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Emissions from 200 000 vehicles: a remote sensing study

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Abstract

We have a device capable of remotely monitoring the mass emissions of CO and HC from passing vehicles in gm/l of fuel used in under 1 s/vehicle. The results from measuring the emissions of over 200 000 vehicles using this device show that a few vehicles, typically less than 10% of the fleet, are responsible for half the total emissions. This 10% of the fleet are referred to as 'gross polluters'. The majority of gross polluters in the USA have had their emissions control systems tampered with despite laws to the contrary. Results from the USA, Canada, Mexico, the UK, and Sweden show that the USA imposition of emission controls has achieved a 50% reduction in fleet emissions, but for fleets everywhere, proper identification, diagnosis, and repair of gross polluters is the low-cost key to future emissions reductions.

Key words: Remote sensing; Vehicle emissions; On-road

1. Introduction

The concept of remote sensing of vehicle emissions and the remote sensor are fully described elsewhere [1,2]. Briefly, the device is a non-dispersive infrared instrument capable of measuring carbon monoxide (CO) and hydrocarbon (HC) emissions from passing vehicles in a single lane in under 1 s/vehicle. The same signal that triggers the beginning of data collection also triggers a computer video board to freeze the image of the license plate of the vehicle being measured. These images are stored on video tape along with that vehicle's emissions. Information from motor vehicle registrations allows us to correlate vehicle emissions with make, model, and age of the vehicle. The measurements are the same as a typical exhaust gas analyser would provide should one have been able to insert a probe in the tail-pipe while the vehicle was being driven. The percent CO measurements can easily be converted to mass emission units such as grams per liter. The instrument's accuracy has been validated twice by means of double-blind studies conducted by the California Air Resources Board [2,3].

Since vehicles can be monitored at a rate of over 1000/h, we have several large sets of data from measurements of over 200 000 vehicles. In this paper we compare CO emissions measurements from Los Angeles [4], London, UK (D.H. Stedman, personal commun. with Royal Automobile Club, London, 6 December 1991), Mexico City (S.P. Beaton, G.A. Bishop and D.H. Stedman, unpublished data) and Gothenburg, Sweden [5]. The results for HCs are qualitatively similar from the more limited amount of data collected. Fleet aver-

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age emissions are strongly affected by the fleet average age, the presence or absence of new vehicle emission standards, and, to a lesser extent, the make of the cars. The effects of vehicle make can be further distinguished between the relatively minor effects of manufactured capability and relatively major effects of owner behavior.

2. Results and discussion

A fleet is defined as that population of motor vehicles that pass by the remote sensor at a particular location during a defined period of time. Data from our measurements show that, with the exception of Mexico City, a small portion of the fleet, typically less than 10%, is responsible for half or more of the CO emissions in any given area. Vehicles comprising this 10% of the fleet are referred to as 'gross polluters'. These overall fleet characteristics are very similar regardless of overall fleet age, location, or the presence or absence of inspection and maintenance (I/M) programs. Most vehicles, again regardless of location, are clean, by which we mean emissions of 1% CO or less in the exhaust. Fleet characteristics are often described in terms of statistics that assume a roughly normal distribution of the emissions data. In reality the populations making up a fleet's emissions are skewed because of the large number of clean vehicles, requiring a different type of statistics handling [6]. The newer the fleet the more skewed the emissions. This is because many more of the fleet have near zero emissions and thus, a smaller number of gross polluters strongly dominates the fleet emissions. Older vehicles are not all gross polluters. In fact, the majority of them are relatively clean. There is a correlation between fleet age and fleet emissions. This correlation has less to do with emissions control technology than it does with vehicle maintenance. Any well-maintained vehicle, regardless of age, can be relatively clean.

Fig. 1 shows the emissions data from over 56 000 vehicle measurements. This represents that part of the total fleet for which make and model year information was available for fleets measured at twenty sites in the USA and Canada. For each hour of data which contains more than 100 vehicles, the percent CO values have been averaged

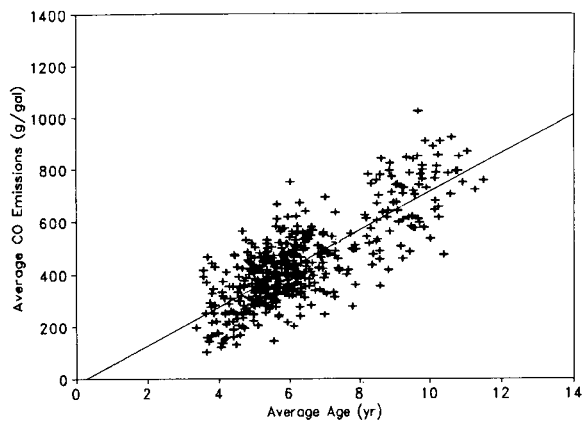


Fig. 1. Scatter plot of average fleet age in years versus average CO emissions in g/gal. Each point represents 100 cars consecutively measured at a single site. Data are derived from over 56 000 vehicle measurements at 20 sites in the USA and Canada.

along with the age of the vehicle for which that measurement was obtained. From Fig. 1 we obtain the following formula for predicting the emissions of a fleet of vehicles:

Mean CO emissions (gm/gal) = [(fleet avg. age (years) − 0.28) × 74.0] ± 99

To derive grams per liter, divide the slope and intercept by 3.79. Average age is determined from the registered model year of manufacture of each individual vehicle subtracted from the date of the on-road measurement. Each model year for this purpose is assumed to start on 1 September and end on 31 August. A linear least squares regression generated the equation which has an r^2 of 0.62. The standard error of the estimate is 99 g/gal.

The equation predicts only the fleet mean CO emissions. It cannot be applied to individual vehicles. The equation is limited in that it applies only to fleets that have been subject to USA new vehicle standards since the 1970s. Vehicles monitored in London and Mexico City lie far above the line in Fig. 1. Vehicles measured in Sweden lie only slightly below the line but within the margin of error. Factors influencing these differences may include the presence or absence of mandated emissions control systems, mechanic competence, and the societal prevalence of tampering behavior.

Fig. 2 shows the 56 000 vehicle measurement data set divided into year of production on the x-axis. Within each year the emissions of that part of the fleet have been rank ordered and then split into five equal sized sets (quintiles). Each quintile's emissions are then averaged and are presented as the height of the bar for that quintile. The bars in Fig. 2 are directly proportional to emissions in grams per liter of fuel. If emissions in grams per kilometer are required then the emissions from each age group need to be multiplied by the average gas mileage for that age vehicle. If the data were converted to grams per kilometer and if gas mileage is taken to be a factor of 2 lower for older vehicles then these bars would become a factor of two higher. This would not change the conclusions.

From Fig. 2a it can be seen that the dirtiest quintile of the newest vehicles (1991) has much higher emissions than the cleanest quintile of the oldest vehicles (1964 and older). It can also be seen that the most rapid deterioration in emissions occurs during the first 5–6 years of ownership. After that time the rate of increase of emissions slows down considerably. It is interesting to note that these vehicles with the most rapidly deteriorating emissions are all new technology vehicles with computer controlled fuel delivery systems and three-way catalysts. All of these vehicles have negligible CO emissions when first purchased.

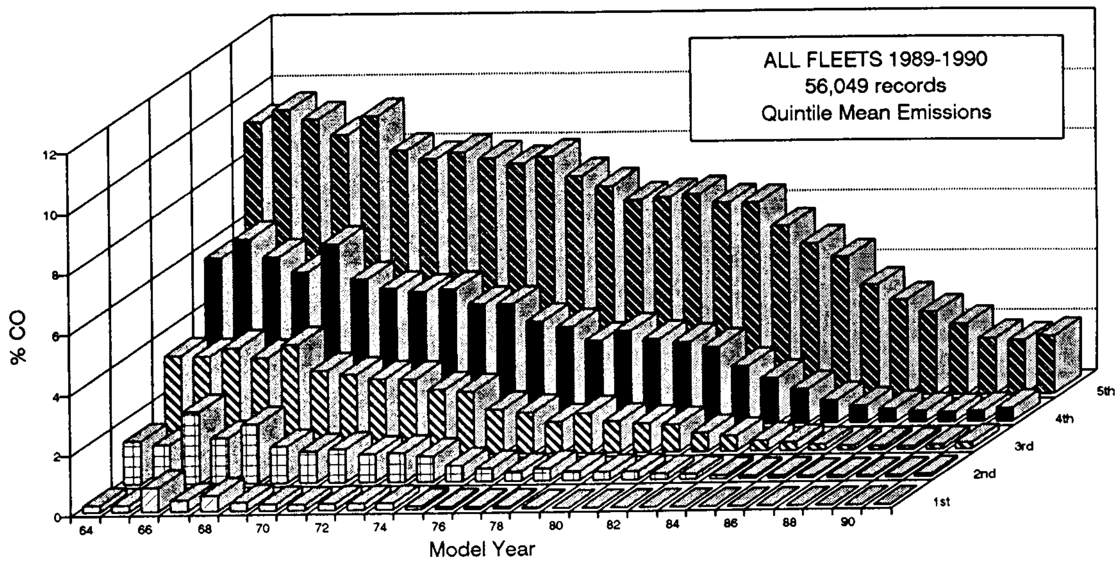
Fig. 2b shows the emissions profile shown in Fig. 2a multiplied by the number of vehicles in each quintile. What it shows is that too much concern about the emissions of older vehicles is not warranted because there are so few of them out on the road. The emissions from the dirtiest quintile of the 1990 vehicles (1 year old) is much higher than the dirtiest quintile of the 1964 and older fleet. Again this is due to the greater number of 1-year-old vehicles in the fleet compared with those 17 years and older.

From looking at both Figs. 2a and 2b, no readily discernable breaks occur in the pattern of fleet emissions that coincide with the introduction of various new technologies designed to control vehicle emissions. Starting with about 1975, most new vehicles were equipped with catalytic converters. Engine technology had changed little and the cleaning was performed in the exhaust pipes. The years of 1981 and 1982 represent transition years as newer technologies were introduced. Starting in 1983 most new vehicles were equipped with computer controlled carburetors or fuel injection systems and three-way catalysts. The philosophy with the new vehicles has been cleaner output from the engines with little assistance needed from reactions in the exhaust stream itself. Both of these figures also demonstrate that vehicle maintenance is a more important consideration than vehicle age in determining and, hence, controlling fleet emissions.

New fleets, regardless of make, all have nearly identical and very low emissions. Since the average emissions of all fleets is dominated by a small percentage of dirty vehicles, we believe the differences over time are caused by maintenance factors. There are two factors affecting maintenance. The first is the owner's willingness to pay for required maintenance. The second is the manufacturer's ability to provide a vehicle which either requires little maintenance or can be easily repaired when maintenance is required.

An analysis of our data addresses this issue. The entire USA database has been searched for vehicles with the maker's names Ford (>4000 records), Chevrolet (>6000 records), and Cadillac (>1000 records). All vehicles with these names are included regardless of whether the vehicles are listed as pickups or passenger vehicles. What stood out is that average Cadillac emissions are almost always the lowest for any given model year and are frequently less than half of the Ford/Chevrolet group [4]. Since the average emissions are again dominated by the number of gross polluters, we ascribe the differences to maintenance. We believe that owners who have spent more money initially to purchase a vehicle are more likely to spend the money required to maintain the vehicle, hence fewer gross polluters. To the extent that many of the European manufactured vehicles are also in the higher price range when new, the lower emissions we have observed from this fleet may be explained by the fact that their owners are willing to spend the money necessary for proper maintenance.

The data from that portion of the 56 000 vehicle



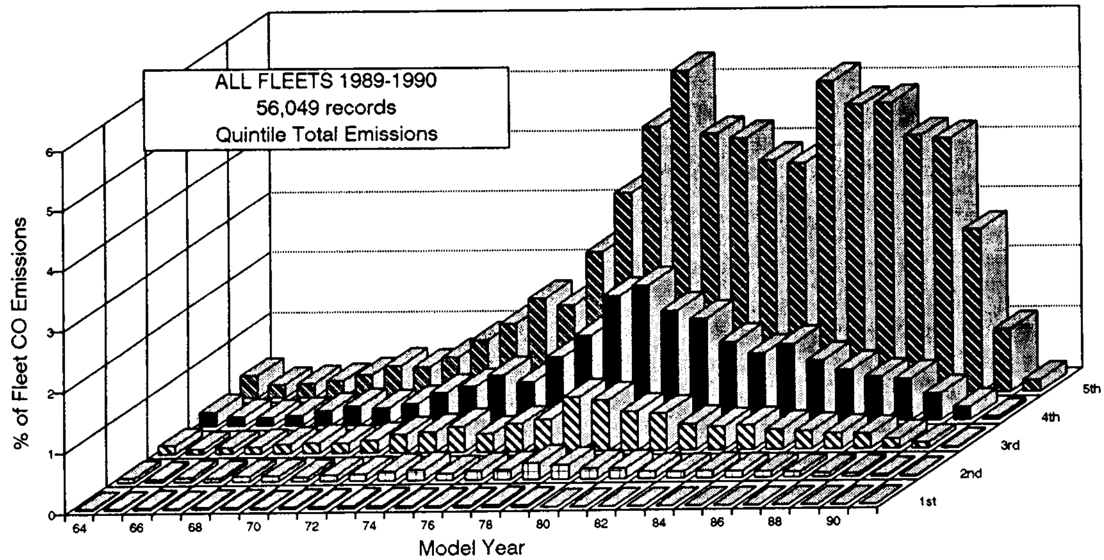


Fig. 2. (**a**) Separation of our vehicle measurements for which registration data exists into groups by model year. Each model year is rank ordered by percent CO emissions and divided into quintiles. The emissions of each quintile is averaged. (**b**) Each quintile of **a** is multiplied by the number of vehicles in that quintile. Each quintile now shows its contribution to total fleet emissions. The more numerous newer, dirty vehicles dominate the fleet CO output.

fleet of European manufacture was separated from the rest of the data and treated in an analogous manner to that seen in Fig. 2a. As seen in Fig. 3, the resulting fleet is sufficiently clean so that it can be studied for the effects of the imposition of different emission control technologies, especially when looking at the lowest emitting four quintiles. The fifth quintile still shows the effect of neglect as the vehicles get to be 5 and 6 years old, when their values have dropped considerably and many have changed ownership. Starting with about 1970, new car standards were such that a well-maintained car

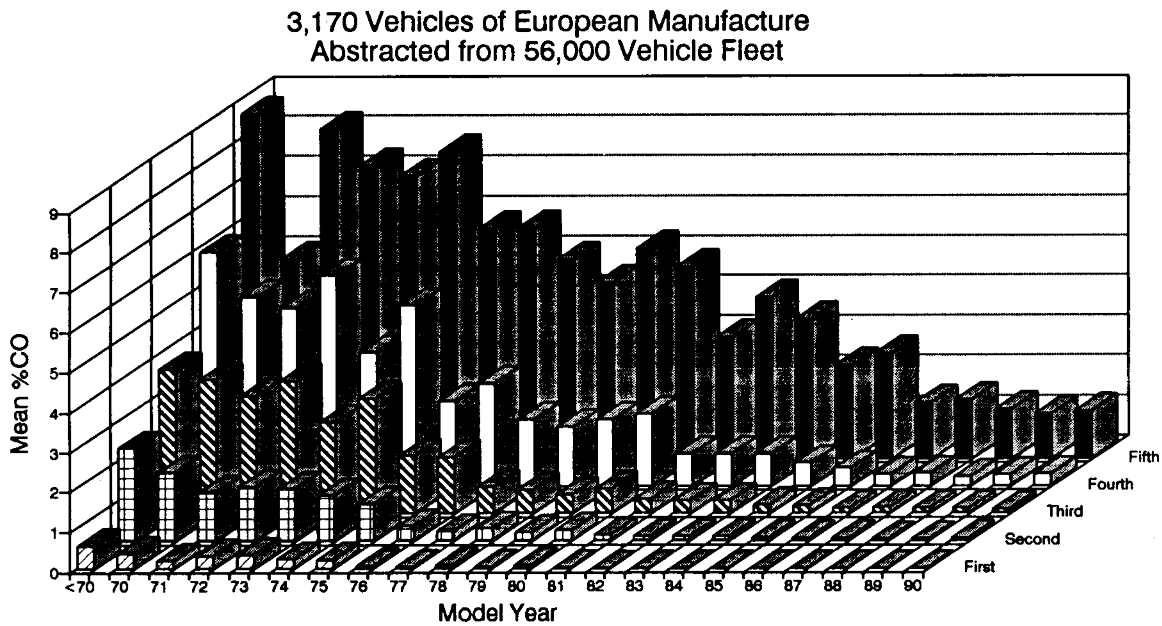


Fig. 3. That part of the fleet of European manufacture separated from the fleet of 56 000 vehicles shown in Fig. 2a. The emissions data from this part of the fleet was treated as in Fig. 2a.

remained a clean car. With the start of the use of catalytic converters in the mid 1970s, not only were the cleanest quintiles very low, but there is a substantial drop in CO emissions from the dirtier quintiles. With the nearly ubiquitous presence of computer controlled fuel systems, oxygen sensors, and three-way catalysts in the early 1980s, emissions in the dirtiest quintile took yet another plunge. The point is that the technology already exists to produce vehicles that can be very clean throughout their existence. It is the owner's willingness to spend the money maintaining the vehicle that determines whether one gets a fleet emissions profile that looks like Fig. 2a or Fig. 3.

In the USA, programs referred to as inspection and maintenance (I/M) have been imposed in many areas suffering from air quality problems. Although the inspection frequency and various other protocols vary greatly from one location to another, they are all designed to decrease vehicle emissions by checking for tampering with the emissions systems and evaluating tail-pipe emissions. They have not been very successful [3]. Lawson [2] showed that 92% of the vehicles identified by a remote sensor as having high on-road emissions and whose owners volunteered to participate, failed the California Smog Check test (California's I/M protocols). Of these vehicles, 41% had clearly had their emissions control systems deliberately tampered with and a further 25% had defective emission control systems. There was no relationship seen between the amount of time elapsed since the vehicle's previous emissions test and its likelihood of failing the Smog Check upon being pulled over. It is quite apparent to us from examining the data that a different approach needs to be tried in the endeavor to limit mobile source emissions.

On the basis of on-road emission studies in London, Toronto, Gothenburg, and Mexico City, there can be no doubt that the USA Federal New Vehicle Emissions Standards have caused a dramatic reduction in fleet emissions. This reduction is the reason that all new and most older vehicles in the USA and Canadian fleet are consistently very low emitters regardless of make or country of origin. In view of the fact that high CO emissions are dominated by a few badly maintained gross polluters, and that there is no evidence of major breaks due to changes in technology or changes in new vehicle emission standards, we believe that further tightening of new vehicle standards is not warranted. If these analyses are correct, there is still considerable room for improvement in average on-road CO emissions of the current USA fleets as measured by on-road remote sensing. This improvement will occur provided that required maintenance is performed on gross polluting vehicles and that illegal emissions system tampering is eliminated.

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