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Roadside air pollution in Hong Kong: Why is it still so bad?

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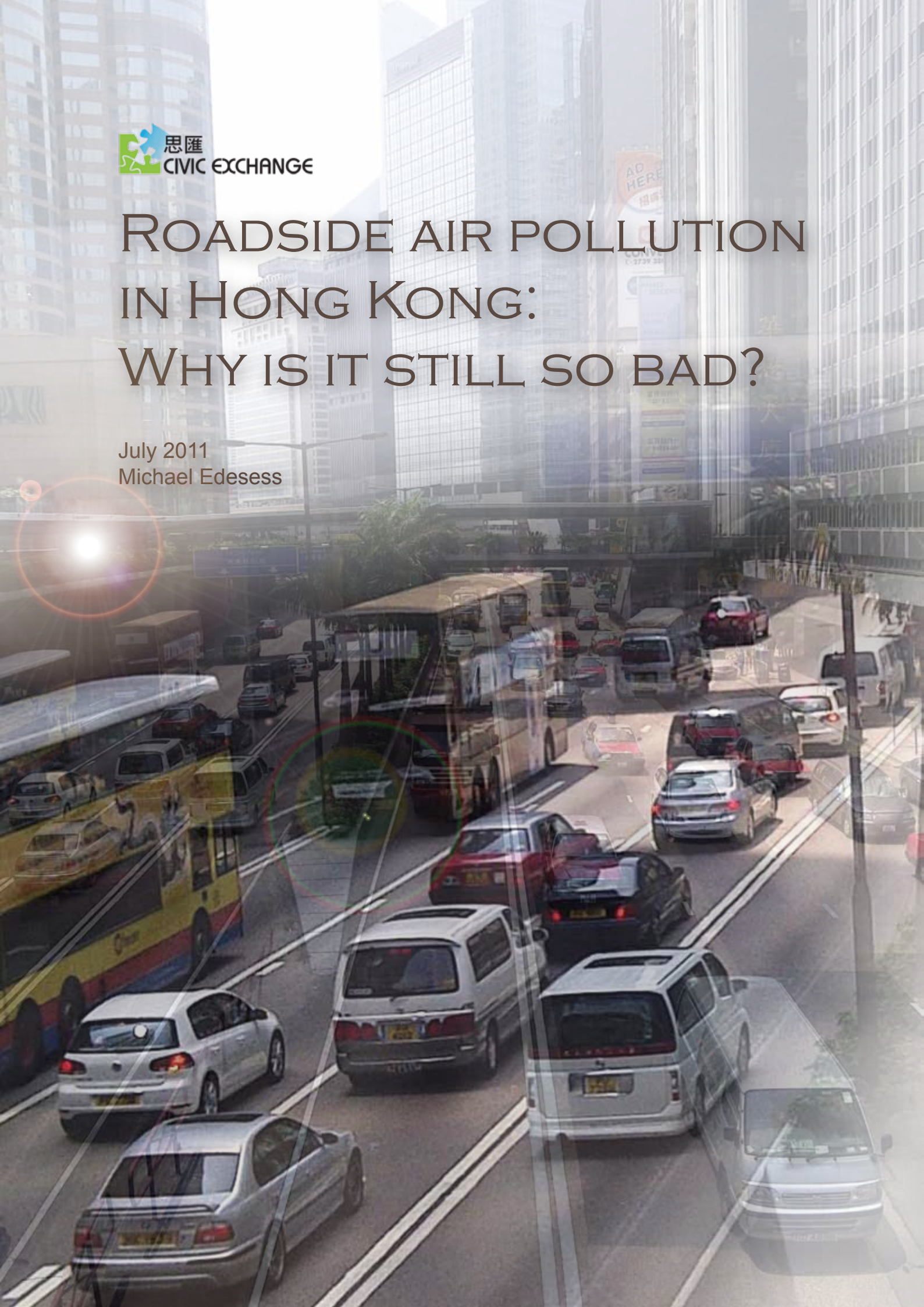
Michael Edesess



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Introduction

Numerous policy measures have been put in place to try to improve Hong Kong's roadside air quality.[1] Official estimates are that these measures have significantly lowered overall emissions. Yet air quality at the roadside, where it is most perceptible and harmful to health, has not improved commensurably.

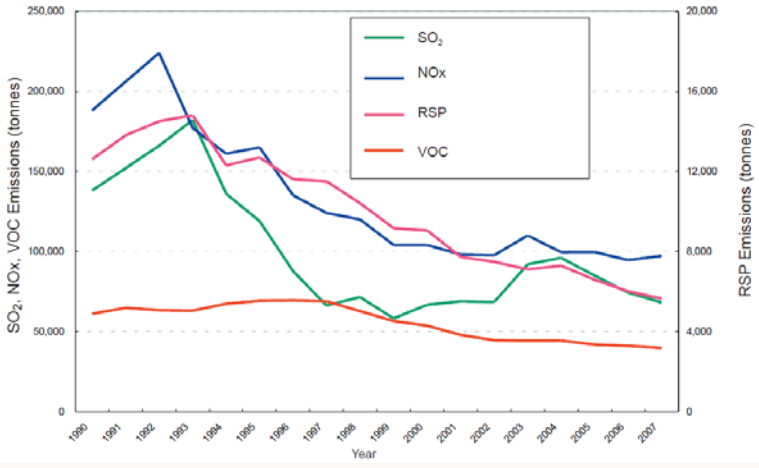
What accounts for differences between the patterns of official emissions and concentrations measured at the roadside? Some of the discrepancy is likely due to the poorly-maintained state of vehicles in Hong Kong. More accurate emissions estimates, derived from direct measurement of emissions from vehicles, are needed to feed into policy assessments and hence policy formulation to provide urgently needed improvements in street level air quality.

Estimating real-world data using theoretical models is hazardous, as experience in the financial services field has shown[2]. Emissions aggregates estimated by models should be suspect. Data should be gathered quickly to determine whether actual emissions are greater than those derived from emissions modeling. Collecting these data may entail random roadside emissions tests, a routine feature of inspection and maintenance (I/M) programmes in several states in the US. If Hong Kong's bad air quality at the roadside is due to poor vehicle maintenance, a much stricter programme of I/M should be quickly established.

Discrepancies between model estimates and roadside measurements

Figure 1 tracks the trend in official emissions estimates, showing substantial declines in emissions of nitrogen oxides (NOx) and respirable suspended particulates (RSP) in spite of increased vehicle numbers.

Figure 1. Air Pollutants Emission Trend in Hong Kong[3]



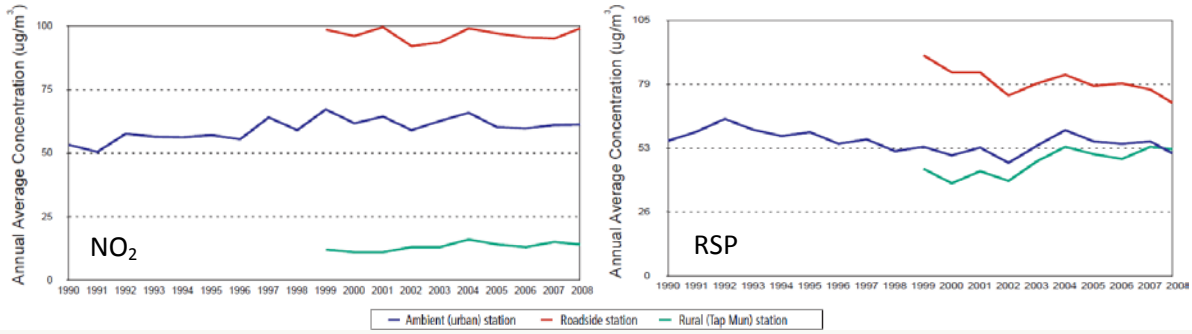
[1] William Wong, "Vehicle Emission Control Programmes in Hong Kong", *Proceedings, Motor Vehicle Emissions Control Workshop*, 3-6 March 2010, Hong Kong, edited by W. T. Hung and William Wong; and Kate Trumbull, *Still Holding Our Breath: A Review of Air Quality Policy in Hong Kong*, pp. 32-43, Civic Exchange, Hong Kong 2007.

[2] Extensively documented since the 2008 financial crisis, e.g., Carrick Mollencamp et al, "Behind AIG's Fall, Risk Models Failed to Pass Real-World Test", *The Wall Street Journal*, October 31, 2008

[3] Environment Bureau, Hong Kong Special Administrative Region Government, "Air Quality Objectives Review Public Consultation" p 9. http://www.epd.gov.hk/epd/english/environmentinhk/air/pub_consult/files/book_en.pdf, accessed 20 March 2011.

Figure 2 shows, however, that concentrations measured locally of two important vehicle-related emissions, nitrogen dioxide (NO_2) and RSP, have not exhibited similar declines.

Figure 2. Local concentration levels of NO_2 and RSP[4]



Roadside measurements for NO_2 have deteriorated even further recently.[5] NO_2 and RSP substantially exceed World Health Organization (WHO) guidelines and also fail to meet the less rigorous lower targets set by the Hong Kong Government. As a result morbidity and mortality costs attributable directly to air pollution remain high.[6] It should be noted that Figure 2 reflects actual measurements of ambient air at the roadside, while the numbers in Figure 1 are derived from a bottom-up modeling process, to be discussed later in this paper.

Efforts to improve the situation

Hong Kong government policies have tried to move the vehicle fleet toward lower emissions targets by requiring or incentivizing the replacement or retrofitting of vehicles with new emissions control equipment that meets tighter European Union (EU) standards.

The large reductions that should be expected as a result in NOx and particulate matter (PM) emissions from new vehicles meeting these tightening standards are evident from Table 1.

Table 1. EU emissions standards for diesel vehicles (g/kWh)

Tier	NOx	PM
Euro I	8.0	0.36
Euro II	7.0	0.25
Euro III	5.0	0.10
Euro IV	3.5	0.02
Euro V	2.0	0.02
Euro VI	0.4	0.01

Table 1 shows that vehicles meeting increasingly strict EU standards can decrease emissions of NOx and particulates by factors ranging from three or four up to factors of 20 to 30. Upgrading vehicle standards can therefore cause emissions to be less than one-twentieth the emissions of Euro I or pre-Euro vehicles.

[4] Ibid p. 7.
[5] http://epic.epd.gov.hk/ca/uid/airdata/p/1, accessed 21 March 2011.
[6] "Air Pollution: costs and paths to a solution", Civic Exchange, June 2006. http://www.legco.gov.hk/yr06-07/english/panels/ea/papers/ea1127cb1-232-1-e.pdf, accessed 9 March 2011.

This assumes, however, that vehicles are maintained so that they continue to meet the standards, or at least that they are not too greatly degraded. If, on the other hand, they are so poorly maintained that their emissions revert to those of a much earlier standard – if, for example, their catalytic converters malfunction, or are disabled or removed – then their emissions could be two to 20 times expectations (see page 5 *The importance of inspection and maintenance (I/M)*).

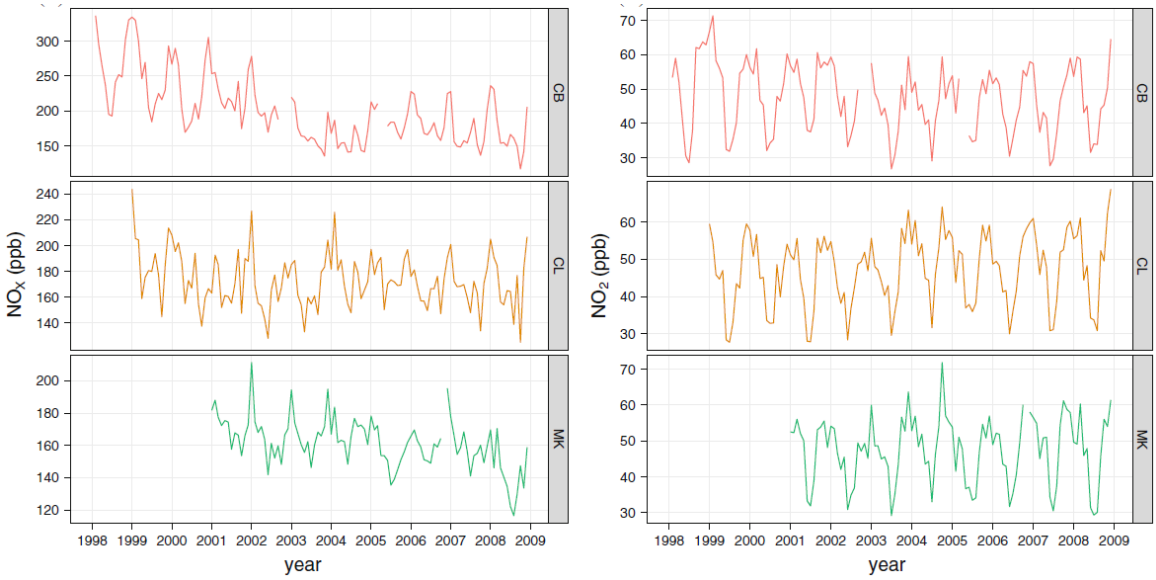
In the past, Hong Kong authorities pushed for tighter emission standards only for new cars, allowing old vehicles to retrofit and retire at their owners' discretion. Hence, while Hong Kong's newer cars meet high emissions standards, its aging vehicles may be sub-standard, possibly severely so if they are poorly maintained. Only recently has the HKSAR Government put forward old vehicle replacement programmes.

NOx and NO_2

NOx signifies a mixture of NO and NO_2. How much of each is in the NOx mixture depends on how much NO is converted to NO_2 by chemical processes and vice versa, and when. NO_2 emissions are more harmful to human health than NO.

Experts have observed that the NO_2 percentage of roadside NOx has been increasing in Hong Kong.[7] Figure 3 shows actual roadside measurements of NOx (left) and NO_2 (right) at three Hong Kong roadside stations, Causeway Bay (CB), Central (CL), and Mongkok (MK).

Figure 3. Trends in monthly mean concentrations of NOx and NO_2 at HK roadside monitoring stations[8]



These charts can be compared with Figures 1 and 2. The chief graphical difference is that the data in Figure 3 are monthly while those in Figures 1 and 2 are annual. In addition, the data in Figures 2 and 3 are acquired from measuring instruments while those in Figure 1 are estimated by a model.

The left side of Figure 3 shows declines in NOx over the years 1998-2009. The pattern of decline in NOx in Figure 3 is roughly consistent with the pattern of decline in Figure 1. The right side of Figure 3 shows NO_2 measurements in those same years. It is consistent with the NO_2 patterns shown in Figure 2.

[7] Linwei Tian et al, "Increasing trend of primary NO_2 exhaust emission fraction in Hong Kong". *Environmental Geochemistry and Health*, published online 18 February 2011 at http://www.springerlink.com/content/q3x86554t8v28567/fulltext.pdf (accessed 8 March 2011).

[8] Ibid.

Several hypotheses are possible as to why the NO_2 percentage of NOx has been increasing. Those who have studied this issue suggest it was the result of retrofitting vehicles with diesel oxidation catalysts (DOCs) from 2000 to 2005.

> *Designed to reduce emission of hydrocarbons … the particulate trap, and diesel oxidation catalysts (DOCs) have the disadvantage that they may increase the NO_2 fraction of total NOx emissions. The DOCs oxidize CO and hydrocarbon emission catalytically by converting NO to NO_2. The NO_2 is then used to assist in the oxidation of trapped particles, therefore reducing emission of hydrocarbons, CO, and particulate matter (PM).*[9]

Other possible explanations are that increased ozone, O_3, blown from the Pearl River Delta has increased oxidation of NO to NO_2, and that the street canyon effect traps NOx longer so that oxidation of NO to NO_2 proceeds further than if the NOx were quickly carried away by air currents.

In any case, neither NOx nor – especially – its constituent NO_2 is declining rapidly enough to meet health standards, nor as rapidly as should be expected given the introduction of new emissions controls.

The importance of inspection and maintenance (I/M)

The difference in emissions between a well-maintained fleet of vehicles and a poorly-maintained one is enormous. The Hong Kong Environmental Protection Department (HKEPD) has stated, "If not properly maintained, emissions from an individual vehicle can increase by more than four times."[10]

The difference between high-emitters and low-emitters could, however, be much greater than that. Studies in Denver, Colorado, showed that since 1999 one automobile in 20 emits more than the other 19 combined.[11] This suggests that while some of the difference between high- and low-polluters is due to differences in makes and ages of vehicles, an entire fleet of poorly-maintained vehicles could emit as much as 20 times that of a fleet of well-maintained vehicles. The difference between high- and low-emitters has become greater since 1999 because the lowest emitters are much cleaner than they used to be, while high emitters are just as dirty. Vehicles emitting the maximum do so because of poor maintenance.

I/M can be even more important than emissions control technology itself. A study showed that "The absolute emissions differences between well- and badly-maintained vehicles of any age are considerably larger than observable effects of emission control technology and vehicle age."[12]

Figure 4 illustrates this effect. The vertical axis shows the average hydrocarbon percentages of emissions for 15 vehicle ages and five quintiles of hydrocarbon content measured in Los Angeles. Hydrocarbon content varies significantly with vehicle age – the horizontal axis – as expected. However, it depends much more on other factors represented on the depth axis – foremost of which is how well-maintained the vehicle is, especially for those that are the least well-maintained.

[9] Ibid. p. 6.
[10] http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/files/additional_PA_measures.pdf, accessed 28/2/2011.
[11] Stedman, Donald H., "Remote Sensing A New Tool For Automobile Inspection & Maintenance" p 5. http://www.altfuels.us/pdf/stedman%5B1mdf%5D.pdf, accessed 22 March 2011.
[12] Zhang, Yi et al, "Worldwide On-Road Vehicle Exhaust Emissions Study by Remote Sensing", *Environmental Science and Technology*, Vol. 29, No. 9, 1995, pp 2286.

Figure 4. CO emission factors by vehicle age divided into quintiles[13]

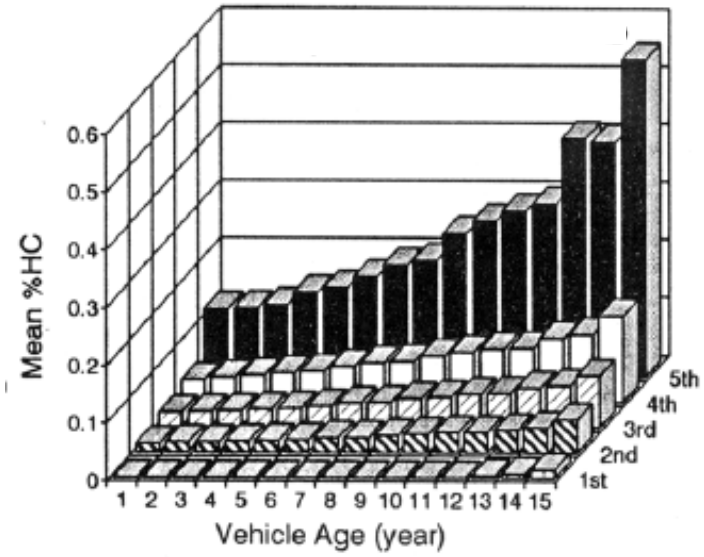


Figure 4 shows that in a location where most vehicles are relatively well-maintained – Los Angeles – the least well-maintained 20% account for the lion's share of the emissions. The same study showed that in a location where most vehicles are badly tuned and poorly maintained – Kathmandu – the emissions histogram is less skewed because instead of only 20% or less being high emitters, most vehicles are high emitters.[14]

According to the Department of Environment of the US state of North Carolina, "Due to poor maintenance, deliberate tampering with or removal of pollution controls (particularly catalysts) and misfueling (i.e., using leaded fuel in vehicles that require unleaded fuel), motor vehicles in use have consistently emitted pollutants well in excess of the established standards."[15]

In Hong Kong, a widespread pattern of poor maintenance, deliberate tampering, and misfueling (with lower-grade fuel) may be the cause of a large percentage of the fleet being high-emitters. This could account for the failure of emissions model estimates to capture the full impact of actual emissions. It is essential for Hong Kong to gather more data to determine the true facts of the situation.

Emissions inventories

The Hong Kong Government has publicized declines in emissions over recent years, attributing them by implication to its anti-air pollution measures. Indeed, there can be no question that regulation to require reductions of sulfur dioxide emissions from coal-fired power plants has been highly effective.

Emissions from on-road vehicles, on the other hand, are a different matter – especially those most damaging to health and most likely to be concentrated where large numbers of people are gathered: NOx and particulates.

It is important to recognize that emissions statistics are estimated from the data that are available; the lower the quality of those data, the rougher the estimates.

[13] Ibid, p. 2291.
[14] Ibid, p. 2288.
[15] North Carolina Department of Environment and Natural Resources, Division of Pollution Prevention and Environmental Assistance, "Motor Vehicle Inspection and Maintenance". http://www.p2pays.org/ref/02/01245/3017120.pdf, accessed 2 March 2011.

Emissions inventories from on-road mobile sources are created in a bottom-up manner. "In the bottom–up approach, one estimates emissions for individual sources and sums all sources to obtain city, regional or country level estimates."[16]

The model that has been used to create emissions inventories for the Pearl River Delta and other areas of mainland China, the U.S. Environmental Protection Agency's MOBILE 5b model, requires data from seven vehicle classes.[17] For each class, emissions factors are estimated for 25 model years, for each calendar year depending on conditions "such as ambient temperatures, average travel speed, operating modes, fuel volatility, and mileage accrual rates."[18]

The MOBILE 5b model then allows additional adjustments to be made for the level of inspection and maintenance (I/M) programmes. The Appendix contains the excerpt from the manual for MOBILE 5 programme users that explains how these I/M programmes are to be entered into the programme. This excerpt shows how complex and difficult it can be to try to adjust estimated emissions factors for I/M programmes. Yet the directions say nothing about how well-executed or well-adhered-to these I/M programmes are.

Maintenance programmes can vary very widely and can make an enormous difference in vehicles' emissions. Inputs to the computer programmes that create the emissions inventories are only approximately estimated; then the programmes themselves use approximation methods and assumptions to go from the input estimates to the output estimates.

While models produce apparently meaningful numbers as their end product, anyone intimately familiar with the process that produces such models knows that those numbers can only be regarded as guesses at best.

Similarly – though estimates depending on scientific or engineering methodology are far better than those that depend on economic assumptions – when human factors are introduced, such as I/M programmes, the process of estimation becomes far more approximate.

This may be why, in the model adapted by the HKEPD, the California Air Resources Board's EMFAC model, I/M is dealt with summarily, as the following paragraph in the HKEPD's document, "Guideline on Modelling Vehicle Emissions," attests:[19]

> *Inspection and Maintenance (I/M) Options*
>
> *3.4 All the default I/M programmes in the EMFAC-HK model have to be disabled because they are not implemented here. Moreover, there is no need to input any I/M options because the effectiveness of local I/M efforts and the substantial alleviation of the smoky vehicle problem in recent years have already been built into the model.*

All of this is to emphasize the following point. If we begin by assuming that the emissions inventories as given – showing sharply declining emissions of NOx and particulates over recent years – are as good as directly observable data, we will be left with an unsolvable mystery: why have measurements of pollutant concentrations at the roadside not decreased significantly?

The fact is that, for a variety of reasons, emissions from on-road vehicles may not have declined as much as emissions inventories suggest. For example, in the years 2000 to 2003 thousands of diesel-fueled taxis were replaced by LPG-fueled vehicles. The catalytic converters in these vehicles have an estimated life of six years and are supposed to be replaced after that time.[20] Do the emissions inventories take into account the fact that many – perhaps most – of these catalytic converters may not have been replaced or maintained? Malfunctioning or poorly functioning catalytic converters will

[16] Zheng, Junyu et al, "A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment," p. 5113. Atmospheric Environment 43 (2009) 5112–5122.

[17] Ibid, p. 5114

[18] "User's Guide to MOBILE5" p iii. U.S. Environmental Protection Agency document EPA-AA-TEB-94-01. Accessed 28/2/2011 at http://www.epa.gov/oms/models/mobile5/mob5ug.pdf.

[19] http://www.epd.gov.hk/epd/english/environmentinhk/air/guide_ref/files/EMFAC_HK_Guidelines_on_Modelling_Vehicle_Emissions_July2005.pdf, accessed 18/4/2011.

[20] Personal communication, Wing-tat Hung, Hong Kong Polytechnic University.

increase emissions by a large multiple. If the emissions factors do attempt to take account of this, by what means could they have obtained their estimates of the number of catalytic converters that have not been replaced or maintained, and how could they estimate the drop-off in emissions-control effectiveness because of it? How, to pose an even more difficult question, can the emissions inventories account for the suspicion that many vehicles have their catalytic converters removed or disabled between inspections in order to increase fuel efficiency and driving performance?

According to HKEPD, the emissions factors used in Hong Kong's emissions estimates have used "existing local traffic, vehicle fleet and ambient data and the in-use vehicle emission databases of US EPA [Environmental Protection Administration] and CARB [California Air Resources Board] since 2005."[21] This appears to imply that the estimates do not take into account the possibly very large differences in I/M programmes and consequent vehicle maintenance gap between Hong Kong and US vehicles.

In short, as a result of many factors, the art and science of producing emissions inventories is a difficult one, prone to error, yielding not only highly approximate outputs but in all likelihood, unavoidably biased ones as well. Therefore, it is best not to fixate on emissions inventories as indicators of emissions trends. It would be different if there were more accurate data available on motor vehicle emissions – such as from random testing of on-road vehicles – but not enough such data are available in Hong Kong.

Need for more data to pinpoint the source of the problem

The source of the problem of NO_2 and RSP emissions at the roadside must lie somewhere among emissions from vehicles in the following table of data from the Hong Kong Transport Department:[22]

Table 2. Motor vehicle km driven by selected class of motor vehicle

Vehicle km (million)	2009
Private car	4,537
Light goods vehicle	2,256
Taxi	2,130
Med/heavy goods vehicle	1,191
Public bus	857
Public light bus	377
Motor cycle	322
Light rail vehicle	7
Tram	6
Others	102

At present, the allocation of NO_2 and RSP emissions among these sources is not known. A joint study by the Transport Department and HKEPD is needed to produce accurate estimates of how much NO_2 and RSPs are produced by each of the vehicle classes in the above table. The study should further break the estimates down as to:

[21] Carol K. L. Wong, "PEMS Program in Hong Kong". Proceedings, Motor Vehicle Emissions Control Workshop, 3-6 March 2010, Hong Kong, edited by W. T. Hung and William Wong.

[22] Hong Kong Transport Department, http://www.td.gov.hk/filemanager/en/content_4387/09fig3.1e.pdf, accessed 14/4/2011.

1. How much of the emissions in each class can be attributed to a well-maintained vehicle of that class (preferably broken down by age and Euro class of vehicle);
2. How much of the emissions in each class – the remaining emissions – can be attributed to below-standard maintenance.

The two main tools for on-road vehicle emissions reductions are

1. New emissions control equipment in new or retrofitted vehicles
2. Maintenance performed to keep the control equipment in good working order.

Maintenance is performed in response to negative incentives such as inspections, with a penalty imposed for failure to pass the inspection. If at the annual inspection one's private personal or goods vehicle, taxi, minibus, school or coach bus, etc. emits more than the standard for any of the several pollutants in the standard, it will not be given the certificate of road-worthiness needed for its use.

In both areas, new emissions control equipment and I/M, Hong Kong has been deficient as compared to most other developed world jurisdictions. For example, in the area of new emissions control equipment for buses it has lagged behind Singapore, as illustrated in Table 2:[23]

Table 3. Comparison of bus fleets in Hong Kong and Singapore by engine type

	Hong Kong		Singapore	
Engine Class	Franchised Buses	Planned year of Retirement	Public buses	Replaced by (year)
Pre Euro	456	2012	0	-
Euro I	1,338	2015	2,700	2011
Euro II	2,688	2019	586	-
Euro III	1,233	2026	207	-
Euro IV	53	-	503	-
EuroV/EEV	-	-	357	-
Total	5,768		4,353	

Sources: Legislative Council Paper No. CB(1) 2312/0809(01) & SGWiki.com/wiki/buses

The HKSAR Government has shown that it is willing to be proactive in remediating these deficiencies, but it must go much further. For franchised buses, the government has considerable control over retirement/replacement policy. There is a need, however, to clarify exactly who has the responsibility for ensuring that franchised buses' emissions control equipment is well-maintained. Strict emissions standards need to be set for all vehicles, monitored by rigorous annual inspections, with refusal to license vehicles that do not meet the emissions standards.

In order to better estimate where the effort should be placed it will be necessary to know better which vehicle classes are most responsible for causing the problem, and how much of the problem is attributable to vehicle age and type (Euro I, II,…) and how much is attributable to sub-standard maintenance, tampering, or low-quality fuel.

Gathering of data needed to determine the scope of the I/M problem

If vehicles emit much greater levels of pollutants than has been assumed because of poor maintenance, deliberate tampering with or removal of pollution controls and misfueling, then it is essential to determine to what extent this is the case.

Hong Kong could collect data by means of random pullovers and roadside emissions tests, and inspections to determine if vehicles' emissions control systems are still present and in working order.

[23] Eric Heimark et al, "Paying for a Cleaner Bus Fleet" p. 4, Civic Exchange, Hong Kong November 2009.

Such random pullovers – usually combined with remote sensing – have been implemented in several US states as part of strict I/M policies.[24]

Hong Kong should initially proceed with this programme to gather realistic data, without necessarily penalizing the driver or vehicle for failing the inspection. The programme should be designed, however, in anticipation of the likelihood of implementing it as part of an ongoing I/M programme, in which vehicle owners would suffer consequences and penalties for failing to pass the inspections.

Hong Kong should upgrade its I/M to match the strict programmes that have been implemented in locations in the US and Europe with degraded air quality. In this process it should be fully informed by the American and European experience of more than two decades.[25] That experience shows that all forms of inspection and emissions detection are needed, including emissions tests, remote sensing, on-board diagnostics, and random testing and inspection.

Plan the establishment of strict emissions standards and inspection programmes

Hong Kong should bring emissions control and I/M standards up to US and European levels immediately. This will require several actions at once.

The fleet of taxis, commercial vehicles, and private vehicles is likely failing to meet emissions standards, since they have not been required to pass strict emissions tests on a regular basis. Bringing them up immediately to standard will require further government subsidies, similar to the funding of selective catalytic-reduction (SCR) converter retrofits that the government has already announced for some franchised buses.

The highest-emitting vehicles often tend to be owned by those with less financial means who can't afford maintenance. Subsidization may therefore be necessary in some cases up to as much as 100% of the cost of bringing vehicles up to standard.

A one-time amnesty programme would allow vehicle owners to bring their vehicles to designated centers where their deficiencies in emissions control can be evaluated and measures determined that are required to bring the vehicles up to standard.[26] Then the government would provide a subsidy of a percentage of the cost of the upgrade, but at the same time require that the upgrade be completed by a specific date upon which the vehicles would have to be brought back for inspection. The percentage of the cost needing to be covered by government would need to be determined, perhaps through an independent assessing body.

After the initial upgrade, vehicles will be required to submit to annual emissions inspections similar to those that are conducted in the US and Europe.

Upgrade of Hong Kong's emission inspection and maintenance capabilities

In order to launch such a programme, Hong Kong's emissions I/M capabilities will have to be upgraded. HKEPD and Transport Department should consider jointly holding a series of meetings with operators of emissions I/M facilities, corporate I/M chains, and emissions research laboratories to determine how to bring Hong Kong's I/M facilities up to standard. These meetings, assisted by consultative studies, will

[24] http://apps.dmv.ca.gov/pubs/vctop/appndxa/hlthsaf/hs44081.htm; http://www.in.gov/legislative/iac/T03260/A00130.PDF; http://www.dmvstat.com/emission_diesel.htm; all accessed 19 March 2011.

[25] Douglas S. Eisinger and Peter Wathern, "Policy evolution and clean air: The case of US motor vehicle inspection and maintenance". *Transportation Research Part D* 13 (2008) 359-368. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH8-4T0FHYH-1&_user=14084&_coverDate=08%2F31%2F2008&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1684826512&_rerunOrigin=google&_acct=C000001598&_version=1&_urlVersion=0&_userid=14084&md5=15f18edb083abdf3c4a76f2faf8d5d23&searchtype=a, accessed 19 March 2011.

[26] See also section on emissions standards, below.

determine what role government and other stakeholders need to play in quickly upgrading Hong Kong's I/M programmes.

Legal structures

To enforce a stricter I/M regime a number of laws and regulations must be established. In the US it is illegal for a catalytic converter to be disabled or removed from a vehicle except for repair or replacement[27]. A similar legal requirement must be put in place in Hong Kong with a penalty adequate for deterrence. In the US, emissions inspectors are prosecuted for falsifying emissions inspection results as some have done in return for bribes. As with other parts of the proposed fast-track path to upgrade I/M of emissions control equipment, the legal means to enforce it should be investigated through consultations with relevant parties and fast-track consultative studies as needed.

Preventing the import of below-grade fuels

Many commercial vehicles cross the border from Hong Kong to the mainland and back, sometimes returning with a tank of fuel that is below its cost in Hong Kong but fails to meet Hong Kong's standards. Burning this fuel in Hong Kong fouls the air with pollutants that are supposed to be reduced by rules governing fuel use in Hong Kong, and can damage the vehicle using the fuel to the point that its emission controls are degraded or even disabled.

Additional measures should be put in place to reduce the amount of fuel imported in the tanks of vehicles from the mainland to Hong Kong. Goods vehicles have been subjected since 1999 to a duty on the fuel imported in their tanks above specified minimum quantities, as shown in the following table:[28]

Table 4. Exemptions from duty for fuel in the tanks of goods vehicles

Cylinder Capacity of Vehicle	Exemption
below 3000 cm^3	100 L
3000-10000 cm^3	200 L
over 10000 cm^3	300 L

Other vehicles that are not goods vehicles are exempted from duty on the fuel in their tanks.

These exemptions still allow vehicles to import large quantities of fuel. In the past, significant amounts of additional fuel were imported to Hong Kong illicitly. This practice has, however, been curtailed by tightened enforcement and by the exemption from duty of Euro V-standard diesel fuel.[29]

Singapore implements a three-quarter tank rule, which requires that vehicles departing Singapore must have at least a three-quarter-full tank of petrol.[30] Establishing such a requirement for vehicles departing Hong Kong would reduce the quantity of lower-quality fuel imported to, and burned in Hong Kong. Stricter measures are also possible, such as requiring randomly-tested vehicles crossing into Hong Kong to dump any lower-quality fuel they may have in their tank, except for enough to drive to a Hong Kong petrol station.

[27] Clean Air Act TITLE 42, CHAPTER 85, SUBCHAPTER II, Part A , § 7522 Prohibited acts (a) Enumerated prohibitions paragraph 3 http://www.law.cornell.edu/uscode/html/uscode42/usc_sec_42_00007522----000-.html, accessed 16 June 2011.
[28] http://www.legislation.gov.hk/blis_ind.nsf/CurAllEngDoc/B2DE9FB37129ECB54825748A00260424?OpenDocument, accessed 27/4/2011.
[29] Personal communication, T C Wong, Divisional Commander, Anti-Illicit-Fuel Investigation Division Customs & Excise Department, HKSAR Customs and Excise Department
[30] http://www.customs.gov.sg/leftNav/trav/Three-quarter+Tank+Rule.htm, accessed 8 March 2011.

Consider use of PEMS

Portable emissions monitoring systems (PEMS) have been tested in the US and China and have been used on light duty vehicles, city buses, heavy duty trucks, and off road construction vehicles.[31] They have been found to measure NOx within 12% deviation from US Federal Reference Method measurements and particulates within 20%.[32] The US and Europe are considering requiring them as on-board real-time emissions inspection and monitoring devices, especially for heavy-duty vehicles. PEMS have been used by researchers in Hong Kong to help build a realistic database to aid in the compilation of emissions inventories. This work should continue. PEMS installation on franchised buses and heavy-duty trucks should be seriously considered for real-time emissions monitoring.

Setting emissions standards

A sweeping upgrade of emissions control technologies and I/M programmes in Hong Kong requires considering to what standards technologies should be upgraded. Information from the study proposed above can provide the input necessary to arrive at a pragmatic and effective schedule for implementing improved standards. It can be argued strongly that all vehicles should be upgraded as soon as possible to Euro V or Euro VI standards. It might seem that noxious emissions would be linearly reduced from Euro I to Euro V standards but that appears to be not necessarily the case. As previously noted, the fraction of noxious NO_2 found in NOx emissions in Hong Kong's roadside air has increased over recent years, perhaps due to the retrofit of diesel oxidation catalysts aimed at controlling other pollutants. Euro V vehicles have more-effective SCR systems that physically remove NOx using urea as a catalyst. Hence, SCR retrofits can effectively reduce NOx emissions to the Euro V standard.

Nevertheless, SCRs are expensive and cumbersome and may be efficient as retrofits only for large vehicles such as franchised buses and heavy-duty trucks. Hence, for smaller vehicles a realistic compromise standard for retrofits may be to replace aging or non-functioning catalytic converters.

There is also a strong possibility that some catalytic converter retrofits – those using particulate filters with burn-off of the trapped particles – may have actually resulted in higher concentrations of fine particle emissions.[33] This should be considered in determining what technologies should be required in upgraded vehicles.

The way forward

The Hong Kong Government has shown itself serious about trying to reduce emissions of NO_2 and particulates by requiring and funding the best available emissions control technology – most recently announcing that it will support the retrofit of Euro V-standard SCRs in some franchised buses.[34]

These efforts will, however, be of little avail if the controls are not extended more widely and vehicle inspection and maintenance standards are not improved. Multiple special interests resist and impede –

[31] Imad A. Khalek, "PM-PEMS Measurement Allowance Program in the United States"; R. A. Giannelli, "Development of PEMS Measurements"; Bao Kiaofeng, "PEMS Activities in Mainland China: From On-road Vehicles to Non-road Machines", Proceedings, Motor Vehicle Emissions Control Workshop, 3-6 March 2010, Hong Kong, edited by W. T. Hung and William Wong.

[32] Thomas D. Durbin et al, "Evaluation and Comparison of Portable Emissions Measurement Systems and Federal Reference Methods for Emissions from a Back-Up Generator and a Diesel Truck Operated on a Chassis Dynamometer", *Environmental Science & Technology*, 2007, *41* (17), pp. 6199-6204.

[33] Phil Johnson and Paul J. Miller, "Ultrafine Particles: Issues Surrounding Diesel Retrofit Technologies for Particulate Matter Control", NESCAUM/NESCCAF, February 5, 2007. Available at www.nescaum.org/documents/ufp-white-paper-20070205-final.pdf (accessed 8 March 2011).

[34] Hong Kong SAR Government Press Release, "Franchised buses and air pollution, 5 Jan 2011.

often understandably – the upgrading of these standards even though the ultimate result would be the benefit of all Hong Kong residents and visitors. Hence, a situation has been created in which the consequence of many people pursuing their own benefit is a result that is the worst for all.

Only a full, dedicated, and tough commitment of HKSAR Government to a sweeping upgrade of emissions control standards and vehicle I/M practices can halt the pattern of emissions control degradation that is responsible for Hong Kong's bad air. Hence, the following policies are recommended:

- Launch a joint study by HK Transport Department and HKEPD to estimate what emissions are produced by each vehicle class, and how much are attributable to inadequacies of the vehicles' emissions control equipment design features, and how much to their inadequate maintenance
- Use the results of the study to design a targeted strategy of stricter emissions and emissions control standards and I/M programs
- Strengthen Hong Kong's I/M capabilities
- Establish stringent emissions control equipment requirements and maintenance standards
- Implement more-rigorous annual emissions inspections
- Deploy remote roadside sensors combined with random pullover emissions inspections
- Enforce strict requirements and penalties for vehicles failing inspections
- Create legal sanctions forbidding emissions control equipment from being tampered with and forbidding inspectors from passing vehicles that have not truly passed the inspections
- Establish measures to prevent import and use of below-standard fuel
- Require use of PEMS for real-time emissions monitoring on heavy-duty vehicles.

The pollution of Hong Kong's urban environment stems from a thousand sources of action and inaction; both polluters and bystanders who breathe the air assume there is little that can be done about it. However, a concerted and fully determined effort to crack down on all of these sources at once – as cities in the US and Europe cracked down more than two decades ago on the sources fouling their urban environments – could clean up Hong Kong's roadside air. It could be effective fairly quickly. So far, this concerted and determined effort has not been made. The time to make that effort is now.

Appendix

Excerpt from MOBILE 5 program users' manual explaining how I/M programs are to be entered:[35]

The user is required to enter two I/M Descriptive Records whenever the IMFLAG in the Control section of the input data is set to 3 or 5 (see section 2.1.9). This second I/M Descriptive Record (see section 2.2.5) is identical to the first, containing all of the same program parameters and using the same format. MOBILE5 reads both I/M records and merges the information contained in them to determine the overall I/M program design intended by the user. When using the option to enter two I/M Program Descriptive Records, there are several considerations to bear in mind when describing the I/M programs.

First is the fact that all of the parameters on both records are considered together. Any parameter set on either record will cause the model to act in a manner consistent with that descriptive input. For example, if one record shows only passenger cars are covered by the I/M program, but the second shows both cars and light-duty trucks are covered, then the model will include both cars and trucks in at least some of the program benefit calculations.

Second, the second I/M Program Descriptive Record always takes precedence over the first whenever there is a conflict. The MOBILE5 model calculates emissions for each model year separately. If both the first and second records claim that a model year is covered by the program described, only the program described in the second record will be used to determine emission reductions for that model year. The information on the first record will be ignored whenever there is a conflict. This feature can be useful in some situations. For example, if the first record indicates an idle test is used for all model years for all vehicle types and the second record indicates use of the IM240 test procedure for 1986 and newer passenger cars, the idle test will be used for all 1986 and newer trucks as well as for pre-1986 passenger cars and trucks. The second I/M descriptive record only supersedes the test type for the 1986 and newer passenger cars.

Finally, the two I/M descriptive records should not be used to show changes in the I/M program over time. The I/M program start date effects [sic] the amount of benefits each model year vehicle gets in any particular calendar year. If the I/M program start date is different in the second I/M program descriptive record, the second I/M program start date will be used to determine benefits for any model years included in the I/M program description.

For example, an existing I/M program which started in 1984 begins using the IM240 test procedure for 1986 and newer vehicles starting in calendar year 1995. If the user sets the I/M program start date for the second I/M descriptive record, which describes the IM240 portion of the program, to 1995, it would appear that a series of calendar year evaluations from 1990 through 1996 would show the change in the program description starting in 1995. However, since the second I/M program descriptive record effectively changes the start date for the 1986 through 1995 model year vehicles, the benefits for those vehicles will not be correct in 1996. In cases like this two separate MOBILE5 runs, one describing the program in effect in the 1990 through 1994 calendar years and the second describing the program after 1995, will be necessary.

In the second runs, the I/M program starting date for both I/M descriptive records would be 1984, reflecting the date on which the vehicles were first inspected.

[35] "User's Guide to MOBILE5" pp 1-16, 1-17. U.S. Environmental Protection Agency document EPA-AA-TEB-94-01. Accessed 28/2/2011 at http://www.epa.gov/oms/models/mobile5/mob5ug.pdf.

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