the suggested additional elements provide additional analysis capabilities.

Figure 1 shows which data are required to meet each objective. Note that many objectives may be met with the basic data on the vehicle inspection records.

TABLE 10. A TALLY OF PHONE CALLS RECEIVED BY CALIFORNIA'S I/M PROGRAM

CATEGORIES	REPORT PERIOD (1 Month)	ACCUMULATIVE TOTAL
HTS Problems	294	2,536
Department of Motor Vehicles	31	374
Qualified Mechanic's List	24	876
Waiver Information	678	4,191
Data Logs - Fleets	4	255
Qualified Mechanic's Procedures	27	376
ECS Application (OEM & Retro)	143	2,417
Engine Changes	134	1,063
General Information	3,003	28,964
Fleet Information & SVIS Calls	62	649
Certifying Heavy Duty Trucks	115	751
Non-Compliance Questions - New Cars	19	202
Non-Jurisdictional	6	145
Seminar Information	159	950
MVPC Information	33	314
Idle Speed, Standards, \$35 NO_x Price	38	521
Reference Materials	11	59
A.R.B.	24	122
Calls from Politicians	0	3
Cost of Inspection	401	1,268

TABLE 11. SUMMARY OF DATA REQUIRED

BASIC DATA

Vehicle Inspection Records

- Date of inspection
- Facility ID
- Test sequence (initial or retest)
- P/F status (including waivers issued)
- HC reading (before and after)
- CO reading (before and after)
- Model year

Sticker Records

- Serial number of stickers issued
- Facility ID

Contractor's Financial Data

Money collected:

- Amount due to contractor
- Amount due to administrating agency

Facility Audit Data

- Date of check
- Results of analyzer calibration checks
- Serial numbers of stickers on hand
- Results of record checks
- Make and model of analyzer
- Results of inspection proficiency checks

Vehicle Registration Records

- Vehicle type (LDV, LDT, HDG, etc.) or gross vehicles weight
- Model year
- Registration date
- License number or VIN

(Continued)

TABLE 11. (Continued)

SUGGESTED ADDITIONAL DATA

Vehicle Inspection Records

- Odometer
- Type of repair (items replaced or repaired)
- Vehicle type (LDV, LDT, HDG, etc.)
- Mechanics ID
- Repair facility ID
- Inspector ID
- Repair cost
- License number or VIN
- Make

Random Surveys in Non-I/M Areas

- HC reading
- CO reading
- Odometer
- Make
- Model

Public Opinion Surveys

Facility Audit Data

- Source of calibration gas

Roadside or Challenge Check Data

- Date of check
- License or VIN
- HC reading
- CO reading
- Tampering check of results
- P/F
- Inspection facility (if indicated on sticker)

Complaints

- Type
- Facility

BASIC OBJECTIVES	BASIC DATA *					SUGGESTED ADDITIONAL DATA												
						VEHICLE INSPECTION RECORDS												
	Basic Vehicle Inspection Records	Facility Audit Data	Vehicle Registration Records	Sticker Serial Numbers	Fees Collected by Contractor	License Number VIN	Make	Repair Cost	Odometer	Type of Repair	Vehicle Type (or gvw)	Repair/Mechanics Facility ID	Inspector ID	Audit Data - Source of Calibration Gas	Roadside or Challenge Checks	Complaints	Random Emission Surveys	Public Opinion Surveys
1. Evaluating the Performance of the Inspection Facilities																		
Determine Failure Rates																		
- By facility	X																	
- By facility and model year	X																	
- By facility and model year and make	X						X											
- By facility and odometer	X								X									
- Standardized	X																	
Determine Repair Costs (decentralized)																		
- By facility	X							X										
Determine Type of Repair (decentralized)																		
- By facility	X									X								
Determine Waiver Rates																		
- By facility	X																	
Determine Analyzer Accuracy		X																
Determine Inspector Proficiency		X																
Determine Gross Accuracy of Inspection	X				X										X			
Determine Complaints by Facility																X		
Determine Idle Emissions	X																	
2. Revise Cut Points																		
Determine Idle Emissions	X																	
Determine Waiver Rates	X																	

*Refer to Table 11 for lists of the basic data elements

Figure 1. Data Requirements to Meet Objectives

BASIC OBJECTIVES (Continued)	BASIC DATA *						SUGGESTED ADDITIONAL DATA											
							VEHICLE INSPECTION RECORDS											
	Basic Vehicle Inspection Records	Facility Audit Data	Vehicle Registration Records	Sticker Serial Numbers	Fees Collected by Contractor	License Number VIN	Make	Repair Cost	Odometer	Type of Repair	Vehicle Type (or gvw)	Repair/Mechanics Facility ID	Inspector ID	Audit Data - Source of Calibration Gas	Roadside or Challenge Checks	Complaints	Random Emission Surveys	Public Opinion Surveys
3. Evaluate Sticker Enforcement																		
Calculate Compliance Coefficient	X		X															
Identify Non-Complying Vehicles	X		X			X												
4. Determine Sticker Accountability	X	X		X														
5. Determine Fee Accountability (Contractor Operated Prog.)																		
Account for Fees	X				X													
Validate the Inspections	X		X			X												
6. Evaluate Vehicle Waiver System																		
Determine Legitimacy of Waivers	X							X		X		X						
Determine Waiver Abuse	X																	
Characterize Vehicles Waived	X						X											
7. Quantify Idle Emission Reductions																		
Calculate Emission Reductions	X																	
Compare Emissions with Non-I/M Case																		
- Using program data	X								X									
- Using samples from non-I/M areas	X								X								X	
8. Reporting (use above results as needed)																		

*Refer to Table 11 for lists of the basic data elements

Figure 1. Data Requirements to Meet Objectives (Continued)

ADDITIONAL OBJECTIVES	BASIC DATA *					SUGGESTED ADDITIONAL DATA												
						VEHICLE INSPECTION RECORDS												
	Basic Vehicle Inspection Records	Facility Audit Data	Vehicle Registration Records	Sticker Serial Numbers	Fees Collected by Contractor	License Number VIN	Make	Repair Cost	Odometer	Type of Repair	Vehicle Type (or gvw)	Repair/Mechanics Facility ID	Inspector ID	Audit Data - Source of Calibration Gas	Roadside or Challenge Checks	Complaints	Random Emission Surveys	Public Opinion Surveys
9. Evaluate Repairs																		
Evaluate Facility Performance																		
- Decentralized programs	X							X		X								
- Centralized programs	X							X		X		X						
Evaluating Effectiveness of Repairs																		
- Type repair vs. failure	X									X								
- *Idle emission reductions by type of repair*	X									X								
- Cost by vehicle parameters	X						X	X										
10. Evaluating Inspector Performance	X												X					
11. Evaluating Equipment Performance																		
Analyzers		X																
Calibration Gas		X												X				
12. Evaluate Public Awareness	X		X											X		X		X

*Refer to Table 11 for lists of the basic data elements

Figure 1. Data Requirements to Meet Objectives (Continued)

3.0 DATA ANALYSIS TECHNIQUES

The goal of data analysis is to determine the performance of various aspects of the I/M program. Program officials need to carefully consider what summaries and types of analyses are pertinent to directly address day-to-day operations and policy making issues. (This is equally true regardless of whether computers or manual techniques are used for data analysis.) The results of the analyses should be presented as graphical or tabular summaries to enhance the reviewer's ability to understand the overall operation of the I/M program. The previous section showed how data could be used to perform several functions in an I/M program. This section describes in greater detail the analysis techniques which may be used to perform these functions.

3.1 Basic Analysis Techniques

Generally the review of I/M data does not involve complicated data analysis techniques. A majority of the analyses can be performed by simply tabulating or averaging the data. In only a few instances is it necessary to calculate standard deviations. However, if samples must be taken to reduce the amount of data handled, then the data analyst will need to employ more sophisticated measures. Sampling techniques are straight-forward and are discussed in Section 3.4 of this document.

3.1.1 Tabulations of Data

By and large a vast majority of I/M data analyses can be performed by simply tabulating the data that are collected. Simple tabulations include determining the failure rate for each facility. Essentially, this involves counting the number of passed and failed vehicles as indicated on the inspection records. If the records are sorted by the facility, then it is easy to determine the failure rate for each facility. More complex tabulations include determining the failure rate for each facility as a function of vehicle make and/or model year. Other examples of tabulations are listed in Table 12.

3.1.2 Averages and Standard Deviations

For some analyses, simple tabulations will not provide an adequate interpretation of the result. For example, a tabulation of the idle emission levels would be meaningless. Consequently, it is sometimes necessary to calculate an average of the values reported for different pieces of data. The following items are best expressed as averages.

- o Idle emission levels (both before and after repair),
- o Overall failure rate of the program (determined by averaging the individual failure rates tabulated by facility), and
- o Repair costs.

Although the average may provide an excellent measure of the central tendency of a set of numbers, it gives no indication of the variability of those numbers. Consequently, the analyst may want to calculate standard deviations. As mentioned in Section 2.1.1, for example, standard deviations of the idle emission levels may give an indication of whether or not an individual inspection station was falsifying the test results. The use of the standard deviation may also be useful in determining the degree of variability of repair costs.

Standard deviations of failure rates could also be calculated in order to set limits of acceptable failure rates for an inspection

TABLE 12. ITEMS THAT COULD BE TALLIED IN I/M PROGRAM

- Failure rates[1] by model year
- Failure rates[1] by make and model year
- Failure rates[1] by facility
- Waiver rates for each facility
- Type of repairs
- Serial numbers of stickers or certificates issued to each facility
- Fees collected by the facility
- Performance of different test equipment
- Complaints or public opinion surveys
- Reason for failure by type of repair

[1]Failure rates should be tallied as follows

- number of vehicles inspected
- number of vehicles initially failed
- number of vehicles failed upon reinspection

station. Concerning this latter point, the limits are just as easily established by observing a certain percentage of the outlying stations. That is, the I/M program manager may want to observe the top or bottom five percent of the stations, instead of observing those stations which fall outside the limits of plus or minus two standard deviations.

3.1.3 Statistical Analysis Packages

Many companies and institutions have prepared standard statistical analysis packages. These packages are available to government and private users and are extremely useful to the analyst. Many of the packages allow for data to be quickly tabulated as a function of 2 or 3 indicators. For example, failure rates can be determined by facility, by make, and by model year. In addition, averages and standard deviations are quickly computed by many of these packages. Table 13 lists many of the available statistical analysis packages.

3.2 Limits to Data Analysis

The limits to the data analysis that can be performed depends upon the method that will be used. There are three basic methods of data analysis: manual, computer assisted, and computer assisted with a data base management system. Obviously computer assisted analyses provide much more flexibility; however, many objectives of data analysis can be met by manually tabulating the data collected in an I/M program. If samples are selected, manual data analysis may also be used to calculate some averages and standard deviations.

TABLE 13. STATISTICAL ANALYSIS PACKAGES

NAME	ADDRESS
SAS	P.O. Box 10066, Raleigh, NC 27609
BMDP	University of Callifornia, 2223 Fulton Street Berkeley, CA 94720
SPSS	Norman H. Nie, Department of Political Science University of Chicago, 5801 S. Ellis, Chicago, IL 60637
Minitab	Prof. Thomas F. Ryan, Jr., Statistical Department 215 Pond Lab., Pennsylvania State University, University Park, PA 16802
Midas	University of Michigan Institute for Social Research Ann Arbor, MI 48104
P. Stat, Inc.	P.O. Box 285, Princeton, NJ 08540

3.2.1 Manual Data Analysis

Manual data analysis is sufficient to perform many of the tabulations previously discussed. In fact some of the operating I/M programs depend strictly upon manual data analysis for feedback of information. Following are some of the tabulations that can be performed by manually analyzing all of the available data:

- o Failure rates by facility,
- o Waiver rates by facility,
- o The compliance coefficient (see Section 2.3),
- o The accountability of stickers or certificates (It is recommended that the lists of serial numbers issued be generated by a computer. However, it is possible to maintain a log book of the serial numbers issued for each facility),
- o Accountability of fees,
- o The performance of different test equipment, and
- o Complaints or public opinion surveys.

The format of the forms is very important if data are to be tabulated manually. Key data elements such as the pass-fail status, the test sequence (initial or retest) and the facility ID should be easy to find on the form. In addition, it would be helpful, particularly in decentralized programs, to collect data periodically instead of continuously. This would prevent forms from different facilities from being mixed together. (Forms are discussed in greater detail in Section 4.)

Manual data analysis is greatly aided if the inspection facilities tally the results (using tally sheets) immediately after the inspection. Figure 2 is a sample tally sheet, and as shown, STATION ____________________

	From	To
Period	__________	__________

Model Year	Pass	Fail
Pre 70		
Total		
70-74		
Total		
75-79		
Total		
80+		
Total		
Grand Total		

FIGURE 2. SAMPLE TALLY SHEET

it will be very easy to calculate the overall failure rate for each facility as a function of model year groupings. Stations could also provide summaries of the number of waivers issued along with the total number of stickers or certificates issued.

With manual data analysis, more sophisticated cross-tabulations, averages, and standard deviations are very difficult to determine for all of the data. It is possible to calculate the overall or average failure rate by averaging the failure rates of each test facility. However, for most of the complicated analyses, it will be necessary to take vehicle samples if manual data analysis is used. Information from samples can be used to determine:

- Cutpoints,
- Average repair costs,
- Types of repairs performed (by type of failure),
- Average emission levels (overall and by model year), and
- Emission reductions (overall, by model year, by type of repair).

Unfortunately, sampling will not alleviate all the problems of manual data analysis -- there will still be some objectives that cannot be met. This is particularly true of decentralized programs, because of the large number of inspection stations. For example, with manual data analysis, it would be very difficult to arrive at the failure rate for each facility by make. Similarly, it would be very difficult to arrive at the average idle emission levels for each facility, either overall or as a function of make and model year.

3.2.2 Computer Assisted Analysis

Unlike manual data analysis, with computer assisted analysis the collection and entry of data is the main bottleneck. Consequently, it may be necessary to collect samples of the data, even if sampling is not necessary for data analysis. Once the data are entered into the computer most of the previously discussed objectives may be met. Section 4 describes methods to enter the data into the computer.

In the absence of a data base management system, it is recommended that an I/M program use a standard statistical package to perform the more sophisticated analyses. The use of these packages essentially affords the program most of the flexibility that is available with a data base management system (DBMS). If these packages are not used, then it is likely that considerable time will be spent in software development. These packages will enable the I/M analyst to perform most of the data analyses techniques that were discussed in Section 2. Of course, some data such as the data from the quality control audits will still need to be analyzed manually, despite the use of computer assistance for many of the other functions.

3.2.3 Use of a Data Base Management System

An online data base management system is ideal for I/M data analyses. Although the use of standard statistical packages will allow the analyst to perform many of the functions that could be performed with a data base management system, the ease of operating the latter system is of great value. For example, there are many times when the I/M program manager needs specific information about the program. This information can be quickly retrieved with a DBMS, and most data base management systems can be used by people that do not have a strong background in computers.

Consequently, there is not a continuous requirement for the data processing department to handle information requests since much analyses can be handled directly by the I/M program manager.

However, it is probably not cost effective for the I/M program to purchase a DBMS strictly for its own use. This option should be investigated if a DBMS is already available to the administrating agency.

3.3 Presentation of Data

In many cases, the presentation of the data is almost as important as the actual analysis that is performed. The results of the data analysis should be presented in a manner that enhances the administrator's ability to spot trends and problem areas. The following is a discussion of the different types of data presentation formats.

3.3.1 Tables

Tables are best used to present large quantities of summary information. For example, the failure rates of different combinations of make and model year vehicles is probably best shown in a table (see Tables 14 and 15). In some cases, however, it may be difficult for the observer to pick out the salient aspects of the analysis if a detailed table is used.

3.3.2 Graphs

Graphs are recommended to point out trends in areas such as: failure rates, monitored reductions, emission levels, or waiver rates. Figure 3 is an example of a graph that was prepared by the New Jersey Department of Environmental Protection. The graph clearly illustrates both the initial failure rate and the failure

TABLE 14. CALIFORNIA - SELECTED TABLES FROM THE MVIP ANNUAL REPORT

Table A-2 - Idle Emission Test Standards and Failure Rates for each Vehicle Category for the First 22 Weeks of the Program

Category	Vehicles Inspected	Model-Year	Cylinders	Emission Control System	Standards with Tolerance HC	CO	Emission Failure Rates	Device Failure Rates	Smoke and RPM Failure Rates	Overall Failure Rates
1	34,764	1955-1965	5 or more	-	1200	9.0	21.43%	40.07%	10.43%	55.34%
2	15,663	1966-1970	5 or more	w/AI	450	3.0	42.14%	54.57%	2.71%	70.23%
3	63,217	1966-1970	5 or more	w/o AI	600	7.0	30.95%	46.53%	2.19%	61.53%
4	26,546	1971-1974	5 or more	w/AI	250	2.2	35.80%	22.96%	1.68%	48.48%
5	46,633	1971-1974	5 or more	w/o AI	450	6.0	30.77%	24.39%	1.26%	46.23%
6	15,137	1955-1967	4 or less	-	1850	8.0	26.43%	21.77%	31.76%	60.18%
7	4,846	1968-1970	4 or less	w/AI	500	3.0	40.69%	48.39%	19.67%	71.32%
8	15,468	1968-1970	4 or less	w/o AI	1000	7.0	30.21%	42.11%	17.90%	62.24%
9	13,650	1971-1974	4 or less	w/AI	350	2.25	42.42%	17.63%	11.33%	54.65%
10	40,711	1971-1974	4 or less	w/o AI	500	6.0	28.99%	17.03%	13.40%	45.48%
11	23,870	1975-1979	All	No cat	350	3.0	22.26%	9.70%	3.48%	30.10%
12	19,137	1975-1979	All	Cat w/o AI	250	2.0	34.77%	10.40%	2.41%	41.04%
13	67,124	1975-1979	All	Cat w/AI	250	2.0	10.37%	10.84%	2.78%	20.66%
14	24	1975-1979	All	3-way cat	250	2.0	4.17%	4.17%	4.17%	8.33%
	386,790						27.05%	26.48%	6.50%	46.74%

A19.

TABLE 15. STATISTICAL REPORT OF COLORADO'S I/M PROGRAM

November 12, 1981

Results of Idle Testing

Mobile Sources Section
Air Pollution Control Division
Colorado Department of Health

EIGHT-COUNTY PROGRAM AREA

STATISTICAL REPORT OF AIR PROGRAM

VEHICLE MODEL YEAR	FIRST TESTS	RETESTS	FAIL RATE	% CO REDUCTION*	% HC REDUCTION**
68	1810	361	19.9	47.62	42.05
69	2646	473	17.9	50.00	46.83
70	3118	504	16.2	49.82	44.19
71	3772	617	16.4	54.95	46.62
72	4972	953	19.2	55.20	49.74
73	5880	1080	18.4	57.19	47.53
74	6409	1114	17.4	56.79	47.96
75	4708	775	16.5	59.70	49.23
76	6163	1023	16.6	58.66	50.28
77	6209	1387	22.3	64.43	51.08
78	7808	1515	19.4	65.29	50.89
79	8441	1680	19.9	67.41	50.85
80	6775	661	9.8	75.29	56.39
81	3884	177	4.6	67.70	57.99
82	91	1	1.1	100.00	100.00
TOTAL:	72,686	12,321	17.0	59.72	48.86

* carbon monoxide reduction

** hydrocarbon reduction

These figures were obtained from report forms of vehicles inspected under the AIR Program from July 1, 1981 to the above date. They do not represent the entire population of vehicles inspected in the program to date, only that portion which has been processed by the computer.

NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION
AND
DIVISION OF MOTOR VEHICLES

MONTHLY VEHICLE INSPECTION REPORT
NOVEMBER 1979

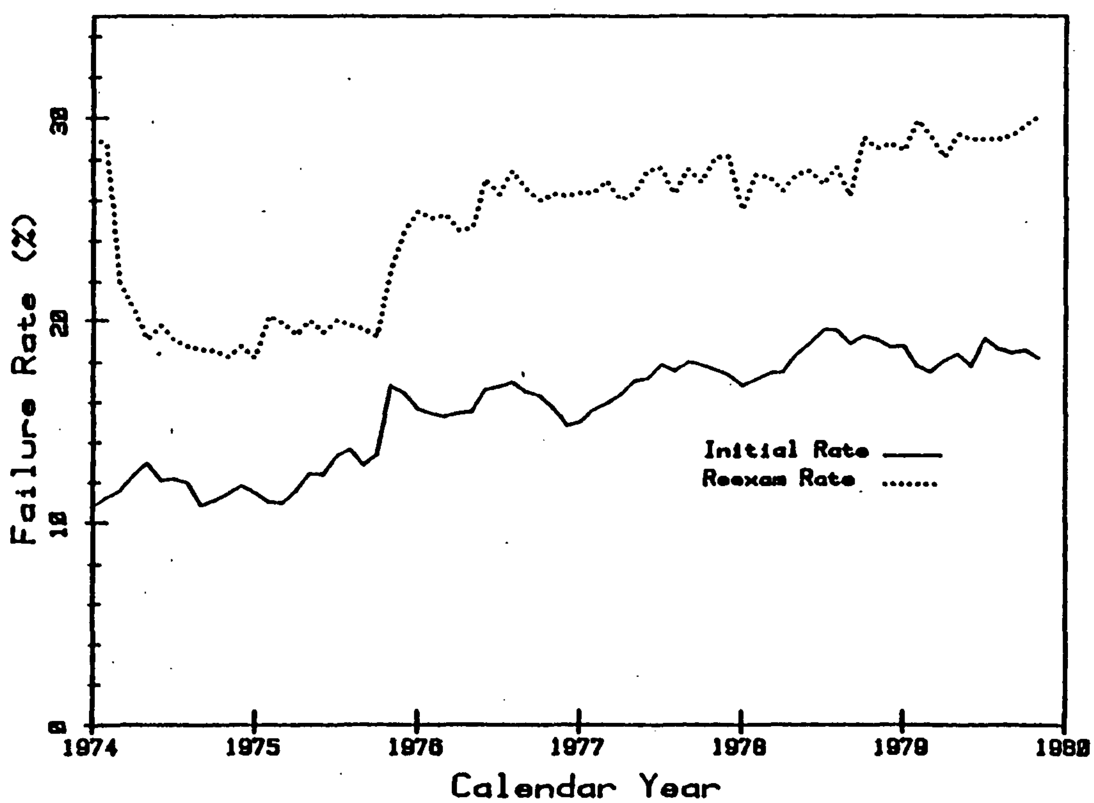

FIGURE 3

rate upon reexamination. It is interesting to note that the sharp rise in failure rate in 1976 was due to the implementation of more stringent cutpoints.

3.3.3 Bar Charts

Bar charts are well suited to illustrate a comparison between two or three populations. For example, the idle emission levels of an I/M population could be graphically compared with a non-I/M population on a bar chart. Bar charts are also useful in illustrating the reductions from repairs.

3.3.4 Reports Generated by Manipulating a Data Base

As mentioned earlier, an online data base management system affords the program manager considerable flexibility in the analysis of data. By manipulating certain key words, reports can be instantly shown on a screen or they can be quickly printed on the teletype. These types of displays are excellent for investigations on program operations or the effectiveness of repairs. For example, the operator can easily determine which stations have questionable failure rates by manipulating a data base. The actual hard copy results can be shown by any of the previous three methods.

3.4 Sampling

In manual (and in some instances, automated) systems it is not always practical to use all the units of a population because of its size. Here the analyst would want to draw a random sample in order to characterize the population. In most semi- and fully-automatic systems, analyses done for reports normally utilize observations from the entire population. In this case sampling is not necessary.

Random sampling is the process of choosing "n" units from a population of "N" units in a manner such that each of the "N" units has an equal probability of being chosen. When it is necessary to sample, it is extremely important to obtain a random sample. The consequences of not obtaining a random sample are biased results.

As discussed in Section 2.1.2, there are methods of overcoming sample biases. Essentially, this involves breaking down the sample into groups that are likely to influence the overall results. For example, newer model vehicles are likely to have lower failure rates. Therefore, if the average failure rate is being calculated from a sample, the analyst must break the sample down into groups of similar model years. It is important, however, that an adequate number of events exist for each group of model years.

3.4.1 Determining Sample Sizes

The following procedure describes a technique to determine the sample size necessary for statistically valid results. It should be noted that a sample must be taken for each group that is analyzed. For example, if the emission levels are being calculated for groups of makes and model years, then samples must be taken for each group.

CALCULATING SAMPLE SIZES

1. Define degree of accuracy.

   o Select tolerance or difference (d) that the sample average is allowed to vary from the population average (e.g., 10%).

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- Select confidence (p) that the error will be less than d.

  - p usually = 95%

2. Take preliminary sample of size n' or use similar data previously collected.

3. Select the parameters "Zp" from Table 16.

TABLE 16. STANDARD NORMAL DISTRIBUTIONS

p (%)	Zp
95	1.64
97.5	1.96
99	2.33

4. Determine ² as a function of n' and p (see Table 17).

5. Calculate sample size (n) per formula below where X_i is the observed data from the preliminary sample.

$$n = \frac{Z_p^2}{d^2} \quad \frac{\left(\sum_{i=1}^{n'} X_i^2 - \frac{\left(\sum_{i=1}^{n'} X_i \right)^2}{n'} \right)}{X^2_{p,n'}}$$

A statistical derivation of this expression is given in Appendix B.

TABLE 17. THE VALUES OF χ^2

	P(%)		
n´	99	97.5	95
2	0.00+	0.00+	0.00+
3	0.02	0.05	0.10
4	0.11	0.22	0.35
5	0.30	0.48	0.71
6	0.55	0.83	1.15
7	0.87	1.24	1.64
8	1.24	1.69	2.17
9	1.65	2.18	2.73
10	2.09	2.70	3.33
11	2.56	3.25	3.94
12	3.05	3.82	4.57
13	3.57	4.40	5.23
14	4.11	5.01	5.89
15	4.66	5.63	6.57
16	5.23	6.27	7.26
17	5.81	6.91	7.96
18	6.41	7.56	8.67
19	7.01	8.23	9.39
20	7.63	8.91	10.12
21	8.26	9.59	10.85
25	11.52	13.12	14.61
30	14.95	16.79	18.49
40	22.16	24.43	26.51
50	29.71	32.36	34.76
60	37.48	40.48	43.19
70	45.44	48.76	51.75
80	53.54	57.15	60.39
90	61.75	65.65	69.13
100	70.06	74.22	77.93

3.4.1.1 Example - Calculating a Sample Size to Determine Mean HC Emissions

Suppose that it is required to determine the sample size in order to get a close estimate of pre-repair HC emissions. Suppose further that a small sample of 40 vehicles was taken for this purpose, and that it is required to determine the emissions to within ±10 ppm with probability 95%. With data from this preliminary sample, the analyst may then proceed to calculate the required sample size.

From Table 17

$$X^2_{95,40} = 26.51$$

From the sample the following items were calculated (see Table 18).

$$\sum_{i=1}^{40} X_i = 9583$$

$$\sum_{i=1}^{40} X_i^2 = 2{,}587{,}039$$

From Table 16

$$Z_{95} = 1.64$$

Therefore, the number of vehicles necessary for an accurate prediction of HC emissions is

$$n = \frac{(1.64)^2}{(10)^2} \left(\frac{2587039 - \frac{(9583)^2}{40}}{26.51} \right)$$

$$n = 295 \text{ vehicles}$$

TABLE 18. PRELIMINARY SAMPLE OF HC EMISSIONS

Observation No.	HC = X (ppm)	X^2
1	239	57,121
2	348	121,438
3	299	89,661
4	263	69,169
5	257	66,049
6	313	97,969
7	255	65,025
8	207	42,849
9	263	69,169
10	144	20,736
11	263	69,169
12	208	43,264
13	114	12,996
14	211	44,521
15	273	74,529
16	359	128,881
17	360	129,600
18	148	21,904
19	229	52,441
20	78	6,084
21	367	134,689
22	71	5,041
23	177	31,329
24	73	5,329
25	233	54,289
26	265	70,225
27	291	84,681
28	245	60,025
29	268	71,824
30	245	60,025
31	72	5,184
32	368	135,424
33	141	19,881
34	234	54,756
35	222	49,284
36	391	152,881
37	315	99,225
38	181	32,761
39	331	109,561
40	262	68,644
TOTALS	9,583	2,587,039

The analyst may find it useful to plot n versus d in order to study the trade-off in sample size versus accuracy. Since n is proportional to $1/d^2$, it may be possible to get a large reduction in sample size, while giving up very little accuracy. This reduction in sample size may be unimportant for calculations with a computer. But if it is desired to calculate how many random emission checks must be performed to independently assess emissions, substantial savings may be involved.

3.4.2 Determining Sample Size for Selection of Cutpoints

The previous procedure was for the general case where samples are selected to calculate a parameter describing the population. However, for the specific case of selecting a sample to determine cut points the procedure is much easier. Again, samples must be selected for each category of vehicles for which the cut points apply (e.g., model year groupings). And the calculation for the sample size must be done prior to sampling. This is to assure that proper random sampling techniques are used.

The following formula can be used to calculate the required sample size to determine the cutpoints for a group of vehicles.

$$n > 4p \frac{(1-p)}{A^2}$$

where

p = desired failure rate, and

A = allowable error (in same units as p) .

The statistical theory behind this formula is shown in Appendix A.

3.4.2.1 Example - Sample Size for Cut Point Selection

Suppose it is desired to calculate the sample size necessary to determine a 30 percent stringency level within an accuracy of 5 percent. It follows that:

$$p = 0.3$$

$$A = 0.05$$

$$n = 4 \times \frac{0.3\ (0.7)}{(0.05)^2} = 336 \text{ vehicles}$$

4.0 DATA COLLECTION AND HANDLING

The previous sections discussed what data are pertinent to an I/M program. Once the data needs are identified, it is very important to assure that the data are accurately collected and stored. Consequently, a key aspect in the handling of data is to investigate measures designed to reduce error. This section discusses the collection, transfer, and maintenance of data.

4.1 Data Collection

There are three basic ways that data may be collected from an I/M program:

1. Data can be manually recorded onto forms or manually entered onto a data tape,
2. Data can be directly entered into a data base, and
3. The results of the inspection can be automatically recorded onto a data tape.

In an I/M program, it is likely that combinations of the above methods will be used.

4.1.1 Data Collection in Decentralized Programs

Decentralized programs present unique problems for data collection. Because of the large number of stations and inspectors, there are difficulties associated with even the most sophisticated data collection methods. It is recommended that data be collected in a machine readable format. This can be accomplished by entering data directly onto a data tape or by filling out "read forms."

4.1.1.1 Data Tapes

An approach taken by some of the upcoming I/M programs is to record data from each inspection onto a data tape that is contained within the analyzer. This method requires a combination of manual and automatic data recording. For example, items such as the license number and the facility identification number must be keyed in manually; whereas, the emissions levels may be automatically recorded.

The advantages of the internal data tape are three-fold; fraudulent inspections are less likely to occur, manual error is reduced because compliance is automatically determined, and the storage of information is simplified. However, it is still possible to incorrectly key in some data items such as license number and model year.

4.1.1.2 Read Forms

The previously mentioned analyzers that have integral data recording capabilities are more expensive than the average analyzer. Consequently, the I/M program may want to opt for strictly manual recording data onto a form. In this case it is recommended that "read forms" coded with a number two pencil be used. These forms can be read by a machine and the data will be automatically stored.

When designing read forms, it is important that they be:

- Easy to read,
- Easy to understand, and
- Contain no ambiguous information.

These forms should also have a fixed number of columns and only certain allowable entries for fields such as model year. In addition, it aids recordkeeping if the same number of digits are used for certain key data items such as station number (e.g., all station ID numbers should fall between 1000 and 9999). Similarly, the boxes on the forms should have the right number of spaces, and not just blank lines. Decimal points should also be on the forms. Finally, methods such as shading could be used to indicate which items must be filled at the initial versus retest. Figure 4 is an example of a read form.

The I/M program that Colorado is in the process of implementing (currently in the change of ownership phase) uses read forms. Initial results have been promising and considerable analysis has been performed (see Table 15). Colorado reports that there have been some data collection problems, primarily from dirty or stapled forms. Colorado stressed the completion of forms during its inspector training program, and thus there have been few problems with errors from improper completion.

4.1.1.3 Basic Forms

Although machine readable forms (or direct data entry), have obvious advantages, an I/M program can be successfully operated even if manually tabulated forms are used. The same considerations that apply to machine readable forms apply to basic forms; they should be easy to fill out and designed to minimize errors (see 4.1.1.2 for design considerations). In addition, it is advantageous to place in a prominent position certain key information, such as: the vehicle license number, the pass/fail results (including whether or not the vehicle was waived), the emission levels, and the model year of the vehicle. A clear layout of the form will simplify the manual tabulation of data. In

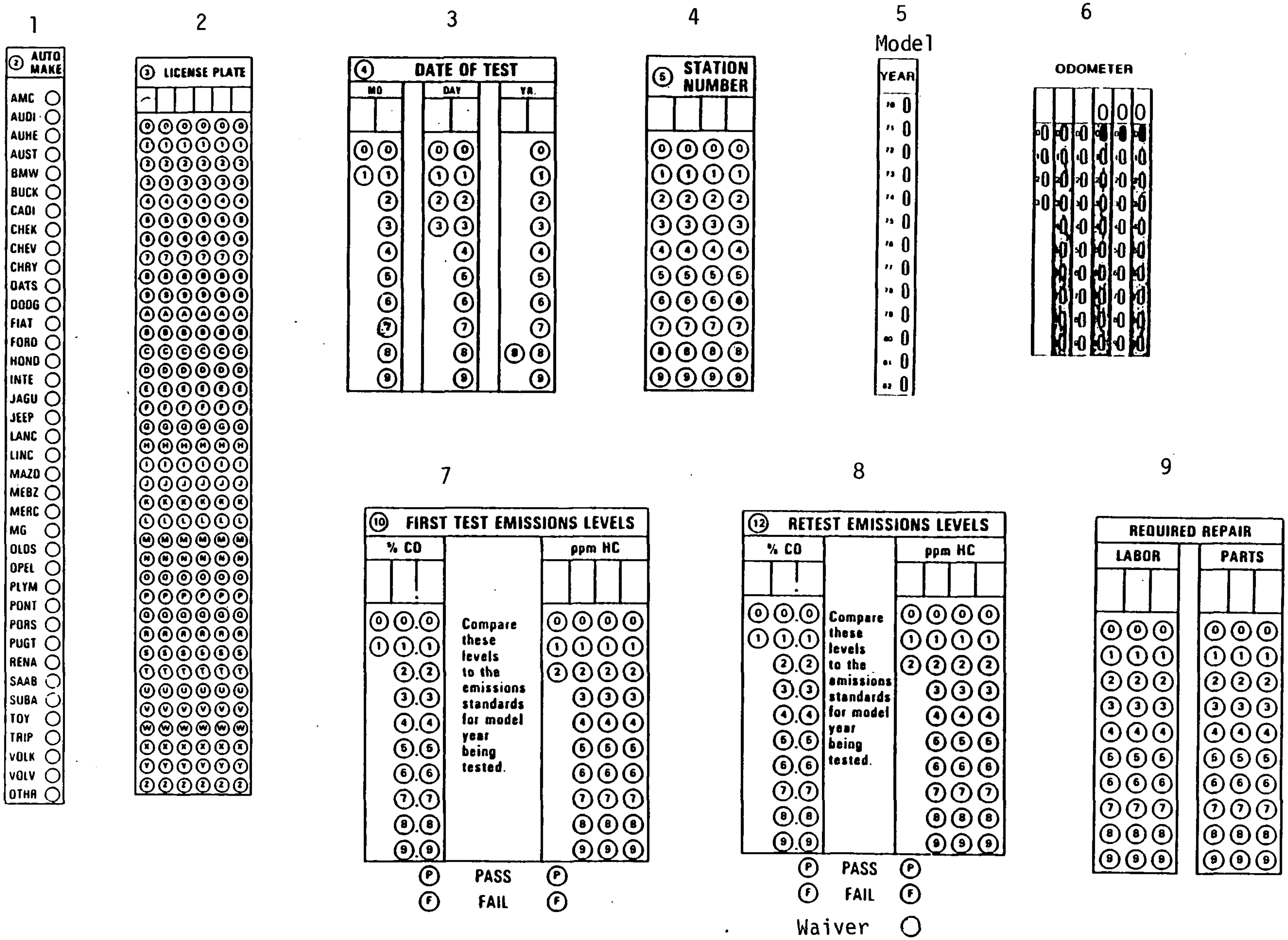

Figure 4. Example Machine Readable Vehicle Inspection Record

addition, it will be easier to keypunch data from such a form. Figure 5 is an example of a basic inspection form.

4.1.1.4 Data Recording Device

Radian has conceptually designed a device to aid in the recording of data from an I/M program. This device is well suited for decentralized programs and can be used with machine-readable or basic forms. It is similar to a sales receipt handler, where each form has two copies: one for the customer and one for records. The device could be used as follows:

- A roll of inspection forms is inserted into the device,
- The inspector fills out the form, turns the crank, the copy for the customer separates and the record copy goes into a box.

A template could be used with this device to aid in filling out the form and to prevent it from getting dirty. This latter point is important for machine-readable forms. In addition, the administrating agency could sell the forms (or the rolls of forms) to the inspection station. This would simplify the tracking of the serial numbers issued.

4.1.1.5 The Collection of Forms

Regardless of the method used to record the data, it is recommended that the data be collected when program officials audit the station. Thus, as a minimum, the stations must keep the data until the next audit, although some data, particularly analyzer quality control data should be kept for much longer periods. The administrating agency should establish a schedule for the maintenance of I/M data.

S A M P L E

MANUAL DATA FORM

STATION NUMBER ☐☐☐☐	DATE (Mo Day Yr) ☐☐☐
LICENSE NUMBER ☐☐☐☐☐☐	MODEL YEAR ☐☐

INSPECTOR'S INITIALS ________

FIRST TEST EMISSIONS LEVELS

HC ☐ ppm   CO ☐ . %

COMPLIANCE STATUS

Pass ☐   Fail ☐

RETEST INFORMATION

REPAIR PERFORMED BY:

Inspection station ☐   Owner ☐   Other ☐

RETEST EMISSIONS LEVELS

HC ☐ ppm   CO ☐ . %

COMPLIANCE STATUS

Pass ☐   Fail ☐   Waiver Issued ☐

REPAIR COST $ ________

Figure 5. Sample Data Form

When the program officials are at the stations, they could review the forms to make sure that they are properly filled out. In addition, if manual data analysis were used it would be relatively easy for the auditors to tally the results of the inspection and prepare periodic summary reports. The auditors could organize the inspection records and other data by facility, thereby preventing a mix-up of data from different facilities.

As mentioned earlier, the stations themselves could tally some of the data, especially if tally sheets were provided by the adminstrating agency (see Figure 2, page 3-8). These sheets could be collected by the auditors (with or without the inspection records).

4.1.2 Data Collection in Centralized Programs

Both manual and automated data collection is much easier in centralized programs, mainly because of the smaller number of stations. Furthermore, there is an additional data collection option available to centralized programs - entering data directly into a data base management system.

If data are collected manually, then the same considerations for decentralized programs apply to centralized programs. However, because of the fewer number of inspection facilities, manual data analyses are greatly aided by the preparation of detailed summary tally sheets (see Figure 6). This type of sheet will enable the analyst to manually perform cross-tabulations such as reason for and frequency of failure (by model year) that would otherwise be very difficult to perform if each inspection record had to be reviewed. Therefore, in centralized programs considerable data analyses can be performed, even if the data are recorded manually.

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OREGON -- LIGHT-DUTY VEHICLE TESTING SUMMARY

DEPARTMENT OF ENVIRONMENTAL QUALITY
VEHICLE INSPECTION PROGRAM
DAILY TESTING SUMMARY - LIGHT DUTY VEHICLES

LOCATION: ______________________

DATE: ______________________

	PASS	REASON FOR NONCOMPLIANCE							
		HC	CO	BOTH	SMOKE	IDLE	OIL	DISC	TOTAL
Pre 68									
Total									
68-69									
Total									
70-71									
Total									
72-74									
Total									
75 Plus									
Total									
G.TOTAL									across
									down

______ Total Light and Heavy Duty
______ Total Certificates
______ Total Money
______ Total Pass
______ Truck Certs Only
______ Noise Tests
______ Over-Short
______ Deposit Slip Number
______ Deposit Slip Number

Absent:	Reason:	From-To:
______	______	______
______	______	______

Overtime:	Reason	From To:
______	______	______
______	______	______

Notes: ______________________

Summary Prepared By: ______

Summary Approved By: ______
(Signatures)

Figure 6

Entry into a computer terminal is easier in centralized programs. More sophisticated data entry techniques may be used, and error checking is possible for some of the fields such as license number (particularly if the data are being entered directly into a data base management system). However, the same general considerations that apply to forms also apply to entry into a computer terminal, that is, the entry format must be easy to read, easy to understand, and contain no ambiguous information. A program that calls for the entry of complex numeric codes without any mnemonic meaning will have a much higher error rate. For example, an operator would be more likely to know he had incorrectly entered GM versus a code like 040.

In addition to operator error there are other sources of error associated with the entry of data into a computer terminal. Terminal malfunction such as key bounce in which a double character is entered can create erroneous information. High quality terminals will help minimize this type of error. Although the cable that connects the emission test equipment and terminals with the data base is usually considered to be an insignificant portion of the system, unshielded or improperly matched cables can introduce substantial error into the data base. Probably the most catastrophic errors occur in the data base itself where in one moment, thousands of records may be lost. Regarding this latter point, the I/M program may want to have hard copy backup data on certain key items such as license number and the pass/fail status.

Like decentralized programs, the administrating agency must set up a schedule to collect data, although in many cases this will be daily or weekly (or even continuously).

4.2 Transcription of Data

Most of the data collected needs to be transcribed or entered into the data base. Most of the time this is a separate step from the collection of data, although as mentioned above, some data are immediately transcribed as they are collected (particularly data entered into a real time data base management system). Errors that occur during this step are called transcription errors. These errors may be human, for example typos, or mechanical. Major types of transcription include:

1. Read Forms Coded By Number Two Pencil - These forms are easy to fill out, and by having a fixed number of data entries they have inherent self-checking mechanisms. Furthermore, these forms can be fed directly into a computer; therefore, they have low processing costs. Figure 4 is an example of one of these forms.

2. Keypunching Field Records - In this method handwritten records from the field are keypunched onto computer cards and then fed into the machine. This method has a higher error rate than the previous method because of the additional step in the handling of the data. The error rate may be reduced by verification, which consists of keypunching the record twice and then comparing the two cards. However, verification obviously increases the time to enter a record by a factor of two.

3. Written Records Entered into a Data Entry Terminal - This method has a slightly lower error rate than keypunching and it is easier and quicker to correct the errors.

4. Direct Entry of Data into a Data Entry Terminal - This method is similar to the previous method except that it eliminates the hardcopy (written) record. Consequently, it could have a slightly lower error rate than (3) but at the risk of losing the hardcopy backup. If the data are directly entered

into an on-line data base system, error checking, such as flagging an invalid license number, is possible.

5. Fully Automatic - Obviously, in a fully automatic system the data transcription occurs automatically. The only errors that are going to occur in this case are hardware errors which can be minimized by having backup storage systems. However, some data items such as license numbers cannot be automatically entered.

4.3 Quality Assurance of the Data Base

This section discusses quality control for the inspection/maintenance data base. A number of checks for invalid data are possible. A printout should be produced of any invalid data identified through automatic checks by the computer. Records that have discrepancies should either be corrected or removed from the data base. These checks fall in several categories, as indicated below.

- Does the entry have a feasible and reasonable value?

  A check of this sort will determine if the values entered for the different paramaters are within an expected range. For example, a CO value of 150 percent would be unreasonable. As discussed, a large number of unfeasible or unreasonable values may be eliminated by using forms with a fixed number of columns and only certain allowable entries per column. For example, it is not possible to enter the impossible emission value, 150 percent CO, on such a form. An automatic or manual check would be beneficial with these forms, to determine whether no circles or more than one circle were filled in under the same column.

- o Are the different entries on a single form consistent?

  Any consistency check which might reveal an invalid data entry should be made. It should be possible to automate these checks. The following are examples of consistency checks:

  - Is the model year consistent (i.e., no more than one year greater than) the year of the test?
  - The pass/fail results should be consistent with the emission levels. For example, if the initial test results indicate compliance, then the emission levels should be within the standard.
  - If a tampering inspection was performed and the catalytic converter visual inspection was failed, then the year and model of car should actually have a catalytic converter (1975 and later domestic vehicles).

- o Are the entries on different forms for the same vehicle consistent?

  If the results of subsequent tests for the same vehicle (identified by the license number) are reported, then several entries on different forms for the same vehicle should be the same, including auto make and model year.

4.4 Cost of Data Processing

This section will discuss the cost elements associated with different methods of collecting and transcribing data. Since basic hardware costs are dependent upon what is already available to the administrating agency, these costs will not be directly addressed. The cost for data collection obviously depends on the method that is used to analyze data from an I/M program: (1) manual, (2) computer assisted, and (3) computer assisted with a data base management system (DBMS).

4.4.1 Manual Data Processing

The primary costs of manual data processing are for the forms and the data analyst. The cost for the data forms can be significant; therefore, there needs to be a budget for forms. A gross estimate for the cost of forms would be ten cents each.

It is very difficult to estimate the cost of a data analyst. Without the assistance of a computer it would take an analyst considerably more time to perform the previously mentioned analyses. However, it is likely that programs using manual data analysis will perform less analysis. Most programs budget for one full-time data analyst regardless of the type of processing that is used.

4.4.2 Computer Assisted Data Processing

4.4.2.1 Keypunched Forms

The costs for computer assisted data processing depend upon the type of data entry. If forms are to be keypunched for entry into the data base, then the following costs would be incurred:

- Forms
- Keypunching
- Programming
- Data analyst
- Computer time

As previously mentioned, a gross estimate of the cost of forms would be ten cents. In addition, it is estimated that it would take an operator approximately 30 seconds (including verification) to keypunch the data items on a typical vehicle inspection record. This would result in an additional five cents per form (assuming $6 per hour wage).

The cost for programming, data analysts, and computer time depends upon the approach taken to analyze the data. If the program purchases a standard statistical package (or leases one) there will be lower costs for programming than if in-house programming were used, although the computer costs are likely to be roughly the same. One full-time data analyst should be budgeted for most programs.

4.4.2.2 Machine Readable Forms

If the forms are machine readable, the program incurs a cost for the forms reader instead of incurring costs for a keypuncher. Forms readers can cost in excess of $100,000. Therefore, the administrating agency should investigate the option of using another agency's forms reader. For example, Colorado leases a form reader from a school district, to read its data forms. The cost for the forms themselves are similar to basic forms (i.e., 10 cents each). Again, as with keypunched forms, the costs for programming, data analysts, and computer time depend upon the method used to analyze the data.

4.4.2.3 Data Tapes

Some analyzers have built in data recording capabilities. Information normally recorded on hard copy (e.g. vehicle information records) are stored instead on a data tape. These data tapes are periodically collected and processed by the administrating agency.

I/M programs that use these analyzers (e.g., the New York I/M program) obviously do not incur costs for keypunching or forms reading. However, the initial cost for these analyzers can be more than $1,000 higher than similar models without automated data recording. The additional analyzer costs can be significant in a decentralized program. Otherwise, the costs for this approach are similar to the previous methods.

4.4.2.4 Entry into a Computer Terminal

The main difference between the above approaches and data entry using a terminal are the costs for the terminal. An additional cost would be the telephone lease lines used to connect the terminal with the central data base. The costs for terminals are highly variable and can be provided by manufacturers. Costs for telephone lease lines are also variable, depending on the length. (These costs can be provided by the phone company). The other considerations for this type of data entry are the same as for machine-readable or keypunched forms (programming, analysts, etc.). Because of the large number of terminals required, this option would be much more expensive that the other options for the decentralized program.

4.4.3 Data Processing With an On-Line Data Base Management System

Like computer assisted data processing, the costs for data processing with a data base management system depend upon the type of data entry. The costs for the different data entry methods are roughly the same as shown above (i.e., the costs for forms, keypuncher, etc.). The costs for programming, data analysts, and computer time depend greatly upon the existing set-up. If an existing data base management system is available, then there are fairly low software and start-up costs. The expense is probably less than with a computer assisted data processing system, unless the latter system uses a standard statistical package. However, as previously mentioned, the cost to produce and set-up an on-line DBMS strictly for the purpose of handling I/M data, is probably considerably greater than the cost for the other data processing systems that were previously discussed.

APPENDIX A

DEVELOPMENT OF A FORMULA TO DETERMINE SAMPLE SIZE FOR CUTPOINTS SELECTION

The following procedure can be used to determine the sample size needed to estimate the HC and CO emission cutpoints. A failure probability is selected a priori, and HC and CO cut points are selected which yield this failure probability. Since one condition has been imposed on two cutpoints, they are not determined uniquely; some freedom of choice remains.

Define:

n = sample size,

$\hat{p}$ = fraction failed as determined from the sample; the cut points are chosen so that $\hat{p}$ equals the failure selected beforehand,

p = true but unknown failure probability given the selected cut points, and

$\hat{s}_p$ = standard error of $\hat{p}$

The standard error of $\hat{p}$ is given by

$$\hat{s}_p = \sqrt{\frac{\hat{p}\,(1-\hat{p})}{n}}$$

Then assuming $n\,p > 5$ and $n\,(1-p) > 5$, the error in $\hat{p}$ is approximately normally distributed. Assuming n is reasonably large ($n \geq 30$), the following is an approximate 95% confidence interval for p:

$$p\,(\hat{p} - 2\,\hat{s}_p < p < \hat{p} + 2\,\hat{s}_p) \simeq .95$$

Thus, the half-width of the confidence interval is $2\,s_p$. Now, suppose it is necessary to estimate p to within a specified accuracy, $\pm A$. To achieve this, we require:

$$2\,\hat{s}_p \leq A$$

or

$$2\sqrt{\frac{\hat{p}\,(1-\hat{p})}{n}} \leq A$$

$$4\,\frac{\hat{p}\,(1-\hat{p})}{n} \leq A^2$$

$$n \geq \frac{4\,\hat{p}\,(1-\hat{p})}{A^2}$$

It is clear that the required sample size n is very sensitive to the specified accuracy A. Improving the accuracy by a factor of two, for example, increases the sample size by a factor of four.

APPENDIX B
DERIVATION OF EXPRESSION FOR SAMPLE SIZE REQUIRED FOR MEAN ESTIMATION

This appendix provides a statistical derivation of the expression given in Section 3.4.] for the sample size required to compute an average with specified accuracy. The expression applies in the general case; the special case of estimating a failure probability is covered in Appendix A.

Suppose a preliminary sample of values, X_i, i = 1 to n' are available. Then the following is an estimate of the population variance

$$S^2 = \frac{\sum_{i=1}^{n'} X_i^2 - \left(\sum_{i=1}^{n'} X_i\right)^2 / n'}{(n'-1)}$$

$$= \frac{SS_X}{(n'-1)}$$

where SS_X is the numerator of the fraction above.

Being derived from a finite sample, S^2 is subject to sampling error. If S^2 happens to be lower than the true (but unknown) variance, an estimate of the required sample size based on S^2 will be too low, and the desired accuracy may not be achieved. It is possible, however, to use the χ^2 statistic to derive an upper confidence limit for S^2. Using the upper confidence limit rather than S^2 provides a higher probability that the accuracy requirements will be met. The following is a derivation of an upper confidence limit for the true variance, σ^2;

$$\underline{P}\left(\chi^2_{p,n'} \leq \frac{SS_X}{\sigma^2}\right) = P$$

where $\chi^2_{p,n'}$ is the value, from Table 16, which is exceeded by a χ^2 random variable for sample size n' (in statistical terms, with n'-1 degrees of freedom) with probability P. Then

$$P\left(\frac{1}{\chi^2_{p,n'}} \geq \frac{\sigma^2}{SS_x}\right) = P$$

(note reversal of inequality)
and

$$P\left(\frac{SS_x}{\chi^2_{p,n'}} \geq \sigma^2\right) = P$$

Thus, $\frac{SS_x}{\chi^2_{p,n'}}$ is an upper confidence limt for the true variance σ^2.

If p is chosen to be 95%, for example, then there is only a 5% chance that the upper confidence limit will not exceed the true variance.

Now, if the sample size n to be determined is larger than 30, it is reasonable to use the Z- statistic rather than the t- statistic to express a confidence interval for the mean μ, which is to be estimated. In the case of interest in this report, n will be at least this large. The confidence interval for the mean is

$$\overline{X} \pm Z_p \frac{S}{\sqrt{n}}$$

where Z_p is a value obtained from Table 15. If p is 95%, for example, this means that the true mean value μ falls in the confidence interval with probability .95. Now, suppose we require a result accurate within ± d; then n should be large enough so that

$$Z_p \frac{S}{\sqrt{N}} \leq d$$

$$\frac{Z_p^2 \, S^2}{d^2} \leq n$$

Substituting the upper confidence limit for S, we obtain the expression for n given in Section 3.4.1;

$$\frac{Z_p^{\ 2}}{d^2} \quad \frac{\sum_{i=1}^{n'} X_i^{\ 2} - \left(\sum_{i=1}^{n'} X_i\right)^2 / n'}{X^2_{p,n'}} \leq n$$

Although the same symbol, p, has been used for the confidence levels for the mean and the variance, different levels could theoretically be used.

APPENDIX C

COMPREHENSIVE LIST OF INSPECTION DATA

Vehicle -

- Facility identification
- Test lane or analyzer #
- Inspector identification
- Date of test
- Test # (for reference)
- License number or VIN
- Model Year
- Odometer
- HC reading (idle, 2500 and/or loaded)
- CO reading (idle, 2500 and/or loaded)
- CO_2 reading
- CO_2 + CO reading
- Idle speed
- Pass/fail
- Test code (initial test or retest)
- Test # of initial test (or retest) if this is a retest record
- Cutpoints
- Engine type (Gas, Diesel, Rotary)
- Fuel type (gasoline, diesel, LPG, CNG, etc)
- Engine CID
- Number of cylinders
- Fuel System (FI, 4V, 2V, etc.)
- Number of exhaust pipes
- Make
- Types of control devices
- Vehicle type (LDV, LDT, HDG, etc.)
- GVW class (less than 6,000, 6,000-8,500, greater than 8,500)
- Compliance certificate issued (yes/no)
- Compliance certificate serial number
- Waiver certificate issued (yes/no)
- Waiver certificate serial number
- Inspection fee
- Cost of repair (Identify parts and labor)
- Items replaced or repaired
- Tire pressure (before and after)
- Tampering (yes/no)
- Items missing and/or inoperable
- Propane gain specification
- Propane gain reading

Quality Control Data

Analyzer (weekly calibration)

- Data of check
  Facility ID
  Inspector ID
  Make, model and serial # of analyzer
  Hexane factor
  HC concentration (calibration gas)
  CO concentration (calibration gas)
  CO_2 concentration (calibration gas)
  Gas cylinder serial numbers
  HC reading (analyzer response)
  CO reading (analyzer response)
  CO_2 reading (analyzer response)
  Compliance with gas (HC, CO, CO_2 - yes/no)
  HC hang up check
  Leakage rate
  Compliance with leak check (yes/no)
  Repairs/maintenance performed (yes/no)
  Types of repairs/maintenance

Audit Data

- Data of check
  Facility identification
  Auditor identification

Analyzer (monthly audit)

- Make, model and serial # of analyzer
  Hexane factor
  HC concentration (calibration gas)
  CO concentration (calibration gas)
  CO_2 concentration (calibration gas)
  Gas cylinder serial numbers
  HC reading (analyzer response)
  CO reading (analyzer response)
  CO_2 reading (analyzer response)
  Compliance with gas (HC, CO, CO_2 yes/no)
  HC hang up check
  Leakage rate
  Compliance with leak check (yes/no)
  Repairs/maintenance performed (yes/no)
  Types of repairs/maintenance
  Calibration gas verification compliance (yes/no)
  Compliance with filter check (yes/no)
  Acceptable location (yes/no)
  Red tag issued (yes/no)

Facility	- Number of stickers/certificates on hand Serial number of stickers/certificates on hand Number of stickers/certificates issued to vehicles Inspection and/or repair, calibration and maintenance of analyzer required records (yes/no) Possess required equipment (yes/no) Have certified inspector on payroll (yes/no) Possess required documents (yes/no) - regulations, manuals, etc.
Inspector Audit	- Inspector identification Certified (yes/no) Perform inspection properly (yes/no) Perform calibration properly (yes/no) Complete records properly (yes/no)

Enforcement Data

- Number of citations issued for non-compliance and number penalized
  Number of inspections (from inspection records)
  Number of vehicle registered
  - a. number waived
  - b. number exempt
  - c. number subject to I/M

  I/M status of registered vehicles
  - a. data base maintained on registered vehicles that indicate I/M status.

  Registration data on areas outside the program area.
  Number of penalties imposed on inspection facilities

Other Data

- Roadside checks (emphasize limited value)
  Challenge checks (provide additional emphasis)
  Other independent emission checks
  Public complaints and other public input