Inspection/Maintenance Program Evaluation: Replicating the Denver Step Method for an Atlanta Fleet

ARTICLE *in* ENVIRONMENTAL SCIENCE AND TECHNOLOGY · JULY 2003

Impact Factor: 5.33 · DOI: 10.1021/es015736q · Source: PubMed

4 AUTHORS, INCLUDING:

Elizabeth A. Corley
Arizona State University

Leisha DeHart-Davis
University of North Carolina at Chapel Hill

Michael O Rodgers
Georgia Institute of Technology

Environ. Sci. Technol. **2003**, *37,* 2801−2806

Inspection/Maintenance Program Evaluation: Replicating the Denver Step Method for an Atlanta Fleet

ELIZABETH A. CORLEY,[†]
LEISHA DEHART-DAVIS,[†]
JIM LINDNER,[‡] AND
MICHAEL O. RODGERS*[,†]

Air Quality Laboratory, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332, and U.S. EPA Certification & Compliance Division, 2000 Traverwood, Ann Arbor, Michigan 48105

The research presented in this paper employs the Step Method of Inspection/Maintenance (I/M) program evaluation to estimate the emissions reduction for an Atlanta I/M program. Stedman et al. (Stedman, D. H.; Bishop, G. A.; Aldrete, P.; Slott, R. S. *Environ. Sci. Technol.* **1997**, *31*, 927−931) introduced the Step Method of evaluation when they presented the results of a 1995 Denver I/M program evaluation. The research presented here replicates the original Denver Step Method analysis for a 1997 Atlanta I/M program. This evaluation was conducted separately for the nine outlying Atlanta counties and the four counties that are closest to the center of the city. The results of the analysis are similar to those found by Stedman et al. in Denver. While the Denver carbon monoxide (CO) weighted program benefit was 6.9%, the Atlanta area CO weighted program benefit is found to be 11.5% and 4.9% for the nine-county and four-county Atlanta areas, respectively. We conclude that the 1997 I/M program change in Atlanta yielded a noteworthy and observable change in fleet emissions.

Clean Air Act and Vehicle Inspection/Maintenance Programs

With the passage of the Clean Air Act (CAA) in 1970, the U.S. Environmental Protection Agency (U.S. EPA) was given, for the first time, oversight for the development of vehicle inspection and maintenance (I/M) programs. Yet, the first mandate for an I/M program in an area with long-term air quality problems did not occur until the Clean Air Act Amendments of 1977. The following year, in 1978, the U.S. EPA issued its first guidance document for I/M programs. Later, the 1990 Clean Air Act Amendments (CAAA), in addition to being more prescriptive concerning I/M requirements, expanded the role of I/M programs as an air quality attainment strategy. The CAAA required the U.S. EPA to develop federally enforceable regulations for two levels of I/M programs: "basic" I/M for locations designated as moderate ozone nonattainment areas and "enhanced" I/M for serious and worse nonattainment areas.

The CAAA also required that I/M program evaluations be conducted biennially and that enhanced I/M programs include the use of on-road testing. In response to this requirement, U.S. EPA's 1992 I/M rulemaking (40 CFR Part 51 Inspection/Maintenance Program Requirements, Final Rule, November 5, 1992) established guidelines for the evaluation of I/M programs by stating that enhanced I/M programs had to perform separate I/M240 tests on a random sample of 0.1% of the subject fleet. Furthermore, in defining the on-road testing requirement, the 1992 rule required that an additional 0.5% of the fleet be tested using either roadside pullovers or remote sensing devices (RSD).

Road-Side Pullovers for I/M Program Evaluation

Traditionally, I/M programs have been evaluated using random roadside testing, tampering audits, and overt and covert inspections of testing stations. During the 1970s and 1980s, the U.S. EPA conducted covert station audits and roadside tampering surveys as mechanisms for evaluating I/M programs. Proponents of this method maintain that the use of roadside pullover data is valuable because it provides in-use emissions measurements using a tailpipe test with corresponding odometer readings. Thus, the method reduces the emissions bias introduced when motorists prepare their vehicle prior to an I/M test or when there is outright test fraud occurring within the I/M program. Although roadside pullover data can be useful, historically, it has only been possible to consistently obtain such data in California. Aside from the logistic and public acceptance difficulties of roadside pullover testing, it is expensive, and the testing is voluntary once a vehicle owner is pulled over. Therefore, some argue that a roadside pullover sample is not an accurate representation of the fleet.

Remote Sensing Data for I/M Program Evaluation

Since there are inherent weaknesses with roadside pullover data, several scholars have advocated the use of remote sensing data for determining the effectiveness of I/M programs (*1*−*7*). RSD data collection employs infrared or laser-based technology beside the road to measure the emissions of vehicles while they travel. Like roadside pullover or recruitment data, using RSD to conduct program evaluations of I/M programs has several advantages over using solely in-program I/M data.

Proponents of the RSD method maintain that motorists do not prepare for a RSD test, so fraud is not an issue as it might be for I/M tests. Using RSD for program evaluations should effectively eliminate the "clean for a day" scenario during which a vehicle typically exceeds I/M emission standards and still passes on the day of the I/M test (due to a temporary fix or test fraud). Although there has been concern in the past that RSD readings can be more variable than traditional I/M tests, there is growing evidence that the method can be used as a valuable tool to characterize fleet emissions. The underlying problem with remote sensing measurements is that the operating conditions of vehicles are not fixed when the data are collected, as they are for I/M tests. The unscheduled nature of the remote sensing data collection, however, is a significant advantage over I/M test data collection, largely for the test fraud reasons already mentioned. Remote sensing data collection can be made more accurate if researchers attempt to account for variable operating conditions by being attentive to the location of the instruments at the data collection site and the estimation of the vehicle load at the time of measurement.

Along with an increase in scholarly interest for using remote sensing data, individual states are becoming increas-

* Corresponding author telephone: (404)894-5609; e-mail: mrodgers@aql.eas.gatech.edu.
[†] Georgia Institute of Technology.
[‡] U.S. EPA Certification & Compliance Division.

10.1021/es015736q CCC: $25.00

Published on Web 05/14/2003

ingly interested in using on-road vehicle emissions data gathered by remote sensing equipment to evaluate I/M programs. This interest is being driven primarily by the versatility of remote sensing data, which can be used for a variety of purposes beyond I/M program evaluation. For example, remote sensing data can be used to detect high-emitting (high-emitter identification) and super-clean vehicles (clean-screening) for special treatment in an I/M program. Unfortunately, guidance on the collection and use of remote sensing data for program evaluation is lacking. To address this shortfall, a group of experts has collaborated with the U.S. EPA to draft guidelines and procedures for collecting and analyzing remote sensing data for I/M program evaluation (*8*).

Wenzel et al. stressed the complications associated with using statistical analysis of remote sensing data and roadside pullover data to determine I/M program effectiveness (*9*). Despite the need for care when analyzing remote sensing data and roadside pullover data, several researchers have used these methods to estimate emissions reductions and program effectiveness. Three program evaluation methods have traditionally been used to determine the effectiveness of I/M programs: the Step Method, which was developed by Stedman et al. (*1*) and was originally applied in Denver; the Comprehensive Method, which was developed by Wenzel et al. (*10*) and has predominantly been applied in Arizona and California; and the Reference Method, which was developed by Rodgers et al. (*11*) and has traditionally been applied in Atlanta. We will briefly describe each method before introducing the research design for our study.

Step Method. In January 1995, spurred by the U.S. EPA recommendations, the State of Colorado replaced an annual, decentralized, idle I/M program with a biennial, centralized, I/M240 program in the six-county metropolitan Denver area. In 1995, odd model year 1982−1994 vehicles were tested in the Denver area, and in 1996, even model year 1982−1994 vehicles were tested. Therefore, at the end of 1995, the odd model year vehicles would have been tested and the even model year vehicles would not have been tested. This program shift provided an opportunity to compare two I/M fleets, one tested and one untested, that were located in the same geographical area. Stedman et al. used this program shift to determine the effectiveness of the new program (*1*) and found that the benefits for CO were significant (4−7%) and that the benefits for hydrocarbons (HC) and nitrogen oxides (NO_x) were not detectable. A follow-up study in 1998 confirmed the findings of the 1997 results (*12*). Since this program evaluation method relies upon a change in an I/M program that takes place in "steps" (i.e., emissions benefit is calculated from an incremental change in an I/M program rather than the full benefit as compared to a non-I/M case), it has become known as the Step Method.

Comprehensive Method. In 2001, Wenzel evaluated remote sensing data from over 100 sites throughout the Phoenix metropolitan area and performed an in-depth evaluation of the Phoenix I/M program (*13*). This analysis used the emissions from 850 000 I/M240 records, which were merged with over 4 000 000 RSD measurements collected on roughly 1 200 000 vehicles. Using the remote sensing data for 412 000 vehicles with matched I/M test results, Wenzel found that the Phoenix I/M program led to an emissions reduction of 11.5% for HC and 7% for CO. In this study, the emissions reductions were calculated by comparing the fleet average RSD measurements 90 days before the I/M test with fleet average RSD reading 90 days after the I/M test. Because of the large number of vehicles analyzed in Wenzel's study and the fact that the large number of measurements allow for detailed study of changes in fleet emissions over time, relative to the time of the I/M test (i.e., in the weeks prior to the I/M test or in the weeks/months after the I/M test),

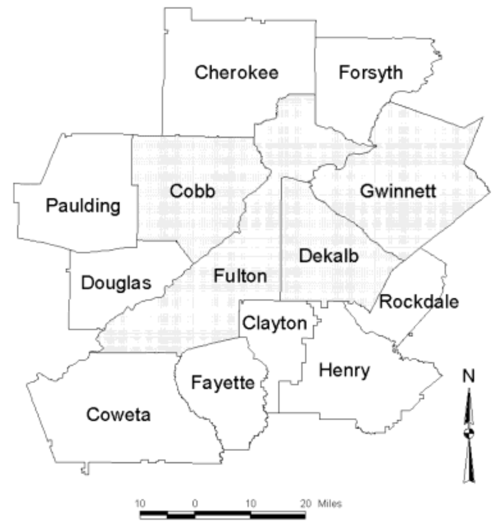

FIGURE 1. Map of four- and nine-county Atlanta metropolitan area. The four-county area is shaded and includes Fulton, Cobb, Dekalb, and Gwinnett Counties. The nine-county area is not shaded and includes the following counties: Cherokee, Forsyth, Paulding, Douglas, Coweta, Fayette, Clayton, Henry, and Rockdale.

this method has become known as the Comprehensive Method.

Reference Method. In 1994, the Georgia idle I/M program was evaluated using the Reference Method of I/M program evaluation. For this study, RSD data from 6 non-I/M sites and 29 I/M sites were used to provide 83 434 measurements for the Atlanta I/M fleet and 18 026 readings for the non-I/M fleet (*11*). These remote sensing samples represented about 6% and 2% of the I/M and non-I/M on-road fleets, respectively. Rodgers et al. computed the emissions reductions by comparing the I/M fleet average RSD measurements and the non-I/M fleet average RSD measurements to the emission levels predicted by the U.S. EPA's MOBILE 5A model. The study estimated that Atlanta's basic I/M program was reducing CO emissions by 20% for cars and 14% for trucks. Since this method of analysis requires comparing an I/M fleet to a non-I/M reference fleet, it has become known as the Reference Method.

Research Design. Even though the Reference Method is the I/M program evaluation tool that has predominantly been employed for Atlanta in the past, a key change in the Atlanta I/M program during 1997 provided the opportunity to apply the Step Method of I/M program evaluation. Because the Step Method is inextricably linked with the timing of I/M program implementation, we will first briefly describe the Atlanta enhanced I/M program change. In January 1997, 13 Atlanta counties in serious nonattainment of Federal ozone standards implemented a biennial, enhanced testing program employing two-speed idle testing technology. Before this program change, the four counties closest to the heart of the city of Atlanta employed a basic decentralized idle testing program, while the remaining nine outlying counties did not have a program (see Figure 1 for the location of the 13 counties in the metro Atlanta area). In all 13 Atlanta counties that are analyzed in this paper, I/M stations are a combination of test-only and test-and-repair station types.

In 1997, throughout the 13 Atlanta counties, odd model year vehicles were required for emissions testing while the even model year vehicles were not subject to inspection until 1998. Vehicle emissions inspections were conducted year-round in 1997, although vehicle registration occurred only during the first four months of the year. To utilize this I/M program implementation schedule, the Atlanta replication of the Denver Step Method is based on remote sensing data

TABLE 1. Comparison of Denver and Atlanta Data Characteristics

characteristic	Denver 1995	Atlanta 1997 four counties	Atlanta 1997 nine counties
no. of valid CO observations (cars and trucks)	26 255	85 414	42 950
no. of data collection sites	1	38	38
model years requiring testing	1982–1994	1975–1995	1975–1995
no. of data collection days	5	46	46

collected between May and December 1997. By May (when our analysis begins), most existing vehicles in Georgia were registered and had been tested (if testing was required in 1997 for that vehicle). Therefore, the use of data collected between May and December increased the probability that a significant fraction of the on-road odd model year fleet had been inspected during the January–April vehicle registration season.

To check this assumption, we calculated the Step Method for trucks in the four-county Atlanta area after ensuring that each odd model year vehicle had been tested and that none of the even model year vehicles had been tested. The result reinforced our initial assumption that a significant fraction of the on-road odd model year fleet was inspected because the Step Method conducted for the fleet that was definitely tested yielded a nonweighted CO benefit of 6.9% and a weighted CO benefit of 5.4%. Both of these nonweighted CO benefits varied less than 1.0% from originally calculated CO benefit for four-county trucks (during which we assumed that a significant fraction of the on-road odd model year vehicles had been tested by May 1997). For the remainder of the Step Method, we make the assumption that the odd model year vehicles have been tested and that the even model year vehicles have not been tested.

For the remote sensing data used in this study, data collection sites were selected based on the presence or absence of certain physical characteristics that affect sampling. First, preference was given to sites with a one to two percent positive grade to ensure that vehicles operated under load, but not in power enrichment. Also, single straight lines of traffic having an average speed of 35 miles-per-hour were sought to ensure single-vehicle measurements and speeds that maximized measurement opportunities. Finally, driver behavior and driving maneuvers were observed at each site to ensure that remote sensing measurements would not be biased by acceleration or braking.

The sample used in this replication of the Step Method consists of 85 414 observations from the previous four-county basic I/M area and 42 950 observations from the nine counties that were tested for the first time in 1997. The emissions measurements of the Atlanta fleet were conducted at 38 sites within the 13-county metropolitan Atlanta area over the course of 46 days. The sample for the Denver on-road testing was significantly smaller, with 26 255 identified, unique vehicles. The Denver evaluation focused on remote sensing data that were collected at one site over the course of 5 days (see Table 1).

The 85 414 and 42 950 remote sensing vehicle measurements from the four-county and the nine-county Atlanta areas, respectively, were further divided into vehicle type categories so the Step Method could be applied for three vehicle types: (i) cars and trucks together, (ii) cars only, and (iii) trucks only. VIN (vehicle identification number) decoding was used to determine the truck and car classifications for this analysis. We classified vehicles as cars if they were VIN decoded as cars. On the other hand, we classified vehicles as trucks if they were VIN decoded as a light-duty trucks, MPV (multipurpose vehicles), or vans. Sport-utility vehicles (SUVs) as well as trucks less than or equal to 8500 GVW were also included in the truck classification.

TABLE 2. Sample Sizes for Atlanta Data with Duplicates Removed

fleet composition	CO sample sizes four counties	CO sample sizes nine counties
tested, cars and trucks	45 144	22 469
untested, cars and trucks	40 270	20 481
tested, cars only	31 619	14 344
untested, cars only	28 326	12 852
tested, trucks only	13 525	8 125
untested, trucks only	11 944	7 629

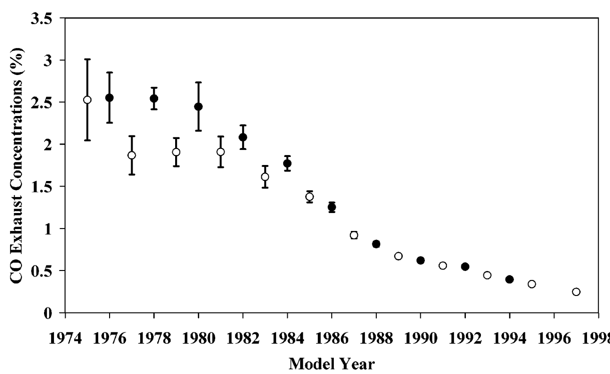

FIGURE 2. Mean on-road CO exhaust concentrations (in %) by model year for cars and trucks in the nine-county metro Atlanta area. Odd model years are represented by open circles, and even model years are represented by filled circles. The uncertainty bars represent the standard error of the mean computed as the standard deviation of the arithmetic mean of CO emissions.

This breakdown of vehicles into type categories provided a broader analysis than that done by Stedman et al. (*1*) for the Denver Step Method. Stedman et al. only analyzed cars and trucks together (*1*). Dividing the data into three groups (i.e., cars and trucks together, cars only, and trucks only) allowed us to explore the effectiveness of the newly implemented Atlanta I/M program for cars and trucks separately. The sample sizes for tested and untested cars and trucks are reported individually in Table 2.

Results

Qualitative Analysis of Program Benefits. Stedman et al. in their analysis of 1995 Denver on-road remote sensing data demonstrated that a program benefit can be demonstrated qualitatively by graphing mean vehicles emissions by model year (*1*). They argued that the program benefit would be displayed on this graph as an up-and-down oscillation between the tested vehicles (odd model years) and the untested vehicles (even model years). We replicated this qualitative analysis of emissions by model year for the Atlanta area. Figure 2 illustrates a graph of mean CO emissions by model year for both cars and trucks in the nine-county Atlanta area.

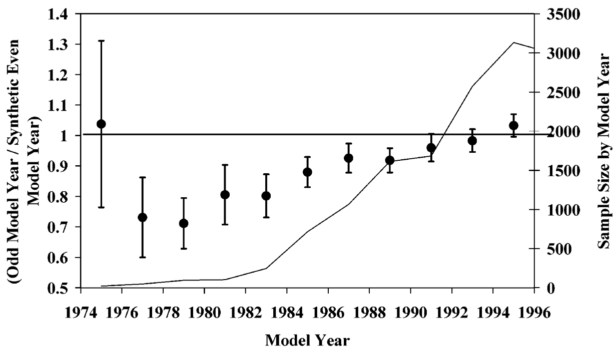

FIGURE 3. Nine-county Atlanta area ratio of CO emissions (cars only). The odd model year CO exhaust concentrations (in %) divided by average mean CO exhaust concentrations (in %) of synthetic even model years surrounding each odd model year. The uncertainty bars represent the mean of odd model year CO exhaust concentrations ± standard error of the mean for odd model years divided by synthetic even model year mean CO exhaust concentrations. The solid line represents the sample size by model year for the calculations. The sample sizes are presented on the secondary *y*-axis.

Stedman et al. found that CO emissions oscillate between inspected and uninspected vehicles, with recently inspected vehicles having lower average emissions than uninspected vehicles. Figure 2 demonstrates a similar oscillation trend for the Atlanta analysis. From Figure 2, we can conclude that an I/M program benefit occurred for vehicles with model years between 1975 and 1981. Stedman et al. found that for cars and trucks combined there was a qualitative oscillating trend only for two model years: 1985 and 1987 (*1*). Therefore, the qualitative (or visual) program benefit for Atlanta spanned several more model years than the comparative analysis for Denver. A stronger series of fluctuations between inspected and uninspected vehicles in Atlanta was expected, given that the CO and HC program benefits for Atlanta turned out to be slightly higher than the program benefits for Denver.

Figure 3 provides an additional analysis of the odd model year/even model year oscillations that are indicative of an I/M program benefit in the Step Method. To compute the values for Figure 3, we divided the average CO exhaust concentrations for odd model years by a synthetically created corresponding even model year CO exhaust concentration. For example, a synthetic even CO concentration to correspond with an odd model year (e.g., 1983) was created by averaging the even model year CO concentrations that straddle the odd model year (e.g., synthetic even = $(CO_{1982} + CO_{1984})/2$). Then, the ratio of the odd model year CO concentration (e.g., 1983) over the synthetic even CO concentration was plotted in Figure 3. Model years having a ratio value of less than 1 demonstrate an I/M program benefit for the corresponding model year because the combined even model year emissions average were greater than the odd model year average. Figure 3 demonstrates that, for nine-county cars, there is a significant CO program benefit for vehicles with model years between 1977 and 1993.

Quantitative Analysis of Program Benefits. The second and more quantitative analysis for the Step Method involved the creation of an age-adjusted control group to compare even (untested) and odd model year (tested) vehicle emissions. For this calculation, the emissions of the two even model years surrounding an odd model year (e.g., 1984 and 1986) were averaged and compared with the emissions from the odd model year vehicles (e.g., 1985). The difference between the average of the uninspected vehicles and the inspected vehicles (e.g., the difference between the average emissions for 1984 and 1986 and the emissions for 1985) was then calculated, weighted by a sample size fraction, and averaged across model years. This averaging provided a weighted and nonweighted CO benefit for the new Atlanta I/M program. The results of this analysis are presented in Table 3. For a more complete description of the calculation of the age-adjusted groups, see ref *1*. This computation is similar to the calculation used to develop Figure 3; however, the results of the odd and synthetic even model year emissions averages are used differently for this quantitative analysis.

Because Atlanta vehicles in the nine-county area were subject to inspection for the first time in 1997, we expected this subfleet to experience the greatest I/M benefit. While the nine-county Atlanta area was implementing a first-time I/M program in 1997, the four-county Atlanta I/M program was undergoing a change from a decentralized, annual, idle program to an enhanced biennial, TSI program. Therefore, we expected that the CO benefit for Denver would be slightly lower than the benefit for the nine-county Atlanta area but higher than the CO benefit for the four-county Atlanta area (see Table 3 for a detailed description of the I/M program changes in each location). We expected Denver to have a higher program benefit than the Atlanta four-county area because, while both locations began with a decentralized annual idle program, Denver transitioned to an I/M 240 program and Atlanta transitioned to a two-speed idle program.

Table 3 provides a summary of our quantitative Step Method results and demonstrates that the trends we expected were realized for CO benefits. The weighted CO benefit for the nine-county area was 11.5%, which is higher than the CO weighted benefits for both Denver (6.9%) and the four-county Atlanta area (4.9%). An individual analysis for the Atlanta area with benefits for cars and trucks calculated separately yielded, again, the same trend. We calculated an 11.8% CO weighted benefit for nine-county cars and a 8.2% CO benefit for nine-county trucks, both of which are higher, respectively, than the calculated 3.2% and the 6.3% CO benefit for four-county cars and trucks.

For the Atlanta data, in all cases the nonweighted CO benefit values were slightly higher than the corresponding weighted CO benefit values. We speculate that this difference is due to a small sample size for early model year vehicles. The earliest model years used in the Atlanta Step analysis (i.e., 1975 and 1976) had smaller sample sizes than the other model years used in the analysis. At the same time, the vehicles with 1975−1976 model years tended to have higher emissions. For each category of our analysis except one, the model years with the highest CO average emissions were in the range of 1974−1976. These older model years also corresponded to the vehicle ages with the lowest sample sizes. The one exception was for nine-county trucks. For this group, the highest average CO emissions were for the model year of 1978.

Given this uneven distribution of emissions and sample sizes for the Atlanta data, the higher emissions from the older vehicles were given smaller weightings than the lower emissions from the newer vehicles (because we used the sample size for each model year to weight the average emissions). Stedman et al. (*1*), while applying the Step Method to Denver, analyzed only the emissions from vehicles with model years in the range of 1982−1994 because these were the model years subject to I/M testing in Denver in 1995. The smaller and newer range of model years for the Denver analysis meant that sample sizes were probably distributed more evenly across the range of model years, and thus, the weighted CO benefit values for Denver were closer in value to the nonweighted CO benefit values.

While Stedman et al. found a negligible HC benefit for cars and trucks in Denver (*1*), we found noteworthy HC benefits in the Atlanta Step Method analysis. In the four-county Atlanta area, cars made up about 70% of the sample

TABLE 3. Results of Atlanta and Denver Step Method Analyses[a]

location	CO non-weighted benefit	CO weighted benefit	HC non-weighted benefit	HC weighted benefit	program change
Denver, cars and trucks	6.7	6.9	negligible	negligible	D, A, idle → C, B, IM 240
Atlanta nine-county, cars and trucks	13.4	11.5	21.3	20.1	no program → D, B, TSI
Atlanta nine-county, cars only	14.3	11.8	28.1	26.7	no program → D, B, TSI
Atlanta nine-county, trucks only	10.4	8.2	12.8	12.6	no program → D, B, TSI
Atlanta four-county, cars and trucks	5.9	4.9	5.7	3.1	D, A, idle → D, B, TSI
Atlanta four-county, cars only	5.3	3.2	4.3	1.6	D, A, idle → D, B, TSI
Atlanta four-county, trucks only	7.6	6.3	22.2	19.2	D, A, idle → D, B, TSI

[a] Legend: D = decentralized, C = centralized, A = annual, B = biennial, TSI = two-speed idle.

(Table 2) and demonstrated an HC weighted benefit of about 1.6%. Four-county trucks made up the remaining 30% of the four-county sample, and with a nonweighted value of 19.2%, the HC benefit for trucks was higher than the benefit for cars. As with the CO benefits, the HC benefits for the nine-county Atlanta area were higher than the HC benefits for the four-county area, with a HC weighted benefit of 26.7% for nine-county cars and 12.6% for nine-county trucks. The nonweighted HC benefit for nine- and four-county cars and trucks was 21.3% and 5.7%, respectively. The nonweighted HC benefit for nine-county cars was 28.1%, and the same benefit for nine-county trucks was 12.8%. Cars comprised about 63% of this sample while trucks made up the remaining 37% of the nine-county observed fleet (see Table 2).

Discussion

While the general trends of the CO and HC benefits are similar to our expectations, we were initially surprised to find such a large discrepancy between HC percentage benefit for trucks in the four-county area and cars in the four-county area. Since Stedman et al. did not complete the Step Method for cars and trucks individually (*1*), we could not compare these values with previous analyses. Given that both cars and trucks in the four-county area were subject to the same I/M program and the same program changes, this discrepancy was initially surprising.

We hypothesize that this drastic difference is attributable to the change in model years that were tested when the four-county area transitioned from an idle program in 1996 (i.e., testing only the last 12 years of vehicles) to a stricter two-speed-idle program in 1997 (i.e., testing vehicles with model years 1975−1995). Since trucks typically survive longer than cars do, we expect that there were more four-county trucks that were required to be tested for the first time (i.e., model years 1975−1983) under the new TSI program than there were four-county cars that were required to be tested for the first time.

As we have discussed throughout this paper, becaise of the lack of an existing program in the nine-county Atlanta area, we expected to find a larger I/M program benefit for the nine-county area than the four-county area. This hypothesis was largely confirmed by our application of the Step Method. However, one additional explanation for why we saw an overall greater I/M benefit in the nine-county Atlanta area than in the four-county Atlanta area could be attributed to a phenomenon called the halo effect. This phenomenon is sometimes observed for areas that have a long-standing I/M program. The driving force behind the phenomenon is that vehicle owners in I/M areas often sell their vehicles (rather than repair them) if the car or truck does not pass the I/M test. Therefore, in an area with a long-standing I/M program, car dealers receive a substantial percentage of vehicles that have failed an I/M test. These vehicles are then sold to the outlying non-I/M counties (in this case, the nine-county Atlanta area before 1997). This selling off to non-I/M counties causes a potential buildup of failing vehicles in the non-I/M area. If the nine-county Atlanta area did experience this halo effect, then a portion of the calculated I/M benefit could be due to the nine-county area having an artificially inflated emissions baseline. Several other scholars have mentioned and recognized this phenomenon for areas with long-standing I/M programs (*1, 9, 12*).

In summary, despite a few caveats (like the halo effect and the unexpectedly large HC benefit for four-county trucks), the application of the Step Method to an Atlanta fleet demonstrated a noteworthy reduction of CO and HC emissions as a result of a newly implemented I/M program. The research presented in this paper has reinforced the assertion that I/M programs, as currently designed, do provide a considerable level of emissions benefit. The replication of the Step Method of I/M program evaluation presented here demonstrates consistent emissions reductions for vehicles categorized in three different ways: cars and trucks combined, cars only, and trucks only. Cars and trucks demonstrated a larger CO benefit in the nine-county Atlanta area than in the four-county Atlanta area. In conclusion, this analysis has added to the existing group of studies showing I/M programs to be beneficial to cities trying to reduce their emissions from mobile sources. Furthermore, we have found that these reductions in emissions occur across vehicles types.

Acknowledgments

This research was supported by the Georgia Department of Natural Resources (GDNR) under Contracts AGR DTD 970530 and 773-10072. Additional funding was provided by the U.S. Environmental Protection Agency under the former Cooperative Agreement 823020 and the current Cooperative Agreement R-82838501-0. The findings are solely the authors' and do not necessarily represent those of the GDNR or the U.S. EPA.

Literature Cited

(1) Stedman, D. H.; Bishop, G. A.; Aldrete, P.; Slott, R. S. *Environ. Sci. Technol.* **1997**, *31*, 927−931.
(2) Zhang, Y.; Stedman, D. H.; Bishop, G. A.; Guenther, P. L.; Beaton, S. P. *Environ. Sci. Technol.* **1995**, *29*, 2286−2294.
(3) Zhang, Y.; Stedman, D. H.; Bishop, G. A.; Beaton, S. P.; Guenther, P. L. *Environ. Sci. Technol.* **1996**, *30*, 1445−1450.
(4) Bishop, G. A.; Stedman, D. H.; Castro, J. de la G.; Davalos, F. J. *Environ. Sci. Technol.* **1997**, *31*, 3505−3510.
(5) Wenzel, T. Evaluation of Arizona's Enhanced I/M Program. Presented at the 9th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 1999.
(6) Sjodin, A.; Andreasson, K.; Wallin, M. Multi-Year Repeat Remote Sensing Measurements of On-road Emissions from Cars Subject to an Annual Centralized I/M-Program Involving an Idle Emission Test. Presented at the 7th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 1997.
(7) Sjodin, A.; Andreasson, K. *Atmos. Environ.* **2000**, *34*, 4657−4665.
(8) U.S. EPA. *Guidance on Use of Remote Sensing for Evaluation of I/M Program Performance*; EPA420-B-02-001; U.S. Government Printing Office, Washington, DC, 2002.

(9) Wenzel, T.; Singer, B. C.; Slott, R. S. *J. Transp. Stat.* **2000**, *3*, 1−14.

(10) Wenzel, T. Evaluation of Arizona's Enhanced I/M Program. Presented at the Colorado State University Clean Air Conference, Breckenridge, CO, 1998.

(11) Rodgers, M. O.; Dehart-Davis, L.; Lorang, P. Measuring I/M Program Effectiveness Using Optical RSD: Results of the Continuous Atlanta Fleet Evaluation. *Atmos. Environ.* (submitted for publication).

(12) Stedman, D. H.; Bishop, G. A.; Slott, R. S. *Environ. Sci. Technol.* **1998**, *32*, 1544−1545.

(13) Wenzel, T. *Environ. Sci. Policy* **2001**, *4*, 359−376.

Received for review October 8, 2001. Revised manuscript received January 24, 2003. Accepted February 7, 2003.

ES015736Q