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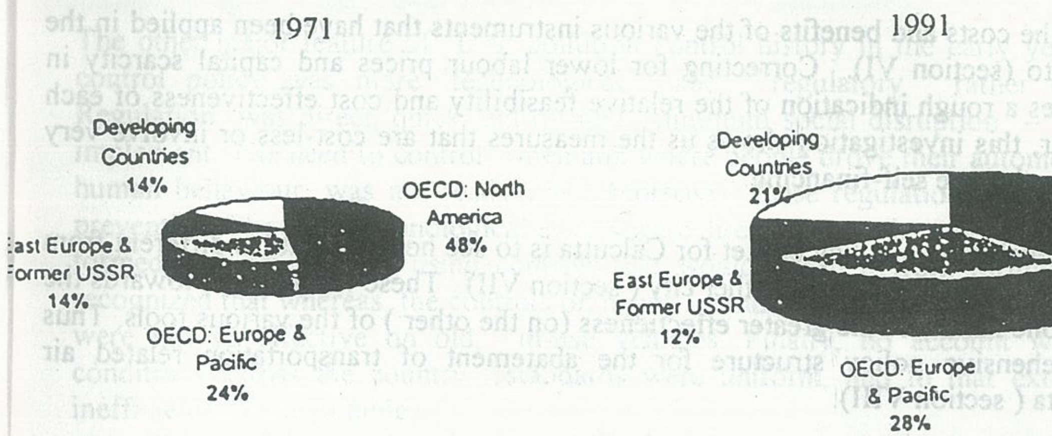
I

Introduction and Framework

Urban air pollution has emerged as one of the most serious environmental problems in the second half of the twentieth century, and whereas pollution from industrial sources has been more easily dealt with, pollution from individual sources and in particular, from transportation is the challenge faced by large cities in the twenty first century. This is all the more true given the fact that the global vehicle fleet, which totaled 580 million in 1990, is estimated to increase to 816 million by 2010 (1). The developed countries, which possess (and have possessed) far more vehicles than the underdeveloped (in 1988 the OECD countries had 80 per cent of the world's cars and 70 per cent of its trucks and buses), have been concerned with the problem for the last fifty years, and have corrected it to a considerable extent. However, the rapidly industrializing nations of the developing world have, as a whole, done little in the realm of pollution control in urban areas. Yet the future growth in the number of motor vehicles is mostly going to take place in these nations, where with industrialization, tertiarization and a high rate of migration into urban areas, the demand for automobiles is expected to increase phenomenally. During 1990-95, the demand for automobiles has increased by 200 percent in the developing world (2). Whereas the number of vehicles has increased by only 1.18 percent in the U.S. in the period 1988-95, it has increased by 79 percent in India. While the share of North America in total transport energy demand declined between 1971 (48 percent) and 1990 (39 percent), it increased in the developing countries (from 14 to 21 percent) in the same time frame. (see Figure 1) (3)

Figure 1

Changes in Regional Share of Transport Energy Demand



This meteoric rise in transportation demand has inevitably had an impact on air quality in urban areas of the developing nations. It is imperative that the developing countries wake up to the realization that drastic and immediate action needs to be taken in the realm of transportation policies for pollution control. A ranking of the twenty four megacities[1] in terms of the degree of air pollution – with 17 of them belonging to the developing world – show that 7 cities have 3 or more pollutants exceeding WHO (World Health Organization) guidelines : 5 of these (Beijing, Cairo, Mexico City, Jakarta and Sao Paulo) belong to the developing world [2] (4).

This research ultimately aims at formulating policies for reducing vehicular air pollution in one such megacity – Calcutta, in India . This city, with an average population concentration of 8594 persons per square kilometre in 1990/1 (expected to increase to 11593 persons in 2010 / 11) and with only 6 percent of urban space devoted to roads, is characterized by a very high level of congestion and high exposures to pollution (5). At least 60 percent of Calcutta's population suffers from respiratory diseases due to air pollution. A part of the problem has been created by the emission of suspended particulate matter (SPM) by industry, which largely uses coal as its source of energy, but transportation is responsible for around 40 percent of total emissions. Moreover , whereas a number of major steps have been taken in controlling the SPM from industrial sources, nearly nothing has been done in the realm of transportation-related pollution abatement. It is thus imperative that a comprehensive policy package be developed for this city.

With this objective in mind, my first step is to set up a preliminary policy structure, based on the experience of the U.S. (which is the unchallenged world leader in the area of emissions control) and to a lesser extent, Europe (sections II , III and IV).

However, given that for a city like Calcutta finance is a major constraint in pollution abatement measures , so that choice in terms of priorities, targets and tools is of utmost importance, it is necessary to develop the most efficient policy mix. To do this, I first look at the economics of pollution control, identifying the ways in which the theoretical principles can and cannot be used in practice (section V).

Secondly, data on the costs and benefits of the various instruments that have been applied in the U.S. are looked into (section VI). Correcting for lower labour prices and capital scarcity in India, this data gives a rough indication of the relative feasibility and cost effectiveness of each policy. In particular, this investigation shows us the measures that are cost-less or involve very low costs, and those that are self-financing.

The next input in developing a policy basket for Calcutta is to see how Calcutta is different from cities in the North or for that matter, any other city (section VII). These would point towards the exclusion (on the one hand) or the greater effectieness (on the other) of the various tools. Thus emerges a comprehensive policy structure for the abatement of transportation related air pollution in Calcutta (section VIII).

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1 population greater than 10 million.

2 the other two are Tokyo and New York City.

II

U.S. Transportation Policy for Air Pollution Control, History and Current Conditions.

In the U.S. the first steps in controlling auto pollution were initiated by the 'smog ' problem [1] in the Los Angeles area, which became acute in the 1940s. Public officials responded to an obvious public problem. Initially the reason for the problem was not identified, but by 1958 ' data showed that air in American cities was getting dirtier, at least as measured by suspended particulate matter. Analysis of the data revealed that the *major sources were the everyday activities of the public, not industrial operations*' (6) Thus, motor vehicles were identified as the major contributor to modern (post World War –II) urban pollution. In California there were 3 million motor vehicles in 1945 which increased to over 7 million in 1956: the corresponding figures for the U.S. were 31 million and 65.1 million , an increase by over 100 percent. Federal and State legislation developed in the 1950s, but the basic thrust was only in the area of research in reducing auto emissions. In the 1960s emissions standards were imposed on car manufacturers and vehicle inspection programs were put into action (7). The first emissions controls were on visible smoke, then carbon monoxide , and later on (exhaust and crankcase) hydrocarbons and oxides of nitrogen.

What is interesting is the fact that one state (California), with its history of severe smog , led the way with the federal government following in its footsteps. Over the 1960s, there was an increasing federal encroachment upon state authority, with uniform emissions limits made mandatory, but California, with its greater problems and stricter standards, was ' exempted ' from national standards.

The other major feature of U.S. pollution control history in the early years was the fact that control policy was more 'technological ' and ' regulatory ' rather than 'institutional'. Regulation was direct, quick and created minimum social disruption -- hence it was easy to implement. The need to control when and where people drove their automobiles , i.e. to control human behaviour, was not really felt. Moreover, these regulations were curative rather than preventive. The early technological efforts were directed towards removing pollution *after* it had formed and not towards using controls that would keep it from forming. It should also be recognized that whereas the controls on newly manufactured vehicles were very effective, they were not so effective on old, in-use vehicles. Finally, no account was taken of varying conditions across the country : standards were uniform, and to that extent, somewhat cost inefficient and inequitable.

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1 Although the term ' smog ' is commonly used to refer to the problem in Los Angeles, it has nothing to do with smoke or fog but is photochemical air pollution.

The 1970s marked a clear break from the softer policies of the first 20 years. The 1970 Clean Air Act required a 90% decline in auto emissions of carbon monoxide, hydrocarbons and nitrous oxides. Regulations were broadened to include the quantity of lead in gasoline, sulphur in diesel fuel and the emission of respirable particulate matter in diesel. Emissions of benzene and formaldehyde, both carcinogens, were also coming under control. Advanced technologies, including catalytic converters and evaporation emissions control, were developed in the latter half of the 1970s (8). 1977 saw the imposition of similar requirements on trucks, and more importantly, stringent vehicle inspection and maintenance programs. In 1990 there have been further amendments to the Act, with the 1990s witnessing continual tightening of regulations. The powers of the Environmental Protection Agency to enforce air quality standards have increased significantly. These amendments doubled the durability requirement for light duty vehicle emission control systems, tightened emissions standards further, mandated cleaner fuels and added standards for cold temperatures (9).

Table 1 shows how standards have changed over the years, and Table 2 gives a listing of current standards for light duty vehicles in the U.S.

Table 1

Progression of U.S. Exhaust Emission Standards for Light-Duty Gasoline-Fueled Vehicles

(grams per mile)

Model year	Carbon Monoxide	Hydrocarbons	Nitrogen oxides
Pre-1968 (uncontrolled)	90.0	15.0	6.2
1970	34.0	4.1	–
1972	28.0	3.0	–
1973-74	28.0	3.0	3.1
1975-76	15.0	1.5	3.1
1977	15.0	1.5	2.0
1980	7.0	0.41	2.0
1981	3.4	0.41	1.0
1994-96 (Tier 1)	3.4 (4.2)	0.25 (0.31)	0.4 (0.6)
2004 (Tier 2)	1.7 (1.7)	0.125 (0.125)	0.2 (0.2)

Note : Standards are applicable over the "useful life " of the vehicle, which is defined as 50,000 miles or five years for automobiles. The durability of the emissions control device must be demonstrated over this distance within allowed deterioration factors. Figures in parenthesis apply to a useful life of 100,000 miles, or ten years beyond the first 50,000 miles.

Source : Faiz, Weaver and Walsh , Air Pollution from Motor Vehicles, 1996.

Table 2

U.S. Exhaust Emission Standards for Passenger Cars and Light-Duty Vehicles Weighing Less than 3,750 Pounds Test Weight.

(grams per mile)

		50,000 miles or five years			100,000 miles or ten years		
Standard	*Year Implemented*	*Carbon monoxide 75/20 F*	*Hydro-carbons*	*Nitrogen oxides*	*Carbon monoxide 75 F*	*Hydrocarbons*	*Nitrogen oxides*
Passenger car [a] (Tier 0)	1981	3.4--	0.41	1.0	--	--	
Light-Duty truck [a] (Tier 0)	1981	10/--	0.80	1.7	--	--	
--Tier 1 [b]	1994-6	3.4/10.0	0.25 NMHC	0.4	4.2	0.31 NMHC	0.6
Tier 2	2004	1.7/3.4	0.125 NMHC	0.2	--	--	--
California Low-Emission Vehicle / Federal Clean-fuel Fleet programs							
Transitional low-emission vehicle (TLEV)	1994 [c]	3.4/10	0.125 NMOG	0.4	4.2	0.156 NMOG	0.6
Low-emission vehicle (LEV)	1997 [c]	3.4/10	0.075 NMOG	0.2	4.2	0.090 NMOG	0.3
Ultra low-emission vehicle (ULEV)	1997 [c]	1.7/10	0.040 NMOG	0.2	2.1	0.055 NMOG	0.3
Zero-emission vehicle (ZEV)	1998 [c]	0	0	0	0	0	0

--- Not applicable.

NMHC = non-methane hydrocarbons

NMOG = non-methane organic gases

Note : The federal Tier 1 standards also specify a particulate matter limit of 0.08 gram over mile at 50,000 miles and 0.10 gram per mile at 100,000 miles. The California standards also specify a maximum of 0.015 gram per mile for formaldehyde emissions for 1993 standard, transitional low-emission, and low-emission vehicles , and 0.008 grams per mile for ultra low-emission vehicles. Likewise, for benzene , a limit of 0.002 gram per mile is specified for low-emission and ultra low-emission vehicles. For diesel vehicles, a particulate matter limit of .08 gram per mile is specified for 1993 standard, transitional low emission, and low-emission vehicles, and 0.04 gram per mile for ultra low-emission vehicles at 100,000 miles.

a. Except for California.
b. Equivalent to California 1993 model year standard.
c. To be phased in over a ten-year period ; expected year of phase-in.

Source : Faiz, Weaver and Walsh Air Pollution from Motor Vehicles, 1996.

In the last two decades of this century, more attention has been paid to policies other than emission regulation (which consists of emission control for new cars, clean fuels and the inspection and maintenance of old cars). These can be categorized as (a) traffic flow improvements , (b) restraints in the use of motor vehicles (c) incentives for having higher occupancy in a vehicle, including for transit use and (d) land use planning aimed at reducing vehicle miles traveled (VMT) or congestion. The last three are usually referred to under the broader category of 'transportation demand management '. As there is serious involvement in pollution control programs at the state level, each states has a different policy package. Also, a considerable amount of research is in progress in the area of alternative fuels. The U.S. policy package will be comprehensively discussed in part IV.

Both emissions control and traffic flow improvements have the problem that they do not focus on reducing vehicles miles traveled (VMT) – improvements in air quality induces a greater demand for cars : i.e, there are modal shifts to lower occupancy vehicles and hence an increase in the aggregate VMT. This has been the major defect of U.S. policy and this has been reflected in the phenomenal increase in the demand for cars and a car-dependant lifestyle, negating much of the positive effects of regulation. Although such a system being based on the present land - use structure , cannot be changed overnight, greater care is being given to the management of transportation demand.

III

The Case of Europe

The need for controlling pollution was felt in the late'60s, but it took some years before some action was taken in the form of a directive from the EC and ECE in 1972 , establishing uniform exhaust emission standards for passenger cars and light duty vehicles with petrol engines. In the first stage the directive limited the emissions of carbon monoxide and unburned hydrocarbons. A few years later, however, Europe experienced significant increases in emissions of nitrous oxides, partly because of the efforts to reduce emissions of carbon monoxide and hydrocarbons and increase fuel efficiency. However, the air quality was nowhere near the situation in Los Angeles, and in 1977 the relatively mild regulation did not require manufacturers to deviate from the prevailing state of the art. Since then, however, standards have been lowered through a number of directives. Some countries aimed at much lower standards and convened a working group named ERGA (Evolution of Regulations, Global Approach), which studied the regulations and also strategies for the introduction of unleaded petrol. These were used by the EC to propose , in 1984, a set of rules. The proposal to make unleaded petrol readily available was unanimously adopted in 1985 at a meeting in Luxembourg. It was also agreed that by 1990 all new cars were to be designed for the exclusive use of unleaded fuels. [3]

The emissions proposals were also largely approved. The 1984 regulation was applied to both gasoline and diesel fueled light duty vehicles, whereas earlier regulations had applied only to gasoline fueled vehicles. These standards are referred to as the " Luxembourg standards "

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1 The two organisations are not formally connected but co-ordinate well, and there is a clear-cut distribution of responsibilities – the politically sensitive tasks are carried out in Brussels and the technical analyses by experts, in Geneva.

2 The founder members of the EEC were Belgium, the Federal Republic of Germany, France, Italy, Luxembourg and the Netherlands (Holland) . Later, Denmark, Greece, Ireland, Portugal, Spain and the United Kingdom joined the commission. Sweden, Austria & Finland have been added in 1995.

3 There were, however, some exemptions for manufacturers who showed difficulties in vehicle conversion. The emissions proposals were also largely approved. The 1984 regulation was applied to both gasoline and diesel fueled light duty vehicles , whereas earlier regulations had applied only to gasoline fueled vehicles. These standards are referred to as the " Luxembourg standards "

The rationale used for developing the Luxembourg standards was based on the " equivalence " principle, which asserted that *total* emissions (of nitrous oxides, which was considered to be the most environmentally damaging pollutant) should be the same as in the U.S. in 1983. The method used to arrive at the equivalence is worth investigating. The relevant variables are (a) total annual car mileage, which is the product of the total car fleet and average car mileage and (b) specific emissions of nitrous oxides for (i) different engine capacities and (ii) by type of driving (urban , suburban and motorway). The total emissions of nitrous oxides were then obtained by multiplying (a) and (b). It was seen that due to a number of differences in the above characteristics (see Table 3), especially in fleet size, mileage and engine size, the application of the higher standards of 1983 (US) would ensure the same total yearly emissions of nitrous oxides (at around 1.5 million tonnes for 1986-7).

Table 3

Transportation Characteristics, U.S. and Europe, 1983–84.

		U.S.	Europe (EC)
Fleet		135 m.[1]	100 m.[1]
	Av. annual	16,000(km/yr)	11,700 (km./yr.)
Mileage	Total annual	2160 (b. km.)	1166 (b. km.)
Engine Capacities	under 1400 cc	insignificant	60%
	1400-2000 cc		34%
	above 2000 cc		6%
Type of Driving (petrol engined cars only)	Urban	58%	53%
	Extra Urban	42%	47%
Diesel cars (as % of total)		4%[2]	18%[2]

1 projection for 1990
2 1986
Source : Society of Automotive Engineers, Motor Vehicle Pollution Control , A Global Perspective, SP 718, 1987.

These standards are .6 grams per kilometre in urban and .8 gms. per kilometre in extra-urban settings. Given that the U.S. standards were applicable from 1983, and the Luxembourg standards a full 10 years later in 1993, and given a fleet turnover period of about 12 years, the full effect of these standards were/would be felt in 1995 in the U.S. and in 2005 in Europe. The emissions in both the U.S. and Europe, with the application of these standards, are given in Table 4 (10).

Table 4

Emissions of Nitrous Oxides (million tonnes)

	1985	1995	2000	2005
U.S.	3	1.53	1.53	1.53
E.C.	3.17	2.68	1.94	1.67

Source : Society of Automotive Engineers, Motor Vehicle Pollution Control, A Global Perspective, SP 718, 1987.

The main defect of the above analysis possibly lies in the fact that rather than establishing a parity between *total* emissions, there should be a parity between emissions per square kilometre - and with a much lower geographical area in Europe, this value would be much higher with the same total emissions. However, this method indicates possible strategies for establishing emissions standards in developing countries. But that apart, it brings up a number of crucial features that should be considered in setting up any kind of strategy. Firstly, the distribution of engine capacities and modes is an important variable. So is the average car speed, and its variance. Nitrous oxide emissions increase sharply at higher speeds, and this increase is far greater in vehicles of large engine capacity. Thus these emissions would be low in urban areas where speeds are low. Moreover, there is little difference in the emissions of small and large vehicles in urban settings. Also, the mileage of large vehicles tends to be higher. Secondly, the distribution of diesel versus petrol powered vehicles is important. Earlier, diesel vehicles were large, usually with engine capacities greater than 2 litres, but slowly there has been a trend towards smaller vehicles. Diesel cars are more expensive but save significantly in terms of fuel costs due to fuel efficiencies and lower prices - hence the annual average mileage of diesel cars is much higher.

Two streams – the Stockholm group (including Austria, Norway, Sweden and Switzerland) with their more stringent policies and the Luxembourg compromise (consisting of most European countries), with its more lenient standards and test procedures, are identifiable. In particular, for the latter the standard on diesel cars was three times higher compared to the U.S. in 1987. The ECE did not adopt standards requiring three-way catalytic converters until 1988, and then only for vehicles with engine capacities of 2 litres or more. Less stringent standards were specified for smaller vehicles, to encourage the use of lead-burn engines. In contrast to earlier directives, the 1991 Consolidated Emissions Directive applied a common set of exhaust emissions standards to all private passenger cars (gasoline or diesel , and all capacities). Further, the standard covers evaporative emissions. These standards are given in Table 5, which also has stricter limits set in 1994, and to be implemented in 1996. Here, again, the standards for

Table 5

European Union Emission Standards for Passengers Cars (grams per kilometre)

	91/441/EEC [a]		94/12/EC[b]	
	Type approval	Con-- formity of production	Gasoline	Diesel
CO	2.72	3.16	2.2	1.0
HC + NOx	0.97[c]	1.13	0.5	0.7[d]
PM	0.14[c]	0.18	--	0.08[d]
Evap. Emissions (g/test)	2.0	2.0	2.0	---

---- Not applicable

a. Effective dates :
i) All light-duty vehicles except direct-ignition (DI) diesels: new models July 1, 1992, all models Dec.31.1992.
ii) DI diesels. July 1, 1994.

b. Effective dates :
i) Gasoline and IDI diesels,; new models Jan 1, 1996, all models, Jan 1, 1997.
ii) DI diesels Oct 1, 1999.

c. DI diesel limits until June 30, 1994 were 1.36 g/km. (HC+NOx) and 0.19 g/km. (PM)
d. Less stringent standards apply to DI diesel until Sept.30, 1999 : 0.9 g/km (HC+NOx) and 0.10 g/km (PM)
Source : Faiz, Weaver and Walsh, 1996.

diesel engines are less stringent for hydrocarbons plus nitrous oxides and for particulate matter. Table 6 gives the standards for light trucks and commercial vehicles by a consolidated Emissions Directive of 1993. The regulation on motor cycles and mopeds is given in Table 7. The regulation of heavy duty vehicle engines has similarly lagged behind U.S. standards. However, there has recently been much stricter limits, given in Table 8 . The first stage standards (Euro 1) took effect in 1992, and are comparable to 1988 U.S. standards. Euro 2 is comparable to 1991 U.S. standards , and Euro 3 is even more stringent.

Table 6

European Union 1994 Exhaust Emission Standards for Light-Duty Commercial Vehicles (grams per kilometer)

Vehicle category	Reference mass (kg) [a]		Exhaust emissions: Carbon monoxide	Exhaust emissions: Hydrocarbons + nitrogen oxides	Exhaust emissions: Particulate matter [b]
Light trucks [c]	RM ≤ 1,250	Type-approval	2.72	0.97	0.14
		Conformity of Production	3.16	1.13	0.18
	1,250 ≤ RM ≤ 1700	Type-approval	5.17	1.4	0.19
		Conformity of Production	6.0	1.6	0.22
	RM > 1,700	Type-approval	6.9	1.7	0.25
		Conformity of production	8.0	2.0	0.29

a. Reference mass (RM) means the mass of the vehicle in running order less the uniform mass of a driver of 75 kg. and increased by a uniform mass of 100 kg.
b. Diesel vehicles only.
c. Includes passenger vehicles with seating capacity greater than six persons or reference mass greater than 2500 kg.

Source : Faiz. Weaver and Walsh. 1996

Table 7

ECE and Other European Exhaust Emission Standards for Motorcycles and Mopeds (gram per kilometer)

Regulation, engine type	Carbon monoxide	Hydro-carbons	Nitrogen oxides	Testing procedure
ECE 40				
Two-stroke, less than 100 kilograms	16.0	10.0	–	ECE cycle
Two-stroke, more than 300 kilograms	40.0	15.0	–	ECE cycle
Four-stroke, less than 100 kilograms	25.0	7.0	–	ECE cycle
Four-stroke, more than 300 kilograms	50.0	10.0	–	ECE cycle
ECE 40.01				
Two-stroke, less than 100 kilograms	12.8	8.0	–	ECE cycle
Two-stroke, more than 300 kilograms	32.0	12.0	–	ECE cycle
Four-stroke, less than 100 kilograms	17.5	4.2	–	ECE cycle
Four-stroke, more than 300 kilograms	35.0	6.0	–	ECE cycle
ECE 47 for mopeds				
Two-wheel	8.0	5.0	–	ECE cycle
Three-wheel	15.0	10.0	–	ECE cycle
Switzerland				
Two-stroke	8.0	3.0	0.10	ECE 40
Four-stroke	13.0	3.0	0.30	ECE 40
Moped	0.5	0.5	0.10	ECE 40
Austria				
Motorcycles (< 50 cc and > 40 km/h)				
Two-stroke (before Oct.1, 1991)	13.0	6.5	2.0	ECE 40
Two-stroke (from Oct. 1, 1991)	8.0	7.5	0.1	ECE 40
Four-stroke (before Oct 1, 1991)	18.0	6.5	1.0	ECE 40
Four-stroke (from Oct 1, 1991)	13.0	3.0	0.3	ECE 40
Motorcycles (<50 cc)				
Two-stroke (before Oct 1, 1990)	12.0-32.0	8.0-12.0	1.0	ECE 40
Two-stroke (from Oct 1, 1990)	8.0	7.5	0.1	ECE 40
Four-stroke (before Oct 1,1990)	17.5-35.0	4.2-6.0	0.8	ECE 40
Four-stroke (from Oct.1,1990)	13.0	3.0	0.3	ECE 40
Mopeds (<50 cc and < 40 km/h)				
From Oct. 1, 1988	1.2	1.0	0.2	ECE 40

--- Not applicable

Note : This table does not show ECE 40 and ECE 40.1 limits for Reference Weight, R (motorcycle weight + 75 Kg) of more than 100 Kg. And less than 300 Kg. Furthermore only limits for type approval are shown in this table. See CONCAWE (1995) for additional information and applicable limits for conformity of production.

Source : Faiz, Weaver and Walsh, 1996

Table 8

European Exhaust Emission Standards for Heavy-Duty Vehicles for Type Approval
(grams per kilowatt hour)

Regulation	Effective date: New models	Effective date: All production	Carbon monoxide	Nitrogen oxides	Hydro-- carbons	Particulate matter
ECE 49 (13-mode)			14.0	18.0	3.5	a
ECE 49.01 (88/ 77/ EEC)	April 1988	October 1990	11.2 (13.2)	14.4 (15.8)	2.4 (2.6) [b]	a
Clean lorry directive (91/542/EEC)						
Stage 1 (Euro 1)	July 1992	October 1993	4.5 (4.9)	8.0 (9.0)	1.1 (1.23)	0.36 – 0.61 [c] (0.40 – 0.68)
Stage 2 (Euro 2)	Oct. 1995	October 1996	4.0 (4.0)	7.0 (7.0)	1.1 (1.10)	0.15 - 0.25 [c] (0.15 – 0.25)
Stage 3 (Euro 3)	1999 (tentative)	n.a.	2.5	5.0	0.7	less than 0.12

n.a. = Not available.
a. Smoke according to ECE Regulation 24.03. EU Directive 72/306/EEC.
b. Figures in parentheses are emission limits for conformity of production.
c. Depending on engine rating.
Source : Faiz, Weaver and Walsh, 1996

The following observations regarding U.S. vis-à-vis European standards may thus be made. Firstly, the EC standards have lagged considerably behind the U.S. standards. In 1995, the European standards were comparable to those adopted in the U.S. in the early 1980s. Part of the reason has been the consensus–based approach, with difficulties in obtaining an agreement between so many countries. Interestingly, Europe produces cars for the U.S. and hence possesses the technology to produce cars with U.S. standards – yet these are not implemented. Recently, however, the procedures require less unanimity and this has allowed individual countries to adopt stricter standards , some of which are now closer to the U.S. standards . Secondly, whereas in the U.S. the standards have been, in the last two decades, ‘ technology forcing ’ -- i.e, they have *forced* the technology to develop in order to attain the standards , in Europe and most other countries they have been ‘technology following ’ – i.e, the technology already existed for the standard to be implemented. As long as Europe and the other countries follow in the footsteps of the U.S., there is probably no harm in such a state of affairs – except for the possibility that the U.S. initiates most of the research in the area of emissions control. This may imply that research potentials in other countries are not being adequately utilized. Also , unlike the U.S. , once the vehicle leaves the factory, the manufacturer has no liability for its continued compliance. Hence, incentives for durability are little. Thirdly, whereas the U.S. has depended more on the stringency of the standards, Europe has made greater use of market mechanisms such as taxes on vehicles or fuel - particularly in Germany, the Netherlands and Luxembourg.

For a variety of differences , such as in vehicle characteristics, economic conditions and types or degrees of air pollution problems, emissions control approaches differ significantly between countries. In short , by the mid – 1970s most industrialized countries had some kind of vehicle emissions control program in place. Japan commenced its program *after* the U.S. (in 1966) , but progressed much faster, especially in terms of its complete switch to unleaded gasoline. Canada and Australia joined the brigade in 1971/2 and Finland in 1975. In 1989, Austria, Norway, Sweden and Switzerland adopted mandatory vehicular standards and regulations of the U.S.'s 1988 models. Emissions regulations were also adopted by rapidly industrializing countries like Brazil, Chile, Hong Kong, Mexico, the Republic of Korea, Singapore and Taiwan (China). Canada and Mexico, through NAFTA, now have the same standards as the U.S. Some former east bloc countries and some Asian countries have adopted the less stringent standards of the European Union. Most countries now have emissions regulations. (11, 12) . Most of the rapidly industrializing countries have also adopted a mix of transportation demand management strategies.

It is clear, from the experiences of different countries, that the time is ripe for the global harmonization of emissions standards. The development of a new model conforming to one set of standards costs manufacturers many million dollars, and takes two to five years. Thus, standardization in emissions control configurations would save billions of dollars for the world as a whole. The United Nations Industrial Development Organization (UNIDO) is funding work to harmonize standards in South East Asia. This work can be extended to cover all countries and the ECE may be made the umbrella organization for co-ordinating this process. In this connection it may be observed that because of the size of the U.S. market, vehicles meeting U.S. standards are available from most international manufacturers.

IV

A Preview of Policies Based on the U.S. (and European) Experience

As has already been discussed, the U.S. has led the crusade for emissions regulation and has concentrated on regulation and its associated technologies rather than dealing with behavioural aspects. However, the U.S. has not ignored the latter. Its experience in the field of demand management is good enough for us to derive lessons from it.

Abatement policies may be segregated into three broad categories :

A. Direct regulation and related technological measures.
B. Transportation Demand Management ,and
C. Traffic Systems Management.

Moreover, the development of a data bank, the question of public involvement and some of the economic (market-oriented) tools that have been used, are discussed separately. Figure II gives a summary view of the comprehensive policy basket.

A. Direct Regulation / Technological Measures

1. This involves setting *limits* to emissions of various pollutants such as carbon monoxide , hydrocarbons, nitrous oxides, sulphur dioxide, particulates, lead, ozone and carbon dioxide for both (a) new cars and (b) old, in–use cars. Separate standards are usually imposed depending on whether the vehicles are two-stroke or four-stroke, whether they are small or big and whether they run on gasoline or diesel. Differentiation based on whether the vehicle is heavily used or whether it operates in highly polluted areas, is also important. The standards may be based on studies regarding health effects, on costs of implementing the standards, or on constraints set by existing technologies. They may also be based on standards set in other countries.

2. Developing new, cheaper *technologies* in car production through financing or subsidizing

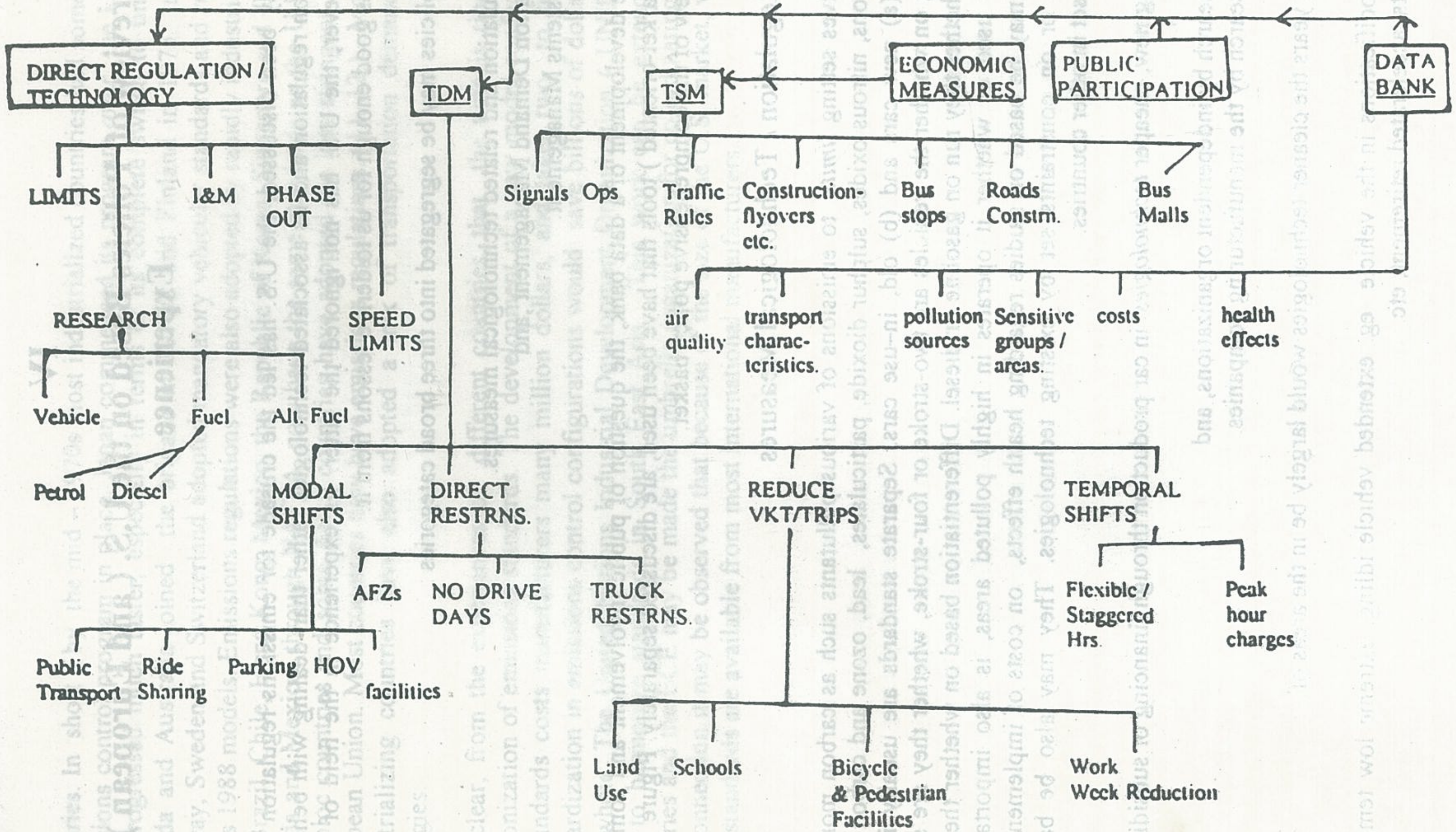
    a) research by independent organizations, and
    b) research by the manufacturing companies.

In the coming years the cleaner technologies would largely be in the areas of

- further modifications in the vehicle eg. extended vehicle idling, extreme low temperature cold starts, accelerated retirement, etc.

Figure II

Transportation Policy for Pollution Control ; Basic Framework



- developing alternative fuels such as alcohol fuels (methanol, ethanol), vegetable oils, natural gas, liquefied petroleum gas, hydrogen , electricity, fuel cells.

- improving existing fuels (gasoline and diesel)–volatility, oxyginated fuels, sulphur content , etc.

Incentives may be given to the manufacturers to develop these, and funds allocated to research institutes.

3. An Inspection and Maintenance program forms the essential core of the regulatory method, for this is the only way that the regulation can be enforced. Inspection should be carried out before the vehicle is sold, and in each year of the vehicles lifetime. It should involve in-engine emission controls, exhaust gas recirculation, on-board electronic controls, exhaust (tail pipe) gas aftertreatment techniques and evaporative emissions controls. Inspection should be followed, if necessary, by maintenance. The former can be state-run, or run by private contractors. It can be centralized and run by one or a few organizations, or can be decentralized and run by a large number of private garages. In the latter case, maintenance can also be carried out by the garages. The best system has been found to be private but large scale inspection units, and separate (private) garages for maintenance (it is not a good idea to have the same organization provide both services). Vehicle-owners are typically charged for both inspection and maintenance, but sometimes maintenance costs are borne by manufacturers for the warranty period. Part of the inspection charges go to the State which has the responsibility of co-ordinating the whole system.

4. The phasing out of vehicles, especially publicly owned ones, which are older than a certain number of years (say, 15). A law for ' phasing out ' is relevant in a situation where and inspection and maintenance program is not already in force : hence this may be the first step in a pollution abatement regime. The phasing–out age should be determined on the basis of average emissions of vehicles of different ages and an idea of unacceptable emissions levels. Alternatively , this can be incorporated in an inspection-cum-maintenance programme where the cost of repairing or retrofitting the car becomes prohibitively high, compelling the vehicle-owner to abandon it. Monetary compensations can be given for scrapping – or benefits such as sales tax exemptions for purchasing a new car can be provided.

5. *Speed* limits to reduce the demand for more powerful cars may be imposed.

B. Transportation Demand Management

Regulatory methods control the amount of emissions from a single car. However, they cannot control the number of cars in operation or the number of miles traversed by each car in a given time period. Total emissions thus depend on the total mileage of motorized transportation or what is called vehicle miles traveled (VMT). But given VMT, it also depends on the *nature* of the vehicle fleet - viz. diesel vs. gasoline vs. electric vehicles, light-duty vs. heavy-duty vehicles, two-stroke versus four-stroke vehicles. Hence, modal split is very important because different kinds of vehicles emit different amounts of the various pollutants. Moreover, it is crucial to recognize that the modal split between higher-occupancy vehicles (HOVs) such as buses or rail and lower-occupancy or single-occupancy vehicles (SOVs) such as cars or scooters is an important variable in determining total emissions because it affects VMT – this it because the HOVs serve many more people on one ride than the SOVs.

Thus it has been considered necessary to influence (a) modal choice (b) trip lengths and (c) number of trips. It is important to note that reducing the number of trips is more crucial than reducing trip length, as cars emit more in cold start situations, so that many small trips are much more harmful than one long one, even for the same total mileage.

Moreover, congestion is a major factor influencing emissions as cars at traffic jams with running engines, cars at very low speeds and cars in stop-and-go situations emit much more pollutants. Hence , for example, temporal demand shifts i.e. shifting the time of travel to off-peak hours are useful for reducing peak-hour traffic. The following are then the tools used for the management of transportation demand.

1. *Modal Shifts* to Higher Occupancy Vehicles (HOVs) are induced by

a) Improved *public transit*. This would involve a large number of possible measures. Mass public transit largely consists of buses or rail transit. The quality of public transit can be improved by reducing the waiting time or trip time and by making travel more comfortable (better seats, air conditioning , smoother rides , comfortable bus stops). Transfers can be made easier between modes and within the same mode, and the network can be extended to increase the potential number of travelers and improve access. Much of the quality improvement can be ensured by increasing the *quantity* of transit, but care should be taken to not exceed the potential demand for mass transit. On the other hand, transit can be made cheaper to attract new travelers. It has generally been seen that improving the quality of transit gives more returns relative to reducing its price.

b) *Ridesharing* , which includes carpools and vanpools. These can be organized by employers ,by the state or by private persons. They can also be co-ordinated by individual employees. In the U.S. the employer-based system has been most successful. In certain states major employers have to have a transportation co-ordinator conduct an annual survey, distribute information on alternative modes, prepare and submit a reduction plan, implement the plan and monitor results. Ridesharing may be encouraged by preferential parking and special lanes. Employers may provide monetary incentives or the state can provide tax deductions for ridesharing.

c) *Parking restrictions* would induce reductions in the use of SOVs. They may be in the form of ' no parking', paid or metered parking, or preferential parking for HOVs. A surveillance system with fines and tow-away arrangements would have to be in force. Sometimes parking restrictions may increase VMT when cars keep cruising round the block, looking for a parking space – but this is possibly a minor negative impact.

d) *Park-and-ride or fringe parking* facilities would prevent commuters from bringing their cars into congested urban areas. In both cases, the commuters would have to use mass transit systems or walk. These facilities would typically involve the purchase of land near mass transit systems such as a metro station and its conversion to a parking lot.

(e) *Special lanes* may be designated to HOVs, or they may be given priority treatment at ramps and entranceways.

2. *Direct restrictions on vehicle use* may be imposed in the following ways :

a) *Auto Free Zones* (AFZs) may be designated in certain parts of the Central Business District (CBD). In such zones all transportation modes may be prohibited, or one may prohibit certain modes. AFZs may require the construction of pedestrian facilities.

b) *No-drive days* for certain vehicle classes or license plate numbers can be mandated.

c) Trucks and lorries may be *prohibited from entering* urban areas in certain hours, such as peak hours or daylight hours.

3. *Incentives or Systems for Reducing Vehicle Trips or Trip Length* are the following :

a) *Land Use Management* : this can be , for example, developing a CBD surrounded by residential areas or a well-distributed set of activity centres instead of a CBD to reduce congestion and linking these centres to mass transport routes. This can be the careful planning of a city so that work places have residential areas nearby. This can be the provision of basic facilities near residential areas, such as grocery stores, medical centres , clubs and schools. ' Swapping ' programs, where offices are converted to residences and vice-versa, are difficult but have been implemented in certain cases.

b) Reforming the *school system* so that children in an area can only go to schools in that area. This system, of course, already exists in certain countries and is controversial.

c) Bicycle and Pedestrian programs : this would include the construction of bicycle pathways and pedestrian footpaths.

d) Reducing the work week to 5 or 4 days (in some countries this is still 6 days). This can be done by increasing the work hours per work day or arranging for at-home work - an increasing possibility due to major advances in communication technology. What, however, should be observed is the off-day activities.These are becoming more important in the total 'trip purpose' structure for the U.S., for example, and offsets policies aimed at reducing work trips.

4. *Temporal Shifts in Demand* will induce ' peak spreading '. This can be achieved through

a) More *flexible or staggered* work schedules. Such flexibilities not only reduce peak hour traffic but also allow for the combining of trip purposes (such as work-trip combined with picking up a child from school) and hence would reduce VMT.

b) Special *charges* for certain roads at *peak hours*. This would encourage travellers to use the roads at non-peak hours, or to use other, less congested roads. However, if the alternative routes are longer, this measure would increase VMT, thereby countering the effects of reduced congestion.

C. Traffic Systems Management

This is concerned with, basically, traffic flow improvements. The avoidance of heavy stop-and-go traffic greatly reduces the increased emissions during long idling times and repeated accelerations. Policies in this field have been particularly successful in the U.S., Japan, Europe, Singapore and Hong Kong - such improvements may be achieved through

a) traffic responsive *signalization*

b) *traffic operations,* such as one-way streets and ' no left turn ' directives

c) the enforcement of *traffic rules* , for example lane changing rules , overtaking, loading regulations, pedestrian control etc. to avoid chaotic traffic which encourages congestion.

d) the building of special systems to deal with cities with a low road space, such as flyovers and *underpasses* or *overpasses.*

e) developing structures to *prevent public transport from disrupting traffic* at the stop-points.

f) building more *roads*

g) building well-distributed *bus-parking malls.*

Improving traffic flow has the unfortunate effect of increasing VMT, as it becomes more comfortable to use transportation , especially SOVs. Thus, TSM has phenomenally increased the use of SOVs in the U.S. Also, it may be noted that TSM can sometimes be very capital intensive . Hence , it should be availed of in a selective fashion.

D. Economic Measures : Monetary Incentives and Disincentives Substituting for Direct Regulation.

Some economic measures (lower transit fares, ridesharing salary incentives or tax concessions, parking fines, parking rates favouring HOVs, and road user charges) have already been discussed, as part of demand management. Additionally, a set of incentives and disincentives can be created to (a) reduce the purchase of motorized vehicles *per se* (b) reduce VMT (c) reduce the purchase of vehicles that emit more (d) reduce the pourchase of unclean fuels (e) shift production in the direction of cleaner vehicles and cleaner fuels, and encourage fuel efficiency.

They are

- environmental fuel taxes : these taxes may be differential, based on the quality of the fuel (leaded or unleaded). A rebate may also be provided based on emissions performance.

- vehicle taxes or emission fees at the point of sale to encourage the purchase of low-emission vehicles.
- correspondingly, subsides for the purchase of fuel-efficient and or low emission vehicles may be provided.
- an emissions tax may be collected at inspection points. This acts as a strong disincentive but implementation is not easy.
- car registration fees may be tied to the emissions level.
- insurance payments may also be tied to fuel efficiency and distances traveled
- mobile source emission reduction credits may be provided. These can be traded with stationary sources or other vehicle owners for whom reducing emissions is more costly in lieu of meeting emission regulations.
- manufacturers of vehicles and fuels can be taxed or subsidized based on the level of pollution created by the product. This creates incentives to develop new technologies.

Most of the above measures are market tools for direct regulation : they can substitute or supplement regulatory measures. The European countries have been more active in taxation and fines, which are politically more difficult to implement. Germany , the Netherlands and Switzerland charge high fuel taxes which have increased fuel prices phenomenally. Germany charges emission fees at the point of sale. The mobile source emission reduction credit system, however, is being implemented in many parts of the U.S.

E. Public Information, Education and Involvement.

The three groups that are involved in air pollution control are the polluters, the victims, and the policy-makers. However, in the case of transportation-related air pollution, the situation is complicated by the fact that the polluters are also the victims (though the reverse is not always true). The policy-makers are mainly the government, but with the involvement of the judiciary and research institutes. The ' government ' , moreover, usually consists of a number of bodies – representing the central (or federal) government, or the state, or local bodies. Organizations that represent the victims are usually community groups , NGOs and other international bodies. The ' polluters ' are the industry groups and also vehicle–owners – but the latter is usually ill-represented. Thus there are typically a large number of organizations involved in policy making. Firstly, the activities of these organizations have to be co-ordinated to avoid a wastage of resources or conflicts. Secondly, the policy-makers should maintain a complete transparency with regard to their actions, and should therefore inform and educate the public and its representatives on the one hand, and industry, on the other. Thirdly, they should involve both the victims and the polluters in decision-making : through discussions, debates and consensus-building. It is important to recognize the necessary tradeoffs between groups and even consider possible compensations. However, the issue of public involvement is not a simple one. Whereas a participatory approach truly serves the public , it is also difficult to carry out and may waste time and create significant lags in decision making. This is the main reason why in the developed countries the public has largely not been directly involved in pollution abatement. although it has indirectly imposed strong pressures for such abatement through public opinion

F. A Data Bank

Not enough attention is paid to this very basic tool of emissions control. Without a data bank, none of the other policies can be implemented. The function of collecting and analyzing data can be carried out by government departments, research institutes or NGOs. Each organizational type has its advantages and disadvantages. If a set of organizations are involved. it should be ensured that there are no overlaps in the tasks undertaken by the various organizations. Most crucial are data on environmental (air) quality, transport characteristics, air pollution sources, pollution sensitive population groups and areas, costs of control measures and the health effects of various pollutants or of ambient air quality. Finally, it should be noted that some policies may be conflicting , such as carpool versus *flextime* hence the formulation of a complete package with complementing or at least non-conflicting policies is crucial. The other aspect that should be kept in mind is the *induced demand* for more vehicles and trips : many of the policies would have induced demand effects in the longer run, but some (such as new roads) more than others. For all policies, thus, the possible impact on induced demand should be taken account of Policies aimed at reducing travel demand (in the aggregate) would be best in this respect. Finally, as discussed earlier , steps should be taken to develop an international level co-ordination of air quality emission limits and other measures.

V

The Economics of Pollution Control : the Theory and its Application.

The two most crucial variables in pollution control theory are the costs and benefits of pollution abatement. How, in practice, are these measured ? Ideally, the true cost is reflected in opportunity cost, but a more practical approach is to simply obtain a monetary value of expenses incurred for pollution abatement. Costs for transportation related air pollution control are borne by (a) the government, (b) industry (both vehicle and fuel) and (c) the vehicle owners. The states' costs are mainly for enforcing the regulations. The company's costs are in the form of equipment for pollution abatement and taxes. These costs may be passed forward to vehicle-purchasers in the form of higher prices, but if the demand for vehicles goes down (due to higher prices), it is passed backward to the workers in the form of unemployment or lower wages. For the industry as a whole, there may be a long-run effect on the number and size of firms. The vehicle owners face costs in the form of various taxes and fines. Moreover, the reduction in the use of transportation or modal shifts have their own costs. As already mentioned, the companies may shift some of their cost burden to the vehicle-purchasers in the form of higher prices. It is crucial to note, however, that taxes or fines (imposed on producers or consumers) are not a cost for society as a whole, as they are used – sometimes even to carry out other pollution controlling activities.

There may also be indirect costs in the form of losses borne by the economy – for example, a reduction in the use of transportation due to increases in fuel prices may reduce national product and may even impact capital accumulation and technical innovation. Other sectors related to the transportation sector may be affected by environmental policy [1]. Moreover, there may be *environmental* costs accompanying pollution-control activities – examples, the reduction of lead in petrol has required the addition of other compounds which have their own negative effects on air quality. Finally, the state or the companies bear costs in carrying out research and development. (R&D). However, some of these short run costs may reduce vehicle production costs in the long run : hence R&D should be an individual category.

The indirect costs are difficult to evaluate , but direct costs may be obtained relatively easily if specific expenditures on pollution abatement (such as engine design changes, tailpipe attachments, catalytic converters, inspection and maintenance, research for pollution abatement, wages of the regular police force, expenses on employer-based HOV programs and so on) can be isolated from other expenditures. However, the task is not simple and a considerable amount of effort has been expended on measurement – most of it in the developed countries.

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1. Macro-modeling the effects of environmental action has shown that in many developed countries, GDP has actually increased, and in some countries it has decreased marginally.

Benefits are typically given by the damages that are borne, if the abatement does not take place. The fact that vehicular air pollution is largely non-cumulative and local (the exception for this is mainly the global warming caused by carbon dioxide) makes it easier to determine damages. The most major damage is in terms of health effects (both mortality and morbidity), but there are other damages , for example to agricultural production, to man-made structures, to biodiversity and to the global climate. Most of the measurement concentrates on health effects, however. These health effects are measured using medical costs, loss of lives and loss of labour productivity (reduced man-days). Clearly, the measurement of damages and hence abatement benefits is more approximate and more difficult relative to costs, because much of it is very qualitative or even when quantitative, difficult to isolate. Moreover, the relationship between emissions and health effects is quite complex because the same level of emissions may lead to different levels of air quality due to differences in temperatures, geographical configuration, etc. and the same air quality may have different health effects due to differing exposure levels.

Other methods of calculating benefits are measuring (a) the willingness to pay for pollution reduction (contingent valuation) or (b) the willingness to accept pollution. Here the victims of pollution are asked how much they would pay, if they had to , to abate pollution or how much they would accept as compensation for polluted air. In theory these two should give the same result, but in practice (b) is higher than (a), because in the first circumstance the polluter may not be willing to reveal his true preferences, due to the suspicion that this may be used for determining future taxes. Also, whereas ' willingness to pay ' is based on the income of the respondent 'willingness to accept ' is not similarly constrained. Both these methods, moreover, yield very approximate results because the victims may not be fully informed of the consequences of pollution or may not know their true preferences. There are also indirect methods of finding out the willingness to pay, such as the cost of travelling to cleaner environs, differential house values or wages and the willingness to pay for *avoiding* health problem, but these yield approximate results.

It must not be forgotten that there is an industry that completely benefits from pollution abatement : the pollution-control industry. For vehicular air pollution, this industry would consists of all the vehicular parts that are necessary for abatement, the inspection and maintenance units, cleaner fuels or fuel additives, etc. Further, those who are employed by the state for regulatory or planning activities are also beneficiaries.

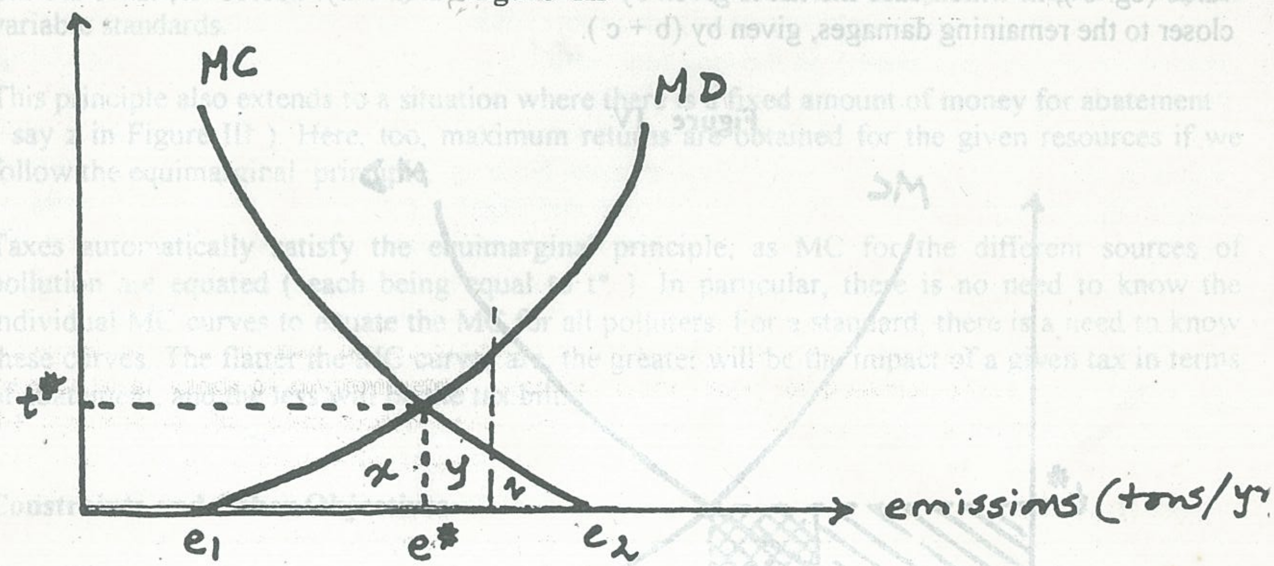
For vehicular pollution, there is a need to distinguish between industry and vehicle-owners. and between the two branches of industry – vehicle-producers and fuel-producers. Standards and taxes are imposed separately for these various groups. In particular, there are separate standards for new and old cars. Standards on fuels and on vehicles are obviously not the same as they are different products altogether. In our theoretical analysis however, we look at single cost and benefit functions. We may assume that these functions represent any one of the groups mentioned or some combination. The latter analysis is also necessary - particularly in order to see how much of the abatement should be the responsibility of each group.

However difficult it may be, in practice, to measure costs and benefits (and this difficulty extends to all kinds of environmental measures), the theory of pollution abatement is based on the assumption that costs and benefits are measurable, and cost and benefit (or damage) functions can be drawn with respect to the level of emissions. Let us , also, make this assumption.

Efficiency

From the total cost and damage functions we can derive marginal cost and damage functions with respect to emissions – see Figure III.

Figure III



It must be noted that the marginal cost function is obtained by the horizontal summation of individual marginal cost functions , where ' individual ' might mean the state , industry and vehicle-owners or even each firm or vehicle-owner.

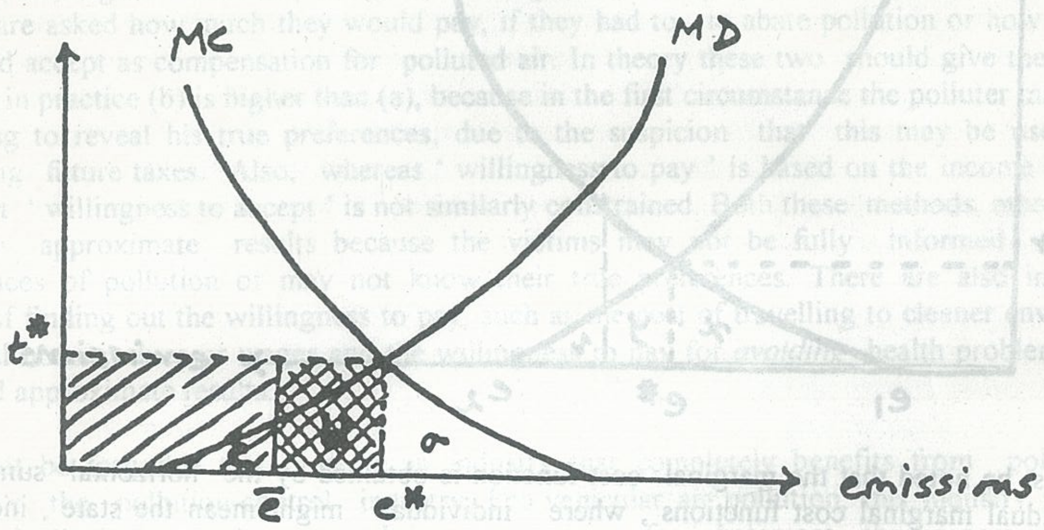
e_1 is the emission level for which there is no damage, and e_2 is the emission level without control. Efficiency is defined as that level of emissions for which marginal damage equals marginal cost (e^*). At e^*, the area **x** represents total damages and y the total abatement cost. (x+y) is the total social cost and this is minimized at e^*. Hence , the aim should be to reduce emissions to e^* and thus abate ($e_2 - e^*$)

Thus, if standards are imposed , these should be at e^*, if efficiency is the only consideration. At a standard of e^*, the cost incurred by the polluters is given by y. A standard is simple and direct, and allows for more flexibilities—hence it is more practicable. But there is always a possibility of non-attainment—as has been the case for the U.S.

But how about taxes (or subsidies)? Here we shall talk about direct taxes on emissions only – but later other kinds of taxes will be discussed. The tax should be t* (see Figure III), as the polluters would equate t* to MC in deciding how much they should abate, for this minimizes their total cost of abatement and tax payment. Hence, only at t*, MC = MD. Thus t* ensures efficiency. This argument assumes, however, that there is enough competition so that firms have enough incentives to minimize costs because they cannot pass on the higher non-abatement costs to consumers.

We shall subsequently discuss the relative merits of taxes and standards, considering a variety of criteria or situations other than efficiency. It suffices here to note that taxes are more costly from the point of view of the polluters relative to standards, for they have to incur the same abatement costs as in the case of an efficient standard (e*), and also pay taxes. In Figure IV, a is the abatement cost for both, but for taxes, there is an additional payment equal to the striped and checked areas. This payment may be reduced if the tax is on emissions *exceeding* a certain value (eg. $\bar{e}$), in which case the tax is given by the checked area only. Moreover, taxes are then closer to the remaining damages, given by (b + c).

Figure IV



However, it must be recognized that taxes are not a cost to society as a whole – they are simply a transfer payment. And if these tax revenues are used for mitigating pollution in other ways, they add to environmental benefits and hence do not affect the cost-benefit accounts at all.

Subsidies (on abatement) have the same effect, in terms of incentives, as taxes. However, instead of a cost, the firm now makes a revenue. The ensuing increase in profits may have a long-run impact of more firms or more vehicle-owners, causing greater emissions as a whole. For example, a subsidy for the purchase of low-emission cars would result in more such cars being sold relative to the tax scenario, causing more pollution.

The Equimarginal Principle

We have obtained the efficient level of *total* abatement. But how much should each polluter abate ? That is, how do we divide up this total abatement ? The least costly way to do so would be to equate each marginal cost : as the MC curves of each polluter looks different, the abatement levels of each would be different for the same total MC. This is the equimarginal principle. The principle implies that equal or even equiproportionate cutbacks are not desirable. Those polluters whose costs increase at a lower rate should bear a greater burden of abatement.

Thus the equimarginal principle would imply that older cars should have higher standards (lower abatement). Also standards should be higher for greater population densities – hence standards should be stricter in high-density urban areas. However, it is more costly for the state to impose variable standards.

This principle also extends to a situation where there is a fixed amount of money for abatement (say z in Figure III). Here, too, maximum returns are obtained for the given resources if we follow the equimarginal principle.

Taxes automatically satisfy the equimarginal principle, as MC for the different sources of pollution are equated (each being equal to t*). In particular, there is no need to know the individual MC curves to equate the MC for all polluters. For a standard, there is a need to know these curves. The flatter the MC curves are, the greater will be the impact of a given tax in terms of abatement, and the less will be the tax bill.

Constraints and Other Objectives

The efficiency solution and the equimarginal principle form the core model for pollution-control policy. They tell us, very simply, how much of emissions we must " optimally " reduce and how much of the burden should be borne by each polluter. The policy-makers' job, then, is very simple. He either specifies the minimum level of emissions (i.e sets standards) given by e* or imposes taxes to achieve this (what this tax should be will be discussed shortly). Why, then, do countries have such a complicated mix of policies and why are these policies changed all the time ? The reason is that real life is not as simple as the model. Firstly, we may have objectives other than those dictated by efficiency considerations. Secondly, we may not really know what the MC or MD curves look like. Thirdly, individual emissions specifications do not determine the total emissions. In particular, the total miles traveled by vehicle-owners cannot be directly controlled by the state. Also, when emissions regulation is freshly imposed, there are vehicles that are already on the streets (" old " vehicles) and it would be impossible to impose the same regulations on these as on new cars.

Let us discuss what other objectives there might be, apart from efficiency considerations . First, the distribution of costs and benefits between industry, the vehicle-owners, other citizens and the state is important from the point of view of equity. The fact that the vehicle-owners (polluters) are also the victims of pollution, is interesting for transportation-related air pollution. Also, the distribution of benefits (and costs) between the affluent and the less affluent - i.e. between income classes, is a crucial aspect. There may or may not be a conflict between efficiency and equity – if there is, the question arises as to what weight we should put on equity or other moral considerations.

Ethically, regulation is more clear-cut as it directly controls the activities of the polluters. However, for transportation –related pollution, the more serious polluters amongst the vehicle owners are those who have very old cars. But these people are also the ones who can least afford to buy new cars. Hence, scrapping policies or the higher taxation of owners of old vehicles may be considered to be regressive. From a moral point of view, moreover, taxes are more acceptable as they punish the polluters , relative to subsidies. Yet subsides are often used because they yield quick results and compliance is not a problem.

Second, care should be given to ensure that no constraint is put on technological innovations to reduce the cost of compliance. In the long run, research as well as education and training bring down the marginal cost curve.

Third, it is one thing to impose restrictions or taxes, but another to ensure that these are complied with. Enforcement involves both monitoring and legal processes. Monitoring costs are significantly lower if the firm keeps its own records and these are trusted. The reduction of enforcement costs sometimes justifies the use of less ‘ perfect ’ and simpler policies which are not easy to evade. As enforcement costs shift MC to the right, this implies a higher level of emissions at MC = MD, ie. at efficiency. The enforcement component of the MC curve may become very steep after a certain level of abatement – this may imply that one should not go above that level.

Political constraints are also a crucial factor in determining the policy-mix. Standards are politically more acceptable than taxes. So are subsides. Some of the other tools that will be discussed later, such as Tradable Discharge permits (TDPs) or Travel Demand Management, are also politically more acceptable.

Fourthly, there may be limitations imposed on the model if a ceiling is placed on emissions by health authorities and this ($\bar{e}$) is lower than e* (see Figure IV) Alternatively there may be a limit on total expenditures (and hence cost) that is less than the efficient level (y) – given by z (see Figure III). In both situations, we have to deal with inefficient solutions and the objective should be to try to *approach* the efficient solution as far as practicable. In such situations all that can be done is to minimize MC for a given level of e (1st case) or minimize e for a given level of MC (2nd case). This brings us to looking at *cost-effectiveness* (minimization of cost subject to given emissions or maximization of emissions reduction subject to given cost). Most of the available data, in fact, is on cost effectiveness.

The argument for studying cost-effectiveness becomes stronger when we recognize the fact that the MC and MD curves are usually not known and this is all the more true for vehicular pollution. In such circumstances, the minimization of cost should be the main objective. Cost-effectiveness would at least take us on the minimum marginal cost function. It is *necessary* for efficiency but of course, it is not *sufficient* for efficiency.

Moreover, even if MC and MD are known for the present, the future involves uncertainty regarding the preferences of future consumers, regarding future population growth and technological improvements. The position taken by policy makers may be risk-neutral, in that case, using expected values of uncertain variables , or risk-averse, where dangerous situations, even if improbable, are avoided. The latter should be the policy for eventualities like global warming. Some countries carry out " scenario analyses" where outcomes are measured for different scenarios based on different assumptions.

It is also important to determine how important the future is, and hence what should be the discount rate for future benefits and costs. One strategy is to ensure sustainability for the future, i.e. ensure that there is no reduction in long-run environmental services. Largely, transportation related policies are undertaken with only the present in mind. However, some consideration for future consequences is possibly imperative, given the threat of global warming.

Finally, in the context of controlling the total vehicle miles traveled, we have to avail of demand-management techniques. This will be discussed at length when we discuss control methods other than standards or taxes.

Standards versus Taxes

We have already discussed a few of the advantages and disadvantages of standards and taxes. From an efficiency point of view, taxes appear to be more appealing. However, let us now look in detail at the other objectives or constraints of a real-world scenario mentioned above, to evaluate the relative merits of standards vis-à-vis taxes.

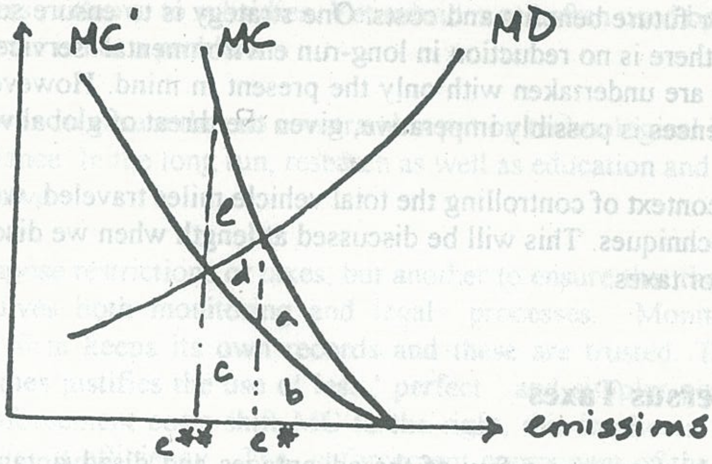
Equity

The *benefits* of pollution-abatement would accrue more to persons who are more on the streets and to young children, but in general, all citizens would get significant benefits in terms of improved air quality . The distribution effect in terms of abatement *costs* would depend on *who* faces the standards or taxes, and how many different standards or taxes are imposed. Standards or taxes may be imposed on car production (affecting producers) and on vehicles based on the year of purchase (affecting consumers). However, the ultimate impact of taxes or standards on car producers would depend on whether they are passed on to vehicle purchasers in the form of a price hike or to workers in the vehicle industry (this will depend on competitive and demand conditions). Also, the impact of taxes will depend on how the tax revenues are spent - whether they are used for other environmental programs, whether they are given to firms to buy pollution control equipment or whether they are distributed to lower-income people. Taxes are convenient for the state as enforcement costs may be met from revenues.

Technological Change and Innovation

Standards and Taxes have different impacts in creating incentives for research and development. To see this, let us assume that with technical improvements, the MC curve shifts down from MC to MC′ (see Figure V). If the standard is set at e*, with MC the cost of abatement is a + b, but with MC′ it is only b – hence, there is an incentive for technical change. If, however, after the technical change takes place, the standard is shifted to e**, the cost will be (b + c) and hence

Figure V

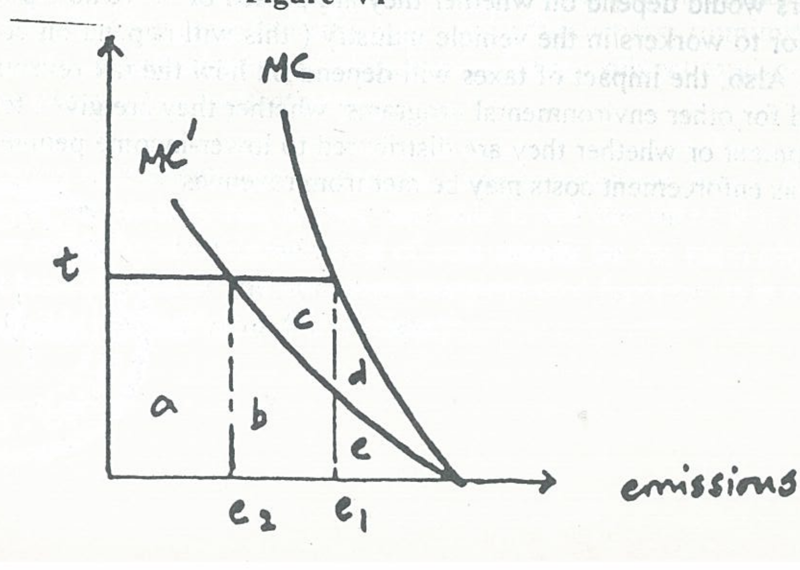


the difference will be [(a+b) – (b+c)] which is (a-c) : as (a-c) may be negative , cost may even be higher with technical change. Hence, there would be no incentive to carry out the technical change.

Standards are " technology-forcing " when from the very start the standard is set at e**. In that case, the cost with MC is (a+b+c+d+e) and with MC′ is b+c, hence the difference is (a+d+e) – thus there would be an incentive to innovate. Much of the U.S. standards policy has been technology-forcing. It should be noted that research can be carried out by the state or by the pollution-control industries - they need not always be carried out by the polluting (vehicle) industry.

On the other hand, with taxes t, the cost would be [(d+e) + (a+b+c)]. (see Fig. VI).

Figure VI

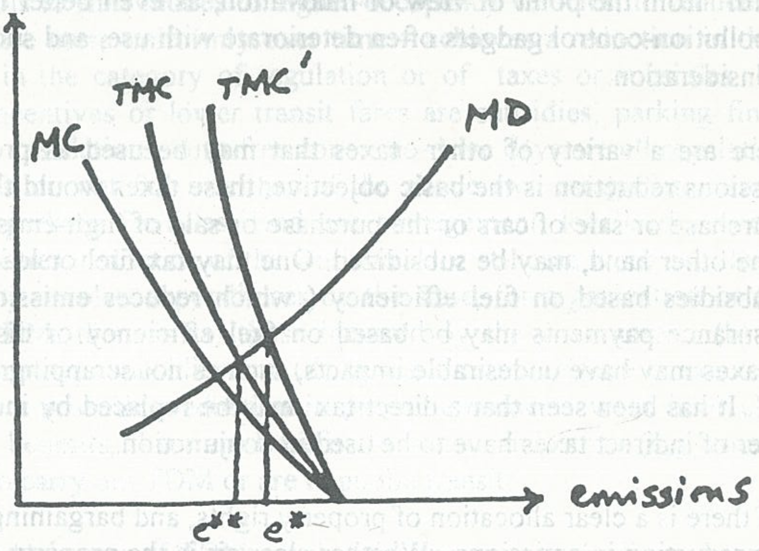


If innovation brings down MC to MC′, cost reduces to [(b+e) + a] (with a reduction in emissions, too, from e_1 to e_2), so that the drop in cost is (c+d) . Hence , taxes are a better incentive for innovation. In addition, emissions automatically decline with innovation, which is not the case under standards.

Enforcement

Enforcement can be easier with standards as checking need not be so regular and can be as frequent as allowed by finances. This is one reason why standards have been popular in many countries. Also, given that standards are chosen as the regulatory strategy, the *level* of standards should be set with enforcement costs in mind. In other words, the marginal cost of enforcement should be added to MC to obtain the 'total' MC, and then the desirable standard is given by the intersection of MD with the 'total' MC. (see Fig. VII). Higher is the enforcement cost (TMC′ vs. TMC), lower is the optimal abatement.

Figure VII



Part of the funds for enforcement can be collected by imposing fines on polluters. However, these fines should also not be very high as courts then become reluctant to impose them on defaulters. Thus, it is important to strike a balance between standard-setting and enforcement considerations. Another problem that is often encountered is that whereas the standard is set by the central government, it is enforced by the state. The former often does not consider costs, therefore. This often results in excessive dilution of the importance of standards at the local level. Hence enforcement costs should be an important consideration in setting lower standards. From the point of view of enforcement, taxes are more difficult as there is a need to constantly monitor the emissions.

Uncertainty

Taxes are better than standards when there is little or no knowledge of MD or MC. First, the imposition of an *efficient* standard requires the knowledge of both MC and MD . Moreover, how the abatement should be divided *between* the polluters is determined by the individual MC curves, which should therefore be known . With taxes, however, although the optimal tax is not obtainable without both MC and MD curves, any tax will automatically ensure the equimarginal principle as all polluters will abate till their MC is equal to the tax rate. Of course, the level of abatement achieved is totally unknown under the circumstances, whereas standards directly determine this level. One possibility is to set the tax, see the impact and accordingly take the next step, but such a process of successive approximation can be constantly jarring for the economy.

Other Tools for Pollution Abatement

a) *Technology Standards* – this specifies, exactly, the technology that should be used for abatement. This method has often accompanied general standard-setting . Technology standards are harmful from the point of view of innovation, as even better methods cannot be used. Also, the pollution-control gadgets often deteriorate with use, and such standards do not take this into consideration.

b) *Other Taxes* - there are a variety of other taxes that may be used as proxies to taxing emissions. As emissions reduction is the basic objective, these taxes would then be indirect. One may tax the purchase or sale of cars or the purchase or sale of high-emission cars. Low emission cars, on the other hand, may be subsidized. One may tax fuel or leaded fuel. There may be taxes or subsidies based on fuel efficiency (which reduces emissions per vehicle mile traveled). Insurance payments may be based on fuel efficiency or distance traveled. However, indirect taxes may have undesirable impacts, such as not scrapping old cars (if car purchase is taxed). It has been seen that a direct tax may be replaced by indirect ones, but in that case a number of indirect taxes have to be used in conjunction.

c) *Property Rights* - if there is a clear allocation of property rights, and bargaining is introduced, this would lead to a reduction in emissions. Whether clear air is the property of the polluters or of the victims, the result would be the same. In the real world, however, such rights can rarely be clearly defined for things such as air quality ; there is a free-rider problem for open-access goods such as air. Moreover, negotiation between so many different players is close to impossible.

However, a new kind of property right called " Tradable Discharge Permits " (TDP) can be created and distributed . Each permit allows the pollutant to emit one "unit " The total number of permits are fixed, and this fixes total emissions at the desirable level. These permits are transferable amongst the participants. TDPs satisfy the equimarginal principle, as the buying and selling goes on until marginal costs are equated amongst the players. This method, though impossible to apply on vehicle owners due to their large number, may be applied on the vehicle-producing firms. It is politically more acceptable than taxes and achieves the same results. Clear trading rules should be set, and the monitoring of emissions is crucial. But the system is such that mutual monitoring is encouraged. The distribution effect is determined by the initial allocation of the permits. TDPs are becoming quite popular in many of the developed countries.

d) *Phasing out* - the scrapping of old cars is encouraged by making a payment for such scrapping. This involves a cost for the state, but the cost may be recovered by taking a deposit at the point of sale of a car, with the promise of refunding this deposit when the car is scrapped. This system has been adopted in certain European countries.

e) *Transportation Demand Management* . The various components of demand management have been discussed in the last chapter. Here we shall discuss how this aspect may be incorporated in the theory of pollution control.

The final product, here, is the service provided by transportation and the consumer is the purchaser of this service. The attempt in demand management is to reduce the use of this service. The abatement, here, is not through the use of devices to reduce the emissions of each vehicle, but to reduce the number of vehicle miles traveled. Emissions standards or taxes may or may not achieve this reduction, though they reduce the emissions per vehicle. But demand management , which uses tools to shift modes to higher-occupancy vehicles, to reduce the use of vehicles and to spread the use more uniformly over time – achieves a reduction in the *total* emissions. The tools may be in the category of regulation or of taxes or subsidies. For example, employer ridesharing incentives or lower transit fares are subsidies, parking fines or road charges are taxes. Parking restrictions, auto-free zones, no-drive days are all regulations. Additionally, there are tools which do not fall in either of the above two categories – such as improving public transit, fringe parking facilities, land use management, localized school systems, bicycle and pedestrian facilities, reduction of the work week or at-home work and flexible work hours. These would generally involve expenditures by the state, for organization or for capital and labour . The cost of TDM, then, is (a) those incurred by the government, (b) fines paid by vehicle owners, (c) employer subsidies and (d) losses in terms of time or convenience due to shifts to HOVs and (e) a *possible* reduction in production due to work hour changes. Apart from the environmental benefits, there are benefits to certain industries (e.g. construction) and to state employees who carry out TDM or are in public transit.

The main disadvantages of TDM are that the impact is sometimes uncertain and that it is costly for the state. But some of the programs may not involve costs (such as work week reduction) or only labour costs. Its advantage is that it directly addresses the problem of *total* emissions, and that it is politically more acceptable as it involves little or no expenditure on the part of industry or the vehicle-owners.

f) *Traffic Systems Management* -Tools which fall under this category simply improve traffic flow, thus preventing congestion and very low speeds which increase certain emissions per unit VMT. Improving traffic conditions is necessary per se ; it also has positive impacts in terms of emissions reduction. However, it is undesirable to lay much stress on flow improvements purely with the objective of emissions reduction , as (i) better road conditions induce a greater use of SOVs, and (ii) much of it is capital intensive and the expenditure is incurred entirely by the state.

g) *Moral Suasion* - Trying to affect the moral consciousness of the vehicle industry or the vehicle-owners is a method that is not unknown. This method may be effective for vehicular pollution, as the polluters are also the polluted. The impact is an uncertain one, as economic behaviour can often be conveniently isolated from moral behaviour. It would help to give exact information regarding the serious health effects of air pollution - especially on children. The cost is largely in terms of advertisement , borne by the state or by NGOs. These costs can be quite high.

VI

Costs, Benefits and Cost-Effectiveness : the U.S. Experience.

As already mentioned in the last chapter, it is difficult to get data on costs and benefits for each level of abatement. However, information on costs and benefits for particular abatement strategies, and especially, on cost-effectiveness, can give us a good idea of policies that should be taken up. In particular, one can make comparative assessments of the various tools that have been brought up so far.

The data that I shall present is from a variety of sources – hence it is not always comparable - the units differ, or the year. Moreover, 'cost' or 'benefit' may be defined differently – sometimes 'cost' is calculated net of benefits other than environmental benefits, sometimes 'benefits' include these 'other' benefits. Often benefits are given in terms of emissions reductions, and not in monetary terms. Some analyses have included cost-effectiveness measures and some have not. All the same, a good idea of the rank of the different tools in terms of feasibility and returns can be obtained from the data.

Firstly, what are the estimates of total cost and total benefit, and is the latter greater than the former ? A conservative estimate of the annual health costs due to motor-vehicle related air pollution in the U.S. is calculated as $ 10 billion (13). Another estimate, which includes damage to materials and other factors, give the range as $ 10 to $ 200 billion per year. This significant range is because of uncertainties regarding the number of deaths and illness due to pollution and the monetary value that can be assigned to them (14). A 1989 study for just the Los Angeles area gives benefits of $ 1.5 to $ 7.4 billion per year (15).[1] A major study by the EPA for the 20-year period 1970-90 gives cost figures (capital – pollution abatement equipment - and operation and maintenance –including inspection costs, higher fuel prices for unleaded fuel and fuel economy penalties) which are actually *negative* for 1990 (-1816 million dollars) (see Table 9) because of savings due to maintenance and fuel density economy. However, these cost figures clearly do not include certain monitoring costs and demand management costs.

The disadvantage of the EPA study is that it mainly looks at the benefits and costs of pollution control as a whole - not just motor vehicle pollution. However, some idea of the contribution of motor vehicles scenario may be gleaned by looking at the reductions in emissions of *specific* pollutants. In the 20-year period, sulphur dioxide emissions were 40 percent lower but only part of this was due to low sulphur fuels. Nitrous oxide emissions were 30 percent lower, mostly due to the installation of catalytic converters on vehicles. Particulate matter emissions , in terms of emissions of primary particles, were 75 percent lower but this was largely due to industry. But suspended particulate matter reduced by 45 percent, due to reduction not only of primary particles but

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1 It should be recognized that the distribution of damages tends to be heavily weighted around larger cities.

Table 9

Estimated Capital and Operation and Maintenance Expenditures for Mobile Source Air Pollution Control (millions of current dollars).

Year	Capital	O&M
1973	276	1,765
1974	242	2,351
1975	1,570	2,282
1976	1,961	2,060
1977	2,248	1,786
1978	2,513	908
1979	2,941	1,229
1980	2,949	1,790
1981	3,534	1,389
1982	3,551	555
1983	4,331	–155
1984	5,679	–326
1985	6,387	337
1986	6,886	–1,394
1987	6,851	–1,302
1988	7,206	–1,575
1989	7,053	–1,636
1990	7,299	–1,816

Source : U.S. E.P.A., The Benefits and Costs of the Clean Air Act. 1970 to 1990, 1997.

also of sulphur dioxide , nitrous oxides and volatile organic compounds (VOCs). On the other hand, lead emissions reduced by 99 percent and this was nearly wholly attributable to the use of leaded gasoline. Further, carbon monoxide and VOC Emissions were 50 percent and 45 percent lower, and this was primarily because of motor vehicle controls. The reduction of ground level ozone, due to reductions in VOCs and nitrous oxides, was calculated to be about 15 percent .

The above-mentioned pollutants have had the greatest impacts in terms of physical consequences. The contribution of the individual pollutants is indicated in Table 10.

This shows that the role played by particulate matter is very significant. Another estimate of the benefits per 10,000 miles displaced of the reduction in VOCs, particulates, sulphur dioxides (heavy duty diesel and light duty diesel) and lead that have been achieved are $2, $39, $7 and

Table 10

Total Estimated Monetized Benefits for 1970 to 1990 (in billions of 1990 dollars).

Endpoint	Pollutant(s)	Present Value ($)
Mortality	PM	16,632
Mortality	Lead	1,339
Chronic Bronchitis	PM	3,313
IQ (Lost IQ Pts.+ Children w/Lead IQ < 70)		399
Hypertension	Lead	98
Hospital Admissions	PM, Ozone, Lead, & CO	57
Respiratory-Related Symptoms, restricted Activity & Decreased Productivity	PM, Ozone, NO2 & SO2	182
Soiling Damage	PM	74
Visibility	Particulates	54
Agriculture (Net Surplus)	Ozone	23

Note : All of these summary results are present values of the 1970 to 1990 stream of benefits and costs, discounted at five percent.
Source : U.S.E.P.A., The Benefits and Costs of the Clean Air Act, 1970-1990, 1997.

$12 respectively. Nitrous oxides have little direct effects, and the impacts of carbon dioxide and ozone are also not significant. This confirms the greater need to reduce particulates and lead. Hence we can only conclude that motor vehicle pollution abatement had an important contribution to the total benefits of 22.2 trillion dollars (a mean estimate) over the 20-year period (1970-90). For Germany it is seen that the costs of air pollution from transportation constituted 46% of estimated costs from all pollution sources. It can perhaps be assumed that transportation accounts, in general, for 40-50% of total pollution. The costs, in this period, were a total of only .5 trillion dollars. Hence, benefits were far greater than costs (16).

Moreover, certain environmental effects such as global warming are not accounted for in these figures. A 1992 OECD study shows that damage costs for the results of a doubling of carbon dioxide are $62 billion for the U.S. annually (1990 prices), which is 1.1% of its GDP. This value rises sharply if a longer time frame is taken (17).

Let us now look at the costs, benefits and cost effectiveness of individual tools. Let us note at the outset that some of the programs involve low expenditures, but the returns may be low or high. Others involve high expenditures, with low or high returns. Then again, there are programs which recover the costs, either through benefits other than air quality (such as decreases in fuel expenses due to fuel efficiency or decline in vehicle miles traveled), or through taxes (in which case the State does not have to spend from other revenues). It is crucial to keep in mind these features of a particular program.

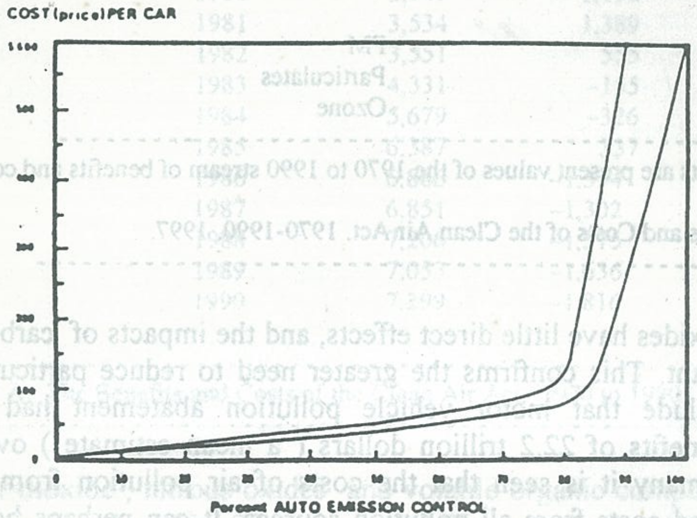
We will first look at individual policies, and then later, go over certain comprehensive studies undergone by researchers.

Technological Changes in the Vehicle

Cost figures for vehicle changes show a sudden hike in expenses for higher levels of control. This is demonstrated in Figure VIII.

Figure VIII

Estimated Cost Price Per Car to Control Auto Emissions



The following figures for vehicle modifications are taken from Faiz et al (18) For light duty gasoline fueled vehicles, the following gives the costs and returns of changes in the vehicle for various categories of control (1995) :

The oxidation catalyst technology appears to have the highest cost – effectiveness, if we look at the percentages controlled. The simpler controls were used in the U.S. and Japan in the 1970s, but in Europe they were applied even in the 1990s. The three-way catalyst system is currently applied in Japan and E.C.E. The lead burn engine system gives better fuel economy and lower carbon monoxide emissions. The last one requires technology that is not yet developed, or alternative fuels. It should be noted that unleaded fuels require catalytic converters.

Less attention has been paid to heavy duty gasoline fueled vehicles, due to their small number – hence the standards for these are less strict. The cost, for each of the categories, is 50 to 100% more because of the larger size of the equipment. However, the same technologies listed above may be used. The heavy loads involve a catalyst durability problem.

Table 11

Exhaust Emission Control levels for Light-Duty Gasoline-Fueled Vehicles

Control level	Emission standard: Grams per kilometer[a]	Emission standard: Percent controlled[b]	Controls required	Fuel economy (percent)	Estimated cost per vehicle (U.S. dollars)
Non-catalyst Controls	Hydrocarbons-1.5 Carbon monoxide-15 Nitrogen oxides –1.9	66 63 11	Ignition timing Air-fuel ratio Air injection Exhaust gas circulation	-5	130
Oxidation catalyst	Hydrocarbons –0.5 Carbon monoxide-7.0 Nitrogen oxides-1.3	89 83 39	Oxidation catalyst Ignition timing Exhaust gas recirculation	-5	380
Three-way Catalyst	Hydrocarbons-0.25 Carbon monoxide-2.1 Nitrogen oxides –0.63	94 95 71	Three-way catalyst Closed-loop carburetor or electronic fuel injection .	-5(carburetor) 5 (electronic fuel injection)	630
Lean-burn engine	Hydrocarbons-0.25 Carbon monoxide-1.0 Nitrogen oxides 0.63	94 98 71	Oxidation catalyst Electronic fuel injection Fast-burn combustion chamber	15	630
U.S. tier 1	Hydrocarbons –0.16 Carbon monoxide-1.3 Nitrogen oxides-0.25	96 97 88	Three-way catalyst Electronic fuel injection Exhaust gas recirculation	5	800
California Low-emission vehicle standard	Hydrocarbons –0.047 Carbon monoxide-0.6 Nitrogen oxides-0.13	99 99 94	Electric three-way catalyst Electronic fuel injection Exhaust gas recirculation	Unknown	More than 1,000

a. At 80,000 kilometres ; b. Compared with uncontrolled levels
Source : Faiz et al, Air Pollution from Motor Vehicles, p. 75

The reason for lenience in or no control on motorcycles and three wheelers is because controls are costly or difficult to install on small, heavily loaded engines, and because these modes are not predominant in the industrialized countries. However, their importance in Asian countries very significant. Costs and emissions reductions for Thailand and given in Table 12.

The first-level control involves a cost of about $ 60, yet can achieve a 90% reduction in emissions of hydrocarbons and particulate matter – which are the main culprits. Catalytic converters have been used on two-stroke motorcycles in Taiwan and on mopeds in Austria and Switzerland. A combination of catalyst and four-stroke engines has not been adopted anywhere.

For diesel-fueled vehicles, Tables 13 and 14 give the costs and returns of various control levels. The main pollutants that have to be controlled are nitrous oxide and particulate matter . For heavy-duty diesel vehicles, the minimal control level corresponds to California's 1970 engines

Table 12

Recommended Emission Control Levels for Motorcycles in Thailand

Control level	Emission Standard: Grams per kilometer[a]	Percent controlled[b]	Controls required	Fuel economy (percent)	Estimated cost per vehicle (U.S.dollars)
Eliminate Two-stroke	Hydrocarbons – 5.0 Carbon monoxide –12.0 Nitrogen oxides -- NR Particulate matter – 0.15	66 50 50-90	Four-stroke engine on advanced two-stroke	30-40	60-80
Non-catalyst Controls	Hydrocarbons – 1.0 Carbon monoxide --12.0 Nitrogen oxides –0.5 Particulate matter –0.15	90 50 200 50-90	Four-stroke or two stroke with catalyst, ignition timing, air-fuel ratio control	0	80-100
Oxidation Catalyst or advanced technology	Hydrocarbons --- 0.5 Carbon monoxide --2.0 Nitrogen oxides --0.5 particulate matter --0.05	98 80 200 85	Four-stroke or advanced two-stroke,ignition timing, air-fuel ratio control, catalytic converter or electronic fuel injection	–5	80-100

-- Not Applicable.
NR -- Not regulated
[a] At 80,000 kilometres.
[b] Compared with uncontrolled two-stroke
Source : Faiz et al. Air Pollution from Motor Vehicles.

Table 13
Emissions Control Levels for Heavy-Duty Diesel Vehicles

Control level	Emissions limit at full useful life: Grams per kilometer-hour	Grams per brake horsepower-hour	Controls required	Fuel economy (percent)	Estimated cost per engine (U.S.$)
Uncontrolled	Nitrogen oxides –12.0 to 21.0 Particulate matter –1.0 to 5.0	9.0 to 16.0 0.75 to 3.70	None (PM level depends on smoke controls & maintenance level)	0	0
Minimal control	Nitrogen oxides –11.0 Particulate mater –0.7 to 1.0 Peak-smoke--20 to 30 percent opacity	8.0 0.5 to 0.75	Injection timing Smoke limiter	–3 to 0	0-200
Moderate control	Nitrogen oxides –8.0 Particulate matter –0.7	6.0 0.5	Injection timing Combustion optimization	–5 to 0	0-1,500
1991 U.S. standard (Euro 2)	Nitrogen oxides-- 6.7 (7.0) Particulate matter-- 0.34 (0.15) [b]	5.0 0.25	Variable injection timing High-pressure fuel injection Combustion optimization charge-air cooling	-5 to 5	1,000-3,000
Lowest diesel standards under consideration	Nitrogen oxides –2.7 to 5.5[c] Particulate matter –0.07 to 0.13	2.0 to 4.0 0.05 to 0.10	Electronic fuel injection Charge-air cooling Combustion optimization Exhaust gas recirculation Catalyst converter or particulate trap	- 10 to 0	2,000-6000
Alternative-fuel forcing	Nitrogen oxides –less than 2.7	2.0	Gasoline/ three-way catalyst	–30 to 0	0-5,000
	Particulate matter-- less than 0.07	0.04	Natural gas lean-burn Natural gas/three-way catalyst / Methanol-diesel		

Note : Kilowatt-hours are converted to brake horsepower-hours by multiplying by 0.7452.

a. Potential fuel economy improvements results from addition of turbocharging and intercooling to naturally aspirated engines.

b. Euro-2 emissions are measured on a steady-state cycle that underestimates PM emissions in actual driving. Actual stringency of control requirements is similar to that of U.S. 1991.

c. C. Not yet demonstrated in production vehicles.

Source : Faiz et al, 1996.

Table 14

Emission Control Levels for Light-Duty Diesel Vehicles

Control level	Emissions limit at full useful life (grams per kilometer)	Reduction (percent)[a]	Controls required	Fuel economy (percent)	Estimated cost per engine (U.S.dollars)
Uncontrolled	Nitrogen oxides-1.0 to 1.5 Particulate matter –0.6 to1.0	0 0	None (PM level depends on smoke controls & maintenance level)	0	0
Moderate control	Nitrogen oxides –0.6 Particulate matter –0.4	40 33	Injection timing Combustion optimization	-5 to 0	0-500
1988 U.S. standard (EU Directive 91/441/EEC)	Nitrogen oxides –0.6 (HC+NOx: 0.97) Particulate matter 0.13 (0.14)	40 78 ..	Variable injection timing Combustion optimization Exhaust gas recirculation	-5 to 0	100-200
Advanced diesel technology	Nitrogen oxides –0.5 Particulate matter-0.05-0.08	40 92	Electronic fuel injection combustion Exhaust gas recirculation Catalytic converter or particulate trap	-10 to 0	200-500

a Compared with uncontrolled levels.
Source : Faiz et al, 1996.

and Europe's early 1990 engines. The moderate level corresponds to U.S.'s 1990 engines. The U.S. 1991 (or Euro 2) has also been adopted in Canada and Mexico. It requires major modifications in engine design. Major developments have occurred in the area of heavy-duty diesel–fueled vehicles, but they have not been applied extensively. In the case of light duty diesel vehicles, the U.S. has not made much progress because the demand for these is very limited. But they are a large part of the European market – hence technology developments in this fields are expected in Europe. Both categories of diesel vehicles are important for Asian cities. For heavy duty diesel vehicles, the 1991 U.S. standard (involving a cost of $ 1000-3000) or Euro 2 appears optimal and for light duty diesel, the 1988 U.S. standard (involving a cost of $ 100-200) is clearly the best.

Interestingly , a much older OECD study cn costs of emissions control for automobiles and light-duty trucks gives a cumulative cost increase of around $ 230.00 (1972 prices) and a cumulative cost increase of $ 314 between the 1966 and 1975 models (19). These, as proportions of the price of a car in 1972, are much higher relative to the recent cost figures discussed. This indicates significant technological developments. However, such developments are not yet evidenced for diesel vehicles.

It must be recognized that technological developments have also lead to fuel economy – which is an added benefit to vehicle-users, apart from emissions reduction. This seems to imply that the costs are actually *lower* than given in the tables. Whereas in 1967 vehicles gave 14.9 miles per gallon on average, this increased by 83% to 27.3 miles by 1987.

We can conclude that vehicular modification costs vary significantly with the level of modification, and they are very high for high levels. Secondly, these costs have gone down with technological advances. Thirdly, costs for diesel powered vehicles are still high compared to the benefits, but technological advances in this area are expected.

Inspection and Maintenance (I / M)

These costs, obviously, vary widely depending on the type of test, inspection frequencies , vehicles fleet size, etc. They also vary depending on local land and labour costs, and on whether inspection stations (for safety, say) already exist. The two major elements are for inspection and for repair. I/M programs can be centralized or decentralized - in the latter case, both testing and repairs are conducted in private garages. The former may be run by the government or contracted to private operators. Decentralized systems usually involve biased inspections and fraud, and are not suitable for developing countries. The centralized private system is most appropriate for these countries. The average cost of a centralized contractor-run system in the U.S. is $ 8.42 per vehicle, and of a government run system, is $ 7.46. The centralized system has higher initial costs . Thus, even if a government-run system is cheaper in the long run, it is feasible to contract I/M facilities. Costs for decentralized systems include licensing and certification of repair facilities. Also, the operating costs of these systems is usually higher due to diseconomies of operating at a small scale. Roadside smoke inspection programs have much lower costs, are more cost-effective, and are least capital-intensive. Such a program has been adopted in British Columbia (Canada). For 1995 , the U.S. E.P.A. has calculated repair costs to be $40 - $ 250. Colorado's program gives an average repair cost of $ 186 (1996) for vehicles which fail inspection , and of $ 86 for older vehicles. The average repair cost for diesel fueled vehicles is $ 97. Repair costs vary significantly, and the data is distorted by warranty coverages by vehicle companies. The above data does not include fuel saving. The cost-effectiveness of an enhanced I/M program is given as $ 500 per ton of hydrocarbons reduced. But less effective and more expensive programs may involve a cost of $ 15,000 per ton (U.S. EPA, 1995). For heavy duty diesel vehicles, the cost per ton of PM reduced is $17,000 (if it is an on-road smoke patrol) to $ 64,000 (for an advanced system) in 1994. A World Bank study shows a cost of $ 839 per ton in Mexico City for a centralized program for high-use commercial vehicles, $ 1720 per ton for a centralized program for private passenger cars, and $ 2056 per ton for decentralized passenger car programs (20).

Let us also look at older data. For 1969, costs of various levels of inspection and maintenance are given as $ 4 to $ 60, with a reduction if $ 9 for fuel savings. The reductions in emissions, achieved with retrofit and tune-up , are on average 34% for hydrocarbons , 18% for carbon monoxide and 20% for nitrous oxides. The cost-benefit ratios show that the simplest system involving expenditures of $ 4- $ 7.50 is much more cost-effective (21). 1981 data gives us an average cost inspection about $10, and average repair costs for failed vehicles of $ 25 - $ 30. Cost effectiveness figures for I/M are $ 53 per ton of carbon monoxide and $ 581 per ton of hydrocarbons (22). A program of I/M with a simple idle test is stated to be capable of reducing carbon monoxide emissions by 37% and hydrocarbons emissions by 39% (1987)·from pre-1981 vehicles, and 28% and 12-29% for post-1981 vehicles. Another data for 1981 gives an average cost of an I/M program at $ 13.5 per vehicle but a net cost of $ 10.8, due to fuel savings of $ 2.7(23).

It is difficult to compare the older data (1969/1981) with the new, especially as the cost definitions are somewhat different. But we can conclude that whereas inspection costs have gone down, possibly due to already existing inspection units and better gadgets, repair costs are at par or higher - partly because of warranty systems. Secondly, these programs seem to be particularly effective in reducing hydrocarbons. Thirdly, a centralized but contracted system is most effective for inspection. Repairs can be done in private garages. Fourthly, more advanced I/M systems are extremely expensive and not cost-effective. Fifthly, the costs of I / M can be recovered totally from the vehicle-owners and so do not involve expenditures on the part of the state. (, Moreover, fuel savings imply negative costs, i.e. benefits (apart from the environmental benefits) for the simplest I/M programs.

Fuel Technology

a) <u>Unleaded Gasoline</u>

In the U.S., Australia , Europe and some other countries , the added cost of refining gasoline with the required octane quality but without lead is about .5 to 3 cents (U.S.) per litre, i.e. 2-10% of the gasoline price before taxes. But the cost for developing countries may be higher because of the initial capital investment. Vehicles with catalytic converters *need* unleaded gasoline, but those without can use it – sometimes engine adjustments are necessary or the fourth or fifth tank fill has to be leaded gasoline (24).

In 1972 the cost of refining capacity for U.K. and Sweden were calculated to be anywhere between $ 8.5 m and $ 600m., for different levels of lead removal and octane levels. Hence the capital costs are quite high for starting the process, but once it is in place, the running costs are not significant.

The benefits of reducing lead can be seen in Table 10. It saved $ 1836 billion over the 20-year period (1970 - 90), which constitutes 8.2% of saving from all air pollution abatement, so that it should be more than 16% of saving from vehicular abatement, even if we assume that 50% of pollution is created by vehicles.

b) Alternative Fuels

Table 15 gives the costs of substitute fuels compared to the cost of conventional gasoline. For trucks, the incremental costs are given in Table 16. An OECD study in 1987 shows that CNG and LPG are economically competitive with gasoline. The competitiveness, of course, depends on future changes in crude oil prices.

Table 15

Costs of Substitute Fuels, 1987
(1987 U.S. dollars)

Fuel	Cost per barrel of gasoline energy equivalent
Crude oil (assumed price)	$ 18
Conventional gasoline	$ 27
Compressed natural gas	$ 20-46
Very heavy oil products	$ 21-34
Methanol (from gas)	$ 30-67
Synthetic gasoline (from gas)	$ 43-61
Diesel (from gas)	$ 69
Methanol (from coal)	$ 63-109
Methanol (from biomass)	$ 64-126
Ethanol (from biomass)	$ 66-101

Source : IEA , 1990

Table 16

Increases in Truck Operating Costs Using Alternative Fuels (constant 1987 U /.S. dollars)

Fuel	Current diesel	Reformulated diesel	Methane (M-100)	CNG	LNG	LPG
Total increase In cost	Base [a]	1%	24%	8%	7%	2%

a. The base cost is about U.S. $ 1.00 per mile.
Source : Faiz et al , 1996.

However, the infrastructural and vehicle retrofitting costs are not insignificant [1,2]. Table 17 gives emissions impacts from cars with alternative relative to conventional fuels. The greatest emission reductions are obtained with hydrogen, followed by CNG and LPG. Electric vehicles have zero emissions on the streets but its production can have emissions of nitrous oxide and sulphur dioxide which exceed those from conventional gasoline or diesel vehicles.

In developing countries , the feasible alternative would be LPG or CNG, assuming that the initial infrastructural expenditures can be carried out.

Vehicle Replacement Program

Clearly , emissions increase significantly with vehicle age. The cost involved has been estimated to be $ 10,000 (per vehicle replaced) multiplied by the number of replaced vehicles for replacing pre-1981 by post-1981 vehicles. The cost effectiveness per ton of carbon monoxide removed (with 133,838 replaced vehicles) was estimated to be $ 37,125, or $ 33.5 million per percent decline in carbon monoxide (25).

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1 The infrastructural costs for CNG, for example, is $ 3500 (for a 5-hour fill system), and the vehicles retrofitting cost is $ 2500-3000 (in Canadian dollars). Other systems have even higher infrastructural costs.

2 Methanol and Ethanol involve double costs, and bio fuels involve a cost of 3 to 4 times the gasoline costs. Electric or hybrid-electric cars involve a minimum cost of $ 5000-20,000 more on a life-cycle basis.

Table 17

Estimated Change in Air Pollution Impacts from Use of Alternative Fuel Vehicles, Relative to Gasoline Vehicles Use (percentage)

	Vehicular emissions						full fuel-cycle emissions
Fuel/ Vehicle	**NMHC**	**CO**	**NOx**	**O_3**	**Sox**	**PM**	**CO_2**
Methanol (ICEV. 3w/ catalyst)	–50	0	0	–50		lower	-15 to +5
CNG, LNG (ICEV. 3w/ catalyst)	–60	?	0	–60		lower	–30 to +5
Hydrogen (ICEV, no catalyst)	–95	–99	–96	–95		lower	–70 to –10
Battery, (power from NG plants)	–100	–100	–100	–100	–100	–100	–50 to –25
Battery, (EV, non-fossil)	–100	–100	–100	–100	–100	–100	–85 to –80
Hydrogen (fuel cell, non-fossil)	–100	–100	–99	–100	–100	–100	–90 to –85

ICEV = internal combustion engine vehicle; CNG= compressed natural gas : LNG = liquefied natural gas; EV= electric vehicle

Source : OECD, 1995

Transportation Demand Management

Ridesharing

In the U.S., a variety of employer-based ridesharing (carpool and vanpool) programs have been and are being implemented in different regions and countries. The increases in average vehicle occupancy of some of these programs give us an idea of the effectiveness of these programs.

It must be recognized that only a 5% reduction plan (per year) is suggested until a maximum SOV modal split is attained. Hence the achievements are marginal and in one case, negative (although there were positive impacts in intervening years).

It has been observed that ridesharing programs (a) without monetary incentives (b) in suburban locations and (c) with free parking , are significantly less successful . A conflicting effect of carpool programs is that transit users may shift to carpools, thereby reducing average vehicle occupancy. Long-distance commuters with moderate household incomes respond most to ridesharing programs. Additional incentives in the form of preferential parking or parking cost subsidies may be provided by the employers.

Table 18
Average Vehicle Occupancy

Program	Percent increase	Base year	Year
Maricopa County Regional Travel Reduction Program (Arizona)	4.33	1.223 (1990)	1.276 (1991)
Los Angeles Regional Area	2.7	1.213 (1990)	1.246 (1991)
UCLA	2.18	1.239 (1970)	1.266 (1988)
ARCO	-2.67	2.25 (1983)	2.19 (1989)

Source : Martello and Vodrazka, 1992.

There are various cost estimates. One estimate by Wegmann (1989) gives average (yearly) national costs of $ 4.50 per employee of a carpool program and $ 889 per van for a vanpool program in 1985. The capital and operating costs (and even planning costs) of vanpool programs can be recovered from a monthly charge to passengers. In an on-going carpool program, only $ 1.04 needs to be added per new employee. Further , costs, decrease with firm size to even $ 92 per employee for firms with 10,000 employees. (. The annual costs of a regionwide program in Los Angeles in 1981 were estimated to be $ 38 million (with $12 million incurred by the government and $ 26 million by the private sector). However, savings to carpool users were estimated to be $ 537 million per year : giving net benefits (apart from environmental benefits) of $ 499 million (26, 27).

Other estimates of carpool programs for urbanized areas gives (1) a range of $ 40,922 to $ 1 million, with typical values of $ 100,000 - $ 200,000 per year, (2) an average of $ 140,000 per year. These costs , mostly for matching and promotion, are borne by the government and the employers. The carpools save, on average, $ 200- $ 850 per year (28).

Thus, in sum, carpool and vanpool programs involve some cost on the part of the state and employers (vanpool costs can be recovered) but yield net benefits for society (leaving aside environmental benefits) due to fuel savings. These programs have not been extremely successful so far in the U.S. for a variety of reasons, but their potential cost-effectiveness is high.

Other Tools in TDM

Parking may be banned, restricted or priced. The cost of enforcing parking restrictions in downtown New York City was $ 13.9 million annually. This cost can be offset entirely or partially by fining or by imposing a tax on all commercial parking prices. The effectiveness of parking restrictions, however, depends on the availability of transit and on the steepness of the fines. The effect of banning parking in Marseilles has yielded benefits (29).

Park–and-ride lots have been used extensively in the U.S. and other countries to encourage transit use. The cost can vary significantly, and involves land purchase, constructions work, operation and maintenance. It can be close to zero in rare situations, but is usually expensive when lots have to be bought in high-density urban areas. Moreover, this does not reduce the number of trips per se but only the vehicle miles traveled. As pollution per unit VMT is much greater for shorter trips because of cold starts and evaporation which may cause 50% of hydrocarbon and 25% of carbon monoxide emissions, the returns to park-and-ride lots is small.

The improvement of transit services is a major element in TDM. The most effective measures have been seen to be reducing transit headways which would decrease the out of vehicle wait time, having express bus routes which decreases in-vehicle wait time, and having passenger shelters which increase travel comfort. Expanding the route coverage, which is supposed to increase the number of potential users, has less of an impact which its costs are significant. A study of the San Francisco Bay Area by Harvey and Deakin shows a decline in emissions by around 3% due to improvements in routes and schedules and transit expansion (30) . The study by the office of Environment and Safety (OES, 1981) also shows a decline an emissions by 2 to 3% due to service improvements, but with much higher local impacts. When an elaborate transit network is already in place, improving this network is not so expensive. However, in general, transit improvements are costly as they involve expanding the vehicle fleet and the workforce. The capital and maintenance costs of 200 new buses are $ 14 million and $ 3-4 million (yearly), implying an equivalent annual cost of $ 5-7 million. Also, in developed countries, transit is perceived as a mode of transportation for lower income groups.

An alternative to improving services is to reduce transit fares. However, it has been seen that fare decreases have little impact, especially relative to service improvements as the price-elasticity of transit demand is low [at -.3 (overall) and -.2 (work trips)] A 50% decline ir. fares world create only a 15% increase in ridership (10% for work trips). A major fare decline in an extensive transit system impact emissions by 1 to 2%, although local impacts are greater. The costs involved are high, with little savings by transit-users (31).

Preferential treatment for carpools, vanpools and transit (i.e HOVs) has also been implemented in the form of special lanes, parking and signalization. Preferential parking involves little or no costs. Special lanes would involve greater surveillance costs but they are generally not very high. Preferential traffic controls, on the other hand, are estimated to cost $ 1000 per intersection and $ 125 per bus (8). Preferential treatment for HOVs can produce emissions reduction of 1–5 percent (32).

Absolute declines in vehicle use are achieved through decreasing the work-week to 4 or 5 days. If the 4-day work-week is then spread out over 6 days, with different groups of people working for different sets of the 4 days, the number of daily commuting journeys could be reduced by as much as one third (33) . The compressed work week has been seen to reduce emissions by more than 5% . Reducing the work week involves no costs, if the employees' production is not affected. Moreover, fuel savings would actually yield net benefits (34). Yet the impact is very major assuming that there are no substitution effects, in terms of an increase in non-work trips. Flexitime, i.e flexible work hours or staggered work hours have involved a cost of $200,000 annually for a city like New York, mainly including salaries for 5 professionals for co-ordination, marketing and technical assistance.

Auto-Restricted Zones (ARZs) achieve very large decreases in emissions , but over small areas. It has been seen that banning vehicles in shopping districts in Tokyo, Marseilles and Vienna has yielded benefits (35). The costs are low, unless construction work is carried out for pedestrian facilities. In the U.S., these facilities have involved costs of $ 50,000 - $ 100,000 per block (36).

For signalization, it has been seen that for a population of 1 million, a computerized master control system would involve a capital expenditure of $ 3 million and $ 300,000 for annual operation and maintenance, implying annualized costs of $ 800,000 (37). The savings are significant in terms of fuel use and time. The short-range decline in emissions is about 1 to 2%. However, as with all other forms of TSM, the induced demand effects can be significant. One-way streets and channelization of particular modes involve little or no costs, but the impact of the former is uncertain as cars have to travel more to reach their destination and transit systems are discouraged.

Other economic measures such as increasing fuel prices, taxing fuel, increasing registration fees and peak period road tolls are effective in terms of reducing VMT if the rates are quite high. However, the long-term effects of fuel price changes are not so high. The advantage of these measures, of course, is that they yield revenues which can be used for other (pollution reducing) purposes. It was estimated for the San Francisco Bay Area that increasing bridge tolls (from $1 to $ 2) would yield $ 94 million per year and would also decrease trips and emissions by .5%. A gas tax of 14 cents per gallon, equivalent to an emissions charge of ½ cents per mile, would yield $ 420 million per year, and also reduce emissions by .7%. A change in vehicle registration fee by $ 4 per year world give $ 24 million per year - but was calculated to have no impact on emissions as the amount was too small to change vehicle purchase rates. Moreover, it was seen that regionwide congestion pricing world decrease emissions by 7% through increasing speeds (VMT would only decrease by 1%), an employee parking charge of $ 3 per day would decrease emissions by about 1.5% , a European-style gas tax of $2 per gallon world reduce emissions by 8% and a mileage and emissions based registration fee would (through inducing vehicle replacement) reduce emissions by 4.5% (38). All these economic measures would not only fund transit and ridesharing measures, but would actually yield net revenues.

Tool Comparisons and Comprehensive Evaluations.

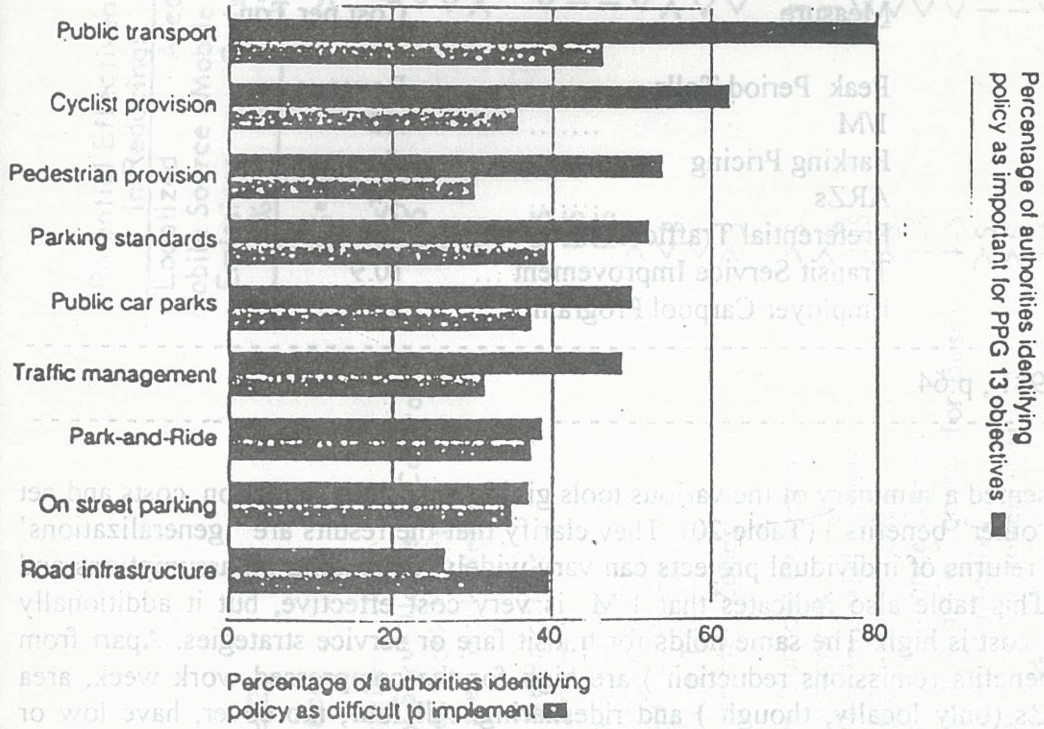
I will present and discuss, mainly, four studies that have been carried out to compare different tools of emissions control. We will try to sum up the different evaluations and perhaps note some contradictions.

Henderson and Bull (1996)[1]

This study, done for the UK, looks at the *perceived* " importance " and " difficulties " of transport policies for improving air quality, by the authorities. The comparative scenario is presented in Figure IX. The policies are ranked in order of " importance ".

Figure IX

Perceived Importance and Difficulty of Transport Policies



Office of Environment and Safety (1981)[2]

A summary of costs per ton of pollutant reduced (hence, cost effectiveness) is made by OES for 8 metropolitan areas in the U.S. The results for Philadelphia only, is presented (see Table 19). Other benefits such as fuel savings are not included, and the pollutant in this case is hydrocarbons.

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1 Policy Options for Improving Air Quality, in PTRC, 1996.

2 The Costs and Effectiveness of Transportation Control Measures in Achieving Air Quality Goals, OES, 1981.

The costs in Table 19 are basically those borne by the state. The social costs would be significantly different (even if we leave out environmental benefits). But costs for the state are important, as they imply the feasibility of implementing the program. It is important to observe that I/M is very cheap and the cheapest if we leave out the revenue–collection measures such as taxes and tolls. This is also true for all the other cities. Secondly, transit improvements and ridesharing programs are most expensive to implement.

Table 19

Summary of Costs Per Ton of Hydrocarbons Reduced (in thousand dollars)

Measure	Cost per Ton
Peak Period Tolls	Revenue
I/M	13
Parking Pricing	3
ARZs	5.4
Preferential Traffic Control ...	6.9
Transit Service Improvement ...	10.9
Employer Carpool Program ...	17.7

Source : OES, 1981 , p.64

OES has also presented a summary of the various tools giving emissions reduction, costs and net costs (i.e, minus "other" benefits) (Table 20). They clarify that the results are ' generalizations' and that costs and returns of individual projects can vary widely, depending on assumptions and local conditions. This table also indicates that I/M is very cost effective, but it additionally shows that the net cost is high. The same holds for transit fare or service strategies. Apart from I/M and transit, benefits (emissions reduction) are high for the compressed work week, area licensing and ARZs (only locally, though) and ridesharing. All four, moreover, have low or *negative* net costs. Ridesharing actually involves high costs for the state or companies but also yields significant " other " benefits. In terms of gross costs, the compressed work week or staggered hours, signalization, parking restriction, tolls, ARZs, vanpool programs and various preferential treatments are clearly the best and hence most feasible for the state to carry out[1]. We may add to these the different taxes and charges that we have already discussed. But they do not all yield the same returns - signalization, staggered hours, parking restrictions, tolls and preferential treatments typically yield emissions reductions ranging from 1 to 5% . We can

1 Park and ride are also included here, but costs are highly variable for this and hence I am leaving it out . I am also leaving out freeway-related measures as they are not applicable for the high-density urban scenario.

Table 20

	Measure	Potential Effectiveness in Reducing: Localized Mobile Source Emissions (%)	Potential Effectiveness in Reducing: Areawide Mobile Source Emissions (%)	Cost: Gross	Cost: Minus Other Benefits
Emission Inspection & Maintenance		>5*	>5*	H	H
Traffic Flow Improvements	Signalization	1-5	1-5	L	(Benefit)
	Freeway Surveillance & Control	1-5	<1	M	(Benefit)
	Staggered Work Hours	<1	<1	L	(Benefit)
	Compressed Work Week	>5	>5	L	(Benefit)
Motor Vehicle Use Restraints	Parking Restrictions	1-5	<1	L	L
	Parking Pricing	1-5	1-5	L	(Benefit)
	Peak Period Tolls	1-5	1-5	L	(Benefit)
	Area Licensing	>5	<1	M	(Benefit)
	Doubling Fuel Price	<1	>5	-	-
	Higher Auto Tax	<1	<1	-	-
	Auto Restricted Zones	>5	<1	L	L
High Occupancy Vehicle Incentives	Employer Carpool Programs	>5	1-5	H	(Benefit)
	Vanpool Programs	>5	1-5	L	(Benefit)
	Arterial Preferential Lanes	1-5	<1	L	(Benefit)
	Exclusive Freeway Lanes	>5	<1	H	L
	Preferential Entrance Ramps	1-5	<1	L	L
	Preferential Traffic Control for Buses	1-5	<1	M	L
	Transit Fare Strategies	>5	1-5	H	H
	Transit Service Improvements	>5	1-5	H	H
	Park-and-Ride Lots	1-5	<1	L	L

Key: L, Low; M, Moderate; H, High; (Benefit), Net Benefit therefore form the following groupings :

Group A : High Emissions Reduction, Low Costs

* Compressed Work Week
* ARZs
* Vanpool Programs

Group B : High Emissions Reduction, High Costs.

- Inspection and Maintenance
- Employer Carpool *
- Transit Fare / Service Strategies

* This yields net benefits , though

Group C : Low Emission Reduction, Low Costs.

- Signalization
- Staggered Work Hours
- Parking Restrictions & Fines
- Tolls
- Fuel Taxes and Fuel Price Increases
- Preferential Treatments..

We can thus conclude that apart from the measures under Group A, the others are all ambiguous and what should be chosen depends on the relative importance of the states' finances and required emissions reductions. Also, some of the revenue-earning measures in Group C, even if they do not give very high direct benefits, can be used to finance the measures in Group B. Moreover, as stressed, the efficiency of different measures depend on local circumstances.

Martello and Vodrazka, 1992[1]

This study has discussed the listing by OES. Moreover, they have also provided ranking in terms of impacts on carbon monoxide emissions. This is presented in Figure X.

This ranking also includes technological measures. The ranking verifies the supremacy of 1/M. In addition, parking, alternative fuels, ridesharing, public transit and work schedule changes are ranked high. This ranking also shows that certain technological measures such as accelerated

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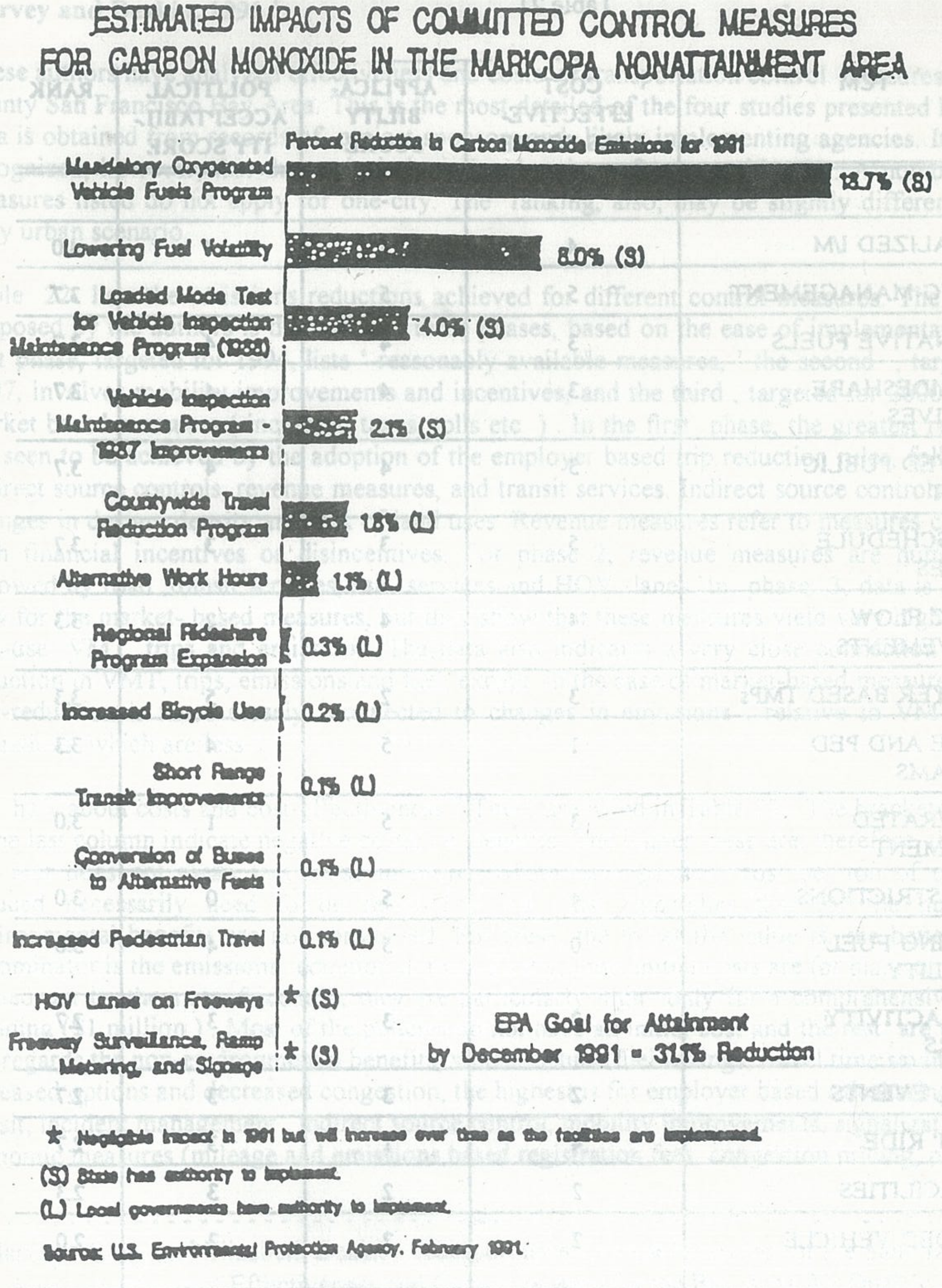
1 Assessment of Transportation Control Measures for Air Quality Improvement , Research Report, University of Nevada, 1992.

Figure X



ESTIMATED IMPACTS OF COMMITTED CONTROL MEASURES
FOR CARBON MONOXIDE IN THE MARICOPA NONATTAINMENT AREA
Percent Reduction in Carbon Monoxide Emissions for 1991
Mandatory Oxygenated Vehicle Fuels Program
18.7% (S)
Lowering Fuel Volatility
8.0% (S)
Loaded Mode Test for Vehicle Inspection Maintenance Program (1988)
4.0% (S)
Vehicle Inspection Maintenance Program - 1987 Improvements
2.1% (S)
Countywide Travel Reduction Program
1.8% (L)
Alternative Work Hours
1.1% (L)
Regional Rideshare Program Expansion
0.3% (L)
Increased Bicycle Use
0.2% (L)
Short Range Transit Improvements
0.1% (L)
Conversion of Buses to Alternative Fuels
0.1% (L)
Increased Pedestrian Travel
0.1% (L)
HOV Lanes on Freeways
* (S)
Freeway Surveillance, Ramp Metering, and Signage
* (S)
EPA Goal for Attainment by December 1991 = 31.1% Reduction
* Negligible Impact in 1991 but will increase over time as the facilities are implemented.
(S) State has authority to implement.
(L) Local governments have authority to implement.
Source: U.S. Environmental Protection Agency, February 1991

Based on these and some other data, they have ranked the various tools (see Table 22).

Table 21

TCM	COST EFFECTIVENESS SCORE	APPLICABILITY SCORE	POLITICAL ACCEPTABILITY SCORE	RANK
	-	-	-	-
CENTRALIZED I/M	4	4	4	4.0
PARKING MANAGEMENT	5	5	1	3.7
ALTERNATIVE FUELS	3	4	4	3.7
AREA RIDESHARE INCENTIVES	3	4	4	3.7
IMPROVED PUBLIC TRANSIT	3	4	4	3.7
WORK SCHEDULE CHANGES	5	3	3	3.7
TRAFFIC FLOW IMPROVEMENTS	4	4	2	3.3
EMPLOYER BASED TMPs	3	2	5	3.3
BICYCLE AND PED PROGRAMS	1	5	4	3.3
ACCELERATED RETIREMENT	3	5	1	3.0
VEH RESTRICTIONS	4	5	0	3.0
LOWERING FUEL VOLATILITY	0	5	4	3.0
MAJOR ACTIVITY CENTERS	2	3	3	2.7
SPECIAL EVENTS	2	3	3	2.7
PARK 'N' RIDE	4	1	3	2.7
HOV FACILITIES	2	2	3	2.3
EXTENDED VEHICLE IDLING	2	2	2	2.0
OXYGENATED FUEL PROGRAM	5	0	0	-
EXTREME LOW TEMP STARTS	NA	NA	NA	NA

retirement, lowering fuel volatility , extended vehicle idling oxygenated fuels and extreme low temperature starts are not necessarily superior and the last three are distinctly inferior, compared to TDM strategies.

Harvey and Deakin, 1991 [1]

These authors have analyzed effectiveness and costs of transportation control measures in the 9-county San Francisco Bay Area. This is the most detailed of the four studies presented here. The data is obtained from records of project sponsors and likely implementing agencies. It must be recognized, however, that the analysis is regional and not for a specific city. A number of the measures listed do not apply for one city. The ranking, also, may be slightly different for the fully urban scenario.

Table 22 lists the emissions reductions achieved for different control measures. The program proposed by the authors is divided into three phases, based on the ease of implementation. The first phase, targeted for 1994, lists ' reasonably available measures, ' the second , targeted for 1997, involves mobility improvements and incentives, and the third , targeted for 2000, stresses market based measures (increased taxes, tolls etc.) . In the first phase, the greatest reductions are seen to be achieved by the adoption of the employer based trip reduction rules, followed by indirect source controls, revenue measures, and transit services. Indirect source controls refer to changes in design, density and mix of land uses. Revenue measures refer to measures connected with financial incentives or disincentives. For phase 2, revenue measures are number one, followed by road transit services, rail services and HOV lanes. In phase 3, data is available only for the market- based measures, but they show that these measures yield very high drops in fuel-use, VMT, trips and emissions. The data also indicates a very close connection between reduction in VMT, trips, emissions and fuel, except in the case of market-based measures, where fuel-reduction is more closely connected to changes in emissions , relative to VMT or trip reductions, which are less.

But how about costs and cost-effectiveness ? These are listed in Table 23 . The bracketed values in the last column indicate negative costs, i.e. benefits. The higher these are, therefore, the better. But that does not mean that those measures which have positive cost per ton of emissions reduced necessarily need to be rejected – we must remember that for the numerator, environmental benefits are not considered. For these, the lower the value is, the better, as the denominator is the emissions reduction in tons. Firstly, most initial costs are for plans or studies carried out by the state. Secondly, they are particularly high only for a comprehensive transit planning ($1 million) . Most of the policies do not have an initial cost and the rest are not high. As regards the non-environmental benefits, which include fuel savings, travel time savings, increased options and decreased congestion, the highest is for employer based ridesharing, public transit, incident management , indirect source control, mobility improvements, signalization and economic measures (mileage and emissions based registration fees, congestion pricing, parking

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1 Harvey , Greig and Elizabeth Deakin, Transportation Control Measures for the San Francisco Bay Area : Analyses of Effectiveness and Costs, prepared for the Bay Area Air Quality Management District, July 1991.

Table 22

a : Summary of State TCM Plan Emissions Reductions for Phase 1 (Reasonably Available Measures)

State Plan Transportation Control Measures	VMT	Trips	HC	CO	NOx	PM10	CO2	Fuel
	Percentage Change in							
STCM 1 Expand Employer Assistance Programs	-.2	-.14	-.18	-.17	-.18	-.20	-.20	-.20
STCM 2 Adopt Employer-Based Trip Reduction Rule	– 3.27	–4.06	–3.57	–3.76	–3.67	–3.27	–3.27	–3.27
STCM 3 Improve Areawide Transit Service	-.48	-.43	-.46	-.44	-.46	-.48	-.48	-.48
STCM 4 Expedite and Expand Regional Rail Agreement	-.07	-.05	-.06	-.06	-.06	-.07	-.07	-.07
STCM 5 Improve Access to Rail	-.02	-.03	-.02	-.03	-.02	-.02	-.02	-.02
STCM 6 Improve Intercity Rail Service	-.05	-.04	-.05	-.04	-.05	-.05	-.05	-.05
STCM 7 Improve Ferry Service			-.015	-.01	-.015	-.011	-.012	-.015
STCM 8 Construct Carpool / Express Bus Lanes on Freeways	-.23	-.22	-.23	-.20	0.22	-.23	-.23	-.23
STCM 9 Improve Bicycle Access	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.01
STCM 10 Youth Transportation	0	0	0	0	0	0	0	0
STCM 11 Install Freeway Traffic Operations	+.02	+.01	-.42	-.65	-.35	+.02	-.45	-.45
STCM 12 Improve Arterial Traffic Management	+.01	+.01	-.02	-.30	-.25	0	-.15	-.15
STCM 13 Reduce Transit Fares	-.11	-.11	-.11	-.09	-.11	-.11	-.11	-.11
STCM 14 Vanpool Liability Insurance	0	0	0	0	0	0	0	0
STCM 15 Provide Carpool Incentives	0	0	0	0	0	0	0	0
STCM 16 Adopt Indirect Source Control Program	-.7	-.7	-.7	-.7	-.7	-.7	-.7	-.7
STCM 17 Conduct Public Education	0	0	0	0	0	0	0	0
STCM 18 Zoning Plans for Higher Densities Near Transit	0	0	0	0	0	0	0	0
STCM 19 Air Quality Element for General Plans	0	0	0	0	0	0	0	0
STCM 20 Conduct Demonstration Projects	0	0	0	0	0	0	0	0
STCM 21 Implement Revenue Measures	-.62	-.55	-.60	-.57	-.60	-.62	-.62	-.62
Total :	-5.64	–6.22	–6.48	6.86	–6.54	-5.64	–5.64	-5.64

b : Summary of State TCM Plan Emissions Reductions for Phase 2 (Mobility and Incentives Measures)

State Plan Transportation Control Measure	VMT	Trips	HC	CO	NOx	PM10	CO2	Fuel
	Percentage Change In							
STCM 3 Improve Areawide Transit Service	-1.0	-.9	–1.0	-.9	-.9	–1.0	–1.0	-1.0
STCM 4 Expedite and Expand Regional Rail Agreement	-.7	-.8	-.8	-.8	-.7	-.7	-.7	-.7
STCM 5 Improve Access to Rail	-.3	-.25	-.3	-.25	-.3	-.3	-.3	-.3
STCM 6 Improve Intercity Rail Service	-.04	-.03	-.04	-.03	-.04	-.04	-.04	-.04
STCM 7 Improve Ferry Service	-.03	-.02	-.03	-.02	-.03	-.03	-.03	-.03
STCM 8 Construct Carpool / Express Bus Lanes on Freeways	-.45	-.35	-.41	-.38	-.4	-.45	-.45	-.45
STCM 9 Improve Bicycle Access	-.02	-.03	-.02	-.03	-.02	-.02	-.02	-.02
STCM 10 Youth Transportation	-.11	-.17	-.14	-.16	-.14	-.11	-.11	-.11
STCM 11 Install Freeway Traffic Operations	+.13	+.09	- 1.4	-1.8	-1.1	+.13	–1.2	–1.2
STCM 12 Improve Arterial Traffic Management	-.01	-.02	-.23	-.33	-.27	-.01	-.17	-.17
STCM 13 Reduce Transit Fares	-.17	-.22	-.21	-.22	-.21	-.17	-.17	-.17
STCM 14 Vanpool Liability Insurance	-.02	-.01	-.02	-.01	-.02	-.02	0.2	-.02
STCM 15 Provide Carpool Incentives	-.3	-.2	-.2	-.2	-.3	-.3	-.3	-.3
STCM 17 Conduct Public Education	0	0	0	0	0	0	0	0
STCM 18 Zoning Plans for Higher Densities Near Transit	- .05	-.05	-.05	-.05	-.05	-.05	-.05	-.05
STCM 20 Conduct Demonstration Projects	0	0	0	0	0	0	0	0
STCM 21 Implement Revenue Measures	–1.3	–1.2	–1.2	-1.2	-1.3	–1.3	–1.3	-1.3
Total :	-4.29 –	4.09	–5.90	-6.21	-5.64	-4.29	-5.72	-5.72

Table 22 (contd.)

c : Summary of State TCM Plan Emissions Reductions for Phase 3 (Market-Based Measures)

State Plan Transportation Control Measure	VMT	Trips	HC	CO	NOx	PM10	CO2	Fuel
			Percentage Change In					
STCM 3 Improve Areawide Transit Service								
STCM 4 Expedite and Expand Regional Rail Agreement								
STCM 5 Improve Access to Rail			Additional TCMs for Phase 3 will be developed					
STCM 10 Youth Transportation			as the pricing measures are implemented.					
STCM 11 Install Freeway Traffic Operations								
STCM 17 Conduct Public Education	0	0	0	0	0	0	0	0
STCM 22 Implement Market-Based Measures	-13.72	-14.6	-20.62	-22.54	-15.53	-13.72	-18.93	-18.93
Total	-13.72	-14.6	-20.62	-22.54	-15.53	-13.72	-18.93	-18.93

d : Summary of State Plan Emissions Reductions for All Phases

Description	VMT	Trips	HC	CO	NOx	PM10	CO2	Fuel
	Percentage Change In							
Phase 1 : Reasonably Available Measures (Target year 1994)	-5.6	-6.2	-6.5	-6.9	-6.5	-5.6	-5.6	-5.6
Phase 2 : Mobility Improvements and Incentives (Target year 1997)	-4.3	-4.1	-5.9	-6.2	-5.6	-4.3	-5.7	-5.7
Phase 3 : Market-Based Measures (Target year 2000)	-13.7	-14.6	-20.6	-22.5	-15.5	-13.7	-18.9	-18.9
Total Change	-22.1	-23.2	-30.1	-32.3	-25.5	-22.1	-27.9	-27.9

Source : Harvey and Deakin, 1991.

charges and fuel taxes). Economic measures indicate very high benefits because of the revenues collected. Economic measures, ridesharing programs and indirect source controls clearly stand out in terms of cost-effectiveness. Bus service expansion in phase 1 and certain other transit-related measures (but definitely not rail expansion) are also not bad in terms of cost-effectiveness.

What stands out in Harvey and Deakin's study is that improving transit measures is costly, but yields high returns. Other tools which are very important are ridesharing and other HOV privileges, and land-use management. Most importantly , market-based measures are shown by the study to be crucial, both in terms of emissions reductions and in terms of providing the revenue for carrying out transit improvements and for providing ridesharing benefits. The market-based measures that are suggested are an increase in tolls, gasoline tax and registration

Table 23

Details for ROG Cost Effectiveness Attributed to State Transportation Control Measures

State Plan Transportation Control Measure # Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-- tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
1a Conduct Employer Audits (FTCM 23)-M	1		$750K	$6M	-.16	250	42.70	$17,564.40	(122,950.82)
1b Telecommuting Guidance	1	30 K	$10K	0	0				
1c Employer/ Employee Survey	1		$200K	0	0				
1d Training Materials-M	1	100 K	$15K	$700K	-.02	250	5.34	2,808.99	(128.277.15)
2a Develop Model TRO (FTCM 27)-M	1		$225K	$2.5M	-.07	250	18.68	12,044.97	(121,788.01)
2b Implement Model TRO (FTCM 28)-M	1								
2c Adopt Trip reduction Rule-M	1		$155M	$110M	–3.5	250	933.98	165,956.44	48,180.90

Table 23 Continued ......"

State Plan Transportation Control Measure # Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduction (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
3a Rail Service Expansion Phase (FTCM 17b)-M,S,X	1				-.20	300			
3b Upgrade Cal Train Service- M,X	1				-.08	300			
3c Comprehensive Transit Planning	1	1 M							
3d Bus Service Expansion: Phase 1-M,S	1		$1M	$6M	-.18	300	59.44	16,823.69	(84,118.44)
3e Rail Service Expansion : Phase 2-M,S,X	2		$100M	$38M	-.5	300	178.02	561.734.64	348.275.47
3f Bus Service Expansion : Phase 2-M,S	2		$140M	$22M	-.5	300	165.12	847.868.22	714,631.78
3g Rail Service Expansion: Phase 3	3								
3h Bus Service Expansion : Phase 3	3								

Table 23 continued ....

State Plan Transportation Control Measure # Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-- tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
4a Rail Extensions : Phase 1 (FTCM 16)-M,S,X	1				-.06				
4b Rail Extensions : Phase 2-M,S,X	2		$140M	$44M	-.8	300	284.83	491,521.26	337,043.15
4c Rail Extensions : Phase 3-M,S,X	3								
5a Rail Access Planning	1	200 K							
5b Rail Access Improvement : Phase 1-M,S	1				-.02				
5c Rail Access Improvement : Phase 2-M,S,X	2		$50M	$17M	-.3	300	106.81	468.120.96	308.959.84
5d Employment Center Coordination for Rail Access-M	2		$100K						
5e Rail Access Improvement : Phase -3	3								

Table 23 continued ......

# Description (State Plan Transportation Control Measure)	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
6a Intercity Rail Improvement : Phase 1 (FTCM 18) –M,X	1				-.05				
6b Intercity Rail Improvement : Phase 2-M,X	2		$10M	$2.5M	-.04	300	13.84	722,543.35	541,907.51
7a Continue Post-Earthquake Ferries (FTCM 17a)	1				-.015				
7b Regional Ferry Planning	1								
7c Implement Regional Ferry Plan M,X	2		$10M	$1.1M	-.03	300	10.38	963,391.14	857,418.11
8a HOV System Expansion : Phase 1 (FTCM 20)-M	1				-.23				
8b HOV Plan refinement	1	250 K							
8c HOV System Expansion : Phase 2 –M	2		$50M	$21.3M	-.41	250	109.41	456,996.62	262,316.06

Table 23 continued ....

State Plan Transportation Control Measure # Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc--tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
9a County and City Bicycle Plans	1	500 K							
9b Regional Bicycle Route Plan	1	50 K							
9c Transit Bicycle Access Plan	1	100 K							
9d Bicycle Plan Implementation: Phase 1-M,S	1				-.01				
9e Bicycle Plan Implementation	2		$5M	$1.4M	-.02	300	6.60	757,575.76	545,454.55
10a Youth Transportation Problem Diagnosis	1	150 K							
10b Youth Discount Transit Tickets-M,S	2		$5M	$3.3M	-.08	300	26.42	189,250.57	64,345.19
10c School Bus Services – M,S	2		$5M	$ 1.4M	-.04	250	11.01	454,132.61	326,975.48
10d Student Ridesharing –M,S	2		$1M	$470K	-.02	250	5.50	181,818.18	96,363.64

Table 23 continued ......

# Description (State Plan Transportation Control Measure)	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc--tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
10e Youth Transportation Improve--ments Phase 3	3								
11a TOS Implementation : Phase 1 (FTCM 26)	1				-.11				
11b TOS Plan Refinement	1	100 K							
11c Regional AVI Plan	1	200 K							
11d Advanced Highway Technology Plan	1	100 K							
11e Surveillance and Incident Management -M,S,X,C	2		$25M	$70M	-.73	300	300.03	83,325.00	(149,985.00)
11f Traffic Advisory System – M,S,X,C	2		$10M	$16M	-.2	300	82.20	121.654.50	(72,992.70)
11g Ramp Metering	2								
11h Electronic Toll Collection	2								

Table 23 continued ....

State Plan Transportation Control Measure # Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-- tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
11i Advanced Highway Technology Implementation	3								
12a FETSIM : Phase 1 (FTCM 25)-M,S,X,C	1		$2M	$10M	-.2	300	82.20	24,330.90	(97,323.60)
12b Arterial Operations Improvement Plan	1	250 K							
12c FETSIM : Phase 2 (FTCM 24)-M,S,X,C	2		$2M	$10M	-.21	300	86.31	23,172.29	(92,689.14)
12d Transit Signal Preemption M,S	2		$2M	$1.4M	-.02	300	6.60	303,030.30	90,909.09
12e SMART Streets	2								
13a Fare Coordination Among Districts (FTCM 21)	1				-.05				
13b Regional Transit Ticket Distribution (FTCM 22)	1				-.06				

Table 23 continued ....

# Description (State Plan Transportation Control Measure)	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-- tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
13c Employer Subsidies for Transit Passes	1								
13d Fare Elasticity Study	1	100 K							
13e Subsidized Bus-Rail Transfers-M,S,X	2		$5M	$3.5M	-.05	300	17.80	280,898.88	84,269.66
13f Reduced Fares for Targeted Groups-M,S,X	2		$10M	$6.9M	-.14	300	49.85	200,601.81	62,186.56
13g Transit " Stores" –M,S	2		$3M	$1.4M	-.02	300	6.60	454,545.45	242,424.24
14a Vanpool Insurance Feasibility Study	1	100 K							
14b Publicly Financed Vanpool Insurance –M	2		$2.1M	$950K	-.05	250	13.34	157,421.29	86,206.90
15a Ridesharing Incentive Plan	1	100 K							

Table 23 continued ....

#	State Plan Transportation Control Measure Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc--tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
15b	Ridesharing Toll Elimination-M	2		$20M	$14M	-.2	250	53.37	374,742.36	112,422.71
16a	Indirect Source Control -M,S,X,C	1		$12M	$50M	-.8	300	328.80	36,496.35	(115,571.78)
17a	Public Education : Phase 1	1		$250K						
17b	Public Education : Phase 2	2		$250K						
17c	Public Education : Phase 3	3		$500K						
18a	Rail Proximity Study	1	300 K							
18b	Higher Density Zoning Near Transit-M,S	2		$500K	$3.5M	-.05	300	16.51	30,284.68	(181,708.06)
19a	Air Quality Element for General Plans	1		$2M						
20a	Telecommuting Demonstration	1		$250K						
20b	Alternate Fuels Demonstration	1		$250K						

Table 23 continued ......

#	State Plan Transportation Control Measure Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-- tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
20c	Automatic Fare Collection Demonstration	2		$250K						
21a	Increase Bridge Tolls to $1.00 (FTCM 13)	1				-.18				
21b	Increase Gasoline Tax by $0.09/gal. (FTCM 15)	1				-.42				
21c	Revenue for Mobility Improvements-M,S,X,C	2		Fees $90M accounted as costs of phase 2 TCMs.		–1.2	300	493.20	4,055.15	(178,426.60)

Table 23 continued ......

State Plan Transportation Control Measure #	Description	Phase	Initial cost	1997 Cost (1)	1997 Travel Benefits (1.2)	Percent ROG Reduc-- tion (3)	ROG Reduction Equivalent Days/ Yr.(4)	1997 Tons of ROG Removed (5)	1997 Cost/Ton	1997 Net Cost/Ton (6)
22a	Mileage-and Emissions -Based Registration Fee – M,S,X,C	3		Fees would be Re- turned	$14M	-4.5	300	1,849.50		(7,569.61)
22b	Regionwide Congestion Pricing – M,S,X,C	3		to the public through additions	$420M	-5.5	250	1,883.75		(222,959.52)
22c	Regionwide Non-Work Parking Charge-M,S,X	3		to the general Fund or a similar	$280M	-4.6	300	1,637.78		(170,963.13)
22d	Fuel Tax Increase to $2.00-M,S,X,C	3		mecha- nism.	$530M	-7.8	300	3,205.80		(165,325.35)

Note :

1. " 1997 Net cost / Ton " is calculated as " 1997 Cost" minus "1997 Travel Benefits" divided by " 1997 Tons of ROG Removed". A value in parentheses indicates a net benefit to the region from implementing the measure.

2. M : full modal system, S : home-based school trips , X : internal / external trips, C : commercial trips.

Source : Harvey and Deakin, 1991, Appendix D.

fees, and also congestion pricing, parking charges and registration fees based on mileage and emissions.

It is seen that traffic operations measures such as incident management (removal of accident-related and other lane blockages) and signalization are good but have a counter-effect in terms of induced demand.

Concluding Remarks

From the four studies I have discussed, it may be concluded that

- an inspection and maintenance regime is crucial for any kind of vehicular pollution control strategy,
- the use of unleaded fuel is also very important.
- various economic measures are essential, both in terms of revenue collection for financing other policies and in terms of emissions reduction.
- improving the public transit system (buses more than other forms), especially where an elaborate system is already in place, is important (and more effective than fare decreases)
- parking restrictions are useful in combination with transit improvements.
- reducing the work week (and also schedules) has major impacts.
- employer-based ridesharing programs yield moderate returns
- alternative fuels such as CNG need to be developed for commercial vehicles such as buses, taxis and autos.

The importance of a variety of other measures is not so obvious, but there is clearly a lot of variation in returns and costs depending on the specific circumstances of the city or area for which a program is being developed. A few points that should be kept in mind are that

- costs become very steep for high levels of control, especially if very advanced technologies are required
- in high-density urban areas , the damage created *per vehicle* is much higher compared to other areas.
- there is an obvious benefit in targeting highly polluting vehicles, as the costs would be lower whilst the returns would be significant.

A few words regarding traffic systems management are in order. These measures attain significant reductions in emissions, but are said to induce the use of vehicles and especially SOVs. However, there are three arguments in favour of TSM. First, trip making is not so sensitive to speed increases in urban areas with a high population (the sensitivity is great only for populations *below* 1 million) Second, it has usually been seen that the decline in emissions due to speed increases more than offsets the increase in emissions due to increases in VMT. However, this result varies, depending on local circumstances. Thirdly, TSM is usually necessary purely in order to reduce the discomfort in and time required for travel - that is, it has other major objectives. If, as a side-effect, emissions are reduced, this would only be an added advantage.

Another aspect that should be considered , in addition to cost-effectiveness considerations, is – who bears the cost. First, the state has financial limitations, hence measures such as transit improvements, traffic flow improvements , flow related construction (bicycle paths, pedestrian paths, new roads, flyovers, etc.) and parking management are difficult to implement from this point of view. The funds, however, can be collected via taxes, fines and fees. Second, if the ordinary public has to bear costs, care should be taken than the steps are not regressive or do not unduly harm economic growth. Parking charges or fuel taxes perhaps affect the more affluent groups, but there may be an impact on the economy. Third, if companies (vehicle, fuel or other) have to bear costs, it is important to see to whom these costs are ultimately shifted - the consumers, or workers, or shareholders. Finally, it is important to evaluate whether the cost is also a social cost or simply a private one. Thus, taxes, fines etc. are borne by individuals but are only transfers.

Regulation or taxes have historically been more effective than TDM because the latter is not compulsory, whilst the former is. The relative inefficacy of TDM measures in the U.S. has been largely due to " suburb-based " land-use structures which strongly favours the use of SOVs, and the non-mandatory nature of TDM ordinances. Moreover, TDM measures are largely aimed at home-based work trips and as only 33% of trips in the U.S. are under that category, the impact has been commensurately small. Finally, fuel prices , in comparison to income levels, have been quite insignificant in the U.S., with low fuel taxes – this has clearly encouraged the use of SOVs.

VII

Calcutta : Features and Differences with Cities in Developed Countries.

India's population has increased from around 360 million in 1951 to around 884 million in 1991/2. The percentage of urban population has increased from 17 to 29 in this period, with 23 metropolitan cities in 1991. The urban population in 2001 is projected as 404.7 million , 35.5per cent of the total population , with 41 cities having populations greater than 1 million [1] . This is fairly representative of the percentage of world population living in urban areas, estimated to be 36.3 percent for 2001. The vehicular population in India has increased from 300,000 in 1951 to around 20 million in 1992, with around one-third of registered vehicles concentrated in the four metropolitan cities. In 1990/1 , the transportation sector accounted for 35 percent of petroleum consumption in India, and this was calculated to have become 41.3 percent in 1996-7. The total urban passenger movements was 350 billion passenger kilometres per year, of which 85 percent was on roads in urban areas. Thus increases in population has caused far greater increases in urbanization and an even greater increase in the use of motor vehicles. All this has clearly caused a significant deterioration in air qualities in the large cities (39, 40, 41, 42).

Calcutta, situated in eastern India , is its largest megacity . Its case is symptomatic of the Indian scenario. Its population increased from 4.67 million in 1951 to 11.86 million million in 1990-1, projected to become around 16 million in 2010 – 1 (a 35 percent increase relative to 1990-1). The rate of increase in population was 1.6% per annum in the last decade .

'Calcutta' refers to three areas – Calcutta Metropolitan District (CMD), occupying about 1400 square kilometres, the Municipal City of Calcutta (CMC) which covers about 14 percent of CMD but accommodates 36 percent of its population, and the City of Calcutta which covers 7 percent of CMD. Moreover, the Central Business District occupies only 1 percent of CMD. The average population density for the whole of the CMD was 8594 persons per square kilometre in 1990/1 but as the population gets more and more concentrated as we move to the centre of the city, the density was very high at 23670 (CMC) and even higher in the CBD. The density, moreover, is greatly exacerbated in the CBD during the day, due to the daily migration of workers from areas even outside the CMD. There are around 725,000 persons per square kilometre occupying the inner core area, compared to 100,000 in New York in 1996 (43, 44).

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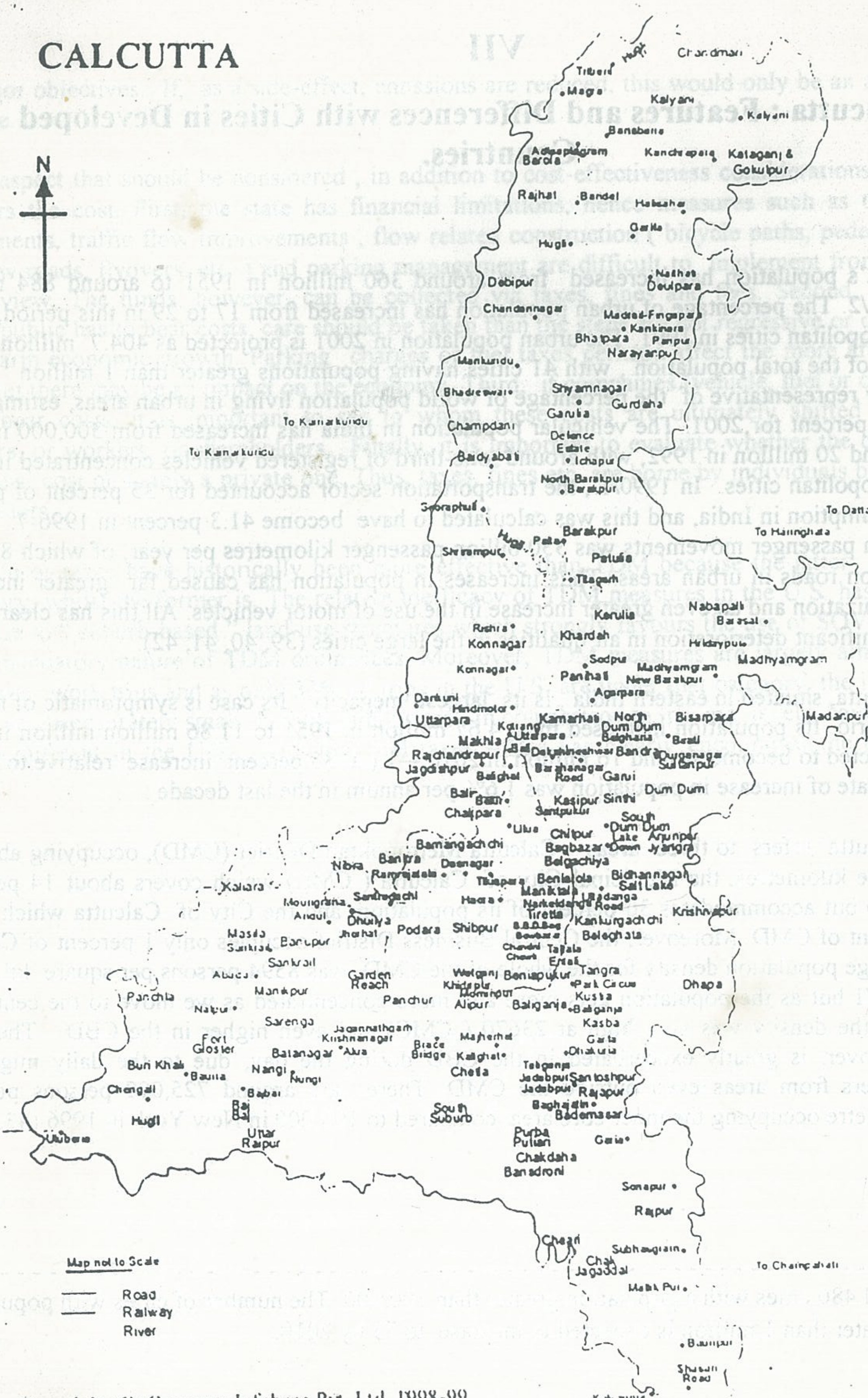
1 and 480 cities with a population greater than 100,000. The number of cities with populations greater than 1 million is expected to increase to 75 by 2010.

CALCUTTA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Bhatpara
Panpur
Narayanpur
Mankundu
Bhadreswar
Shyamnagar
Gurdaha
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Ichapur
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Serampur
Patulia
Titagarh
Nabapalli
Barasat
Rishra
Konnagar
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Rajchandrapur
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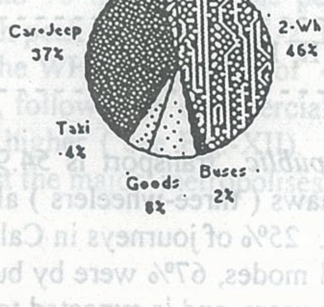
Bamangachchi
Bantra
Baghbazar
Belgachiya
Bidhannagar
Salt Lake
Maniktala
Narkeldanga
Kolaara
Krishnapur
Shibpur
Podara
Kankurgachchi
Beleghata
Sankrail
Garden
Reach
Tangra
Park Circus
Beniapukur
Dhapa
Panchla
Manikpur
Panchur
Kasba
Alipur
Ballyganj
Sarenga
Fort
Gloster
Batanagar
Buri Khali
Nangi
Chengail
Behala
Chetla
Jadabpur
Santoshpur
Hugli
Rajpur
South
Suburb
Baghajatin
Bademasar
Uluberia
Uttar
Raipur
Purba
Putiari
Chakdaha
Bansdroni
Garia
Sonapur
Rajpur
Chandi
Subhasgram
Chak
Jagaddal
To Champahati
Malik Pur
Baruipur
Shasan
Road
Kalyanpur
Map not to Scale
Road
Railway
River

Calcutta has expanded linearly, as it is confined within marshes and swamplands in the east and the river Hooghly on the western side, leaving about 4 kilometers in the middle (see Map A). The land use pattern has developed haphazardly and is largely mixed, although there does exist a CBD of 14 square kilometres and an inner core of 4 square kilometres. Calcutta is basically a commercial city, with 41 percent of the business in wholesale and retail trade. The informal sector constitutes a major part of the economy. Around three fourths of the housing units are used only for dwelling. Around one-third of the population lives in slums. Although some areas have been developed in an organized fashion (eg. Salt Lake City) since the 60s, these are only pockets in a largely unplanned city. Localities are segregated, with slums, low-income and high-income areas, but these localities exist side-by-side (45). Only 6 percent [1] of the total area is devoted to roads (whereas the international norm is 20 to25percent). Moreover, road-side hawkers encroach upon this limited road space in many parts of the city. Hence jams and congestion are a rule rather than an exception . The roads are often in bad repair. Calcutta's windspeed has contributed to the problem by becoming progressively lower due to increased densities of built areas and taller buildings.

The number of vehicles has increased from around 50,000 in 1951 to around 500,000 in 1991, a ten-fold rise (in the same period , population rose by 39 percent). Calcutta's motor vehicle population doubles every 6 years. The annual registration of motor vehicles went up at a rate of 7% between 1984/5 and 1990/1, though it declined to 4.2% between 1990/1 and 1994/5. Currently, Calcutta has around 850,000 vehicles. Such trends are also observable in the other major cities, including Delhi. Yet Calcutta had only 31 vehicles per 1000 people in 1995/6. In that year, vehicle registration in Calcutta were 600,000 , compared to 2.5 million in Mexico City, 8 million in Los Angeles , and 2.7 million in London in 1988-9. However, the rate of growth of vehicle ownership for Calcutta and other Indian megacities is much higher (46, 47, 48, 49).

Moreover, private vehicles are growing faster than mass transit modes and the greatest increase is in the number of 2-wheelers. In 1995, the share of scooters and motorcycles together accounted for 46 percent of the total registered vehicles. Figure XI gives the fleet mix.

Figure XI



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1 Some estimates are lower at 4 or 5%.

The number of motorized *passenger* vehicles is expected to increase by 19 percent in the period 1995/6 and 2010/11. Passenger travel demand, at 12 billion passenger kilometers (bpkm.) in 1990/1, is expected to increase 1.3 times by 2010 /11 (50).

Other that the above on-road transportation modes, there are also suburban railways, the metro rail (a single line from south to north), a circular beltway, trams and water-ferries. Non-motorized modes constitute rickshaws, bicycles ,and hand-carts.

Although buses constitute only about 2 percent of the fleet, it caters to 32 percent of total travel demand (1997). The contribution of the different public transport modes in terms of travel demand is given in Table 24.

Table 24

Passengers Served by Modes of Transport, 1995

	Modes of Transport	No. of passengers served on average weekday 1995 (in millions)	Percentage share	
1	Suburban Railway including Circular	1.54	14.2	
2	Metro Rail	0.20	1.8	
3	Buses			
i)	CSTC Government bus.	0.82	7.6	
ii)	CTC Government bus.	0.26	2.4	54.9
iii)	Private regular bus.	3.54	32.7	
iv)	Private Mini bus.	1.08	10.0	
v)	Chartered Private bus.	0.24	2.2	
4	Tram	0.20	1.8	
5	Passenger Ferry	0.30	2.8	
6	Taxi	1.15	10.6	
7	Auto Rickshaw	1.50	13.9	

Source : Bandyopadhyay, CODATU VII, 1996.

Hence, the contribution of buses in *public* transport is 54.9%, whereas the suburban and circular railways, taxis, and auto rickshaws (three-wheelers) also cater to a reasonable fraction of demand. It is estimated that in 1980, 25% of journeys in Calcutta were made on foot, and of the 75% of journey made by motorized modes, 67% were by bus. This percentage, as we have seen, has declined significantly over the years, and is expected to decline even further in Calcutta (51).

The demand for gasoline is 167 thousand tonnes of oil equivalent and that of diesel is 135. Thus, nearly equal amounts of both are used (52). However, the use of diesel is expected to rise much faster, under the present price differential *(Rs. 27.50 per litre for gasoline and Rs. 14.20 per litre for diesel).*

A few words on the socio-economic condition of the city may be said. As for all cities, there is a large variation in the socio-economic status of the population , but the upper and upper middle classes are a minor percentage of the total. However, there is a significant number in the middle-income bracket that can go for more expensive transits such as " executive " buses and the metro. There are strong political constraints to increasing fares for public transport or any other policies that are regressive or go against strongly unionized groups such as bus, auto or taxi owners. The need for non-work travelling does exist but has gone down significantly in recent years, due to deteriorating traffic conditions, weakening family ties and television-viewing. Medical and other facilities have improved in the residential localities. Hence, most trips are work-based. Finally, a word on whether Calcuttans have an intrinsic tendency to create chaos on the roads. The true cause is the absence of an efficient monitoring fleet and punitive action. The metro is better monitored and this example can surely be emulated on the streets.

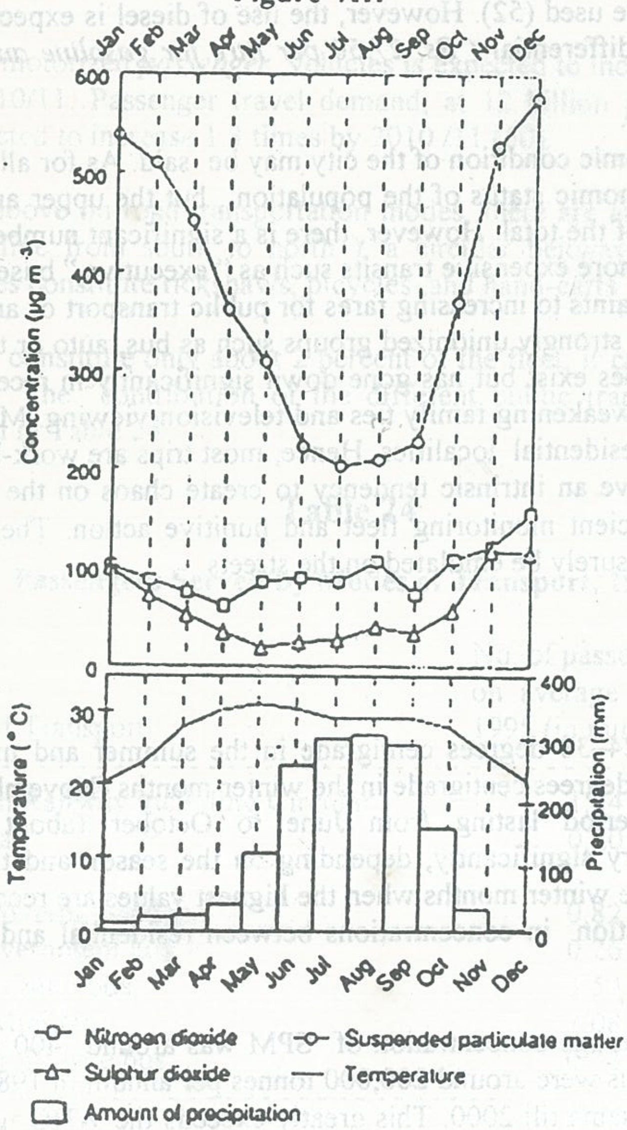
Air Quality

Calcutta has temperatures of 24–38 degrees centigrade in the summer and monsoon months (March – October) and 12 – 27 degrees centigrade in the winter months (November– February). There is a long monsoon period lasting from June to October (about five months). Concentrations of pollutants vary significantly, depending on the season and the time of day. They increase significantly in the winter months when the highest values are recorded during the night. Also, there is some variation in concentrations between residential and commercial or industrial areas.

Between 1978 and 1994, the average concentration of SPM was around 400 micrograms per cubic metre. Total SPM emissions were around 200,000 tonnes per annum in 1980 and 1990 and have remained more or less the same till 2000. This greatly exceeds the WHO guidelines (60 – 90 mg./m ^{3}) and Indian air quality standards . There is no significant difference in concentrations between various sites (residential, commercial and industrial). In the monsoon months, concentrations are half those of the winter months (see Figure XII).

Sulphur dioxide averaged around 70 mg/ m^3 in the period 1978- 87, but there has been a declining trend in the 1980s, with peak levels in 1981-2. In 1987 concentrations ranged from 40 to 55 *mg/m – barely satisfying the WHO guidelines of 40 – 60 mg/. m*^{3} . These concentrations are higher in the industrial areas, followed by commercial and lastly by residential areas. Winter concentrations are significantly higher (see Fig.-XII). In 1995-6, sulphur dioxide emissions were 1550 tons, the least amongst the major metropolises.

Figure XII



Nitrous oxide (specifically , nitrogen dioxide) emissions increased in the late 1970s and early 1980s and peaked around 1985. However, since then levels have been falling and are around 100 mg/m^3. The WHO guidelines are at 150 mg/m^3. At 83,000 tons, nitrous oxide emissions were the highest in India in 19-6. Maximum concentrations are in the commercial areas. There is no clear seasonal influence on monthly concentrations.

For 1995, TSP, Sulphur dioxide and Nitrous oxide concentrations in Calcutta are given below :

TSP	375 mg/m^3
SO_2	49 mg/m^3
NO_2	34 mg/m^3

In 1990, carbon monoxide emissions totaled around 177,000 tonnes per annum. By 1995, this value increased to 50782.8 tonnes . The emission of hydrocarbons in the same year was 20414.3 tonnes. There is no monitoring of carbon monoxide or hydrocarbons and hence air quality data is unavailable.

Although the lead content of petrol from the refinery at Haldia, which supplies Calcutta, is lower than in Delhi or Bombay at .1 gm. per litre , annual airborne lead levels were the highest in India in 1990 but have gone down in the '90s. Concentrations were .73 mg/m^3 in residential and commercial sites in 1990 - higher than in industrial sites. This value is below the WHO guideline of 1 mg/m^3. In 1995-6, annual lead emissions were 31 tons (52, 53).

Hence, in sum, the concentration of pollutants other than SPM are within WHO limits, but not significantly below these limits. Secondly, in winter the values are much higher than the average yearly values. Thirdly, apart from SPM, the variations in emissions between different areas are not significantly high and are sometimes higher in residential areas. Fourthly, average values peaked in the 1980s and have gone down in the 1990s, perhaps due to some measures taken by the State Pollution Control Board.

Let us now see to what extent transportation is responsible for the pollution levels. For SPM, industry accounted for 98% of the emissions in 1990. The main reason is the use of coal by the thermal power plants (44% of emissions) and the chemical industries (15%). Industry accounts for 64% of sulphur dioxide emissions and 44% of nitrous oxide emissions. However, the role of transportation in sulphur dioxide and nitrous oxide emissions is increasing rapidly , particularly for nitrous oxide. Also, the main source of nitrous oxide are diesel-driven trucks and buses. For carbon monoxide , transport accounted for 48% , industry 34% and the remaining 18% was due to "domestic " sources in 1990. Hence, transportation is the most major source, although there are other significant sources. And finally, lead emissions are wholly accounted for by the use of leaded petrol in transportation.

Hence for Calcutta, industry is still the most major source of pollution, especially as SPM concentrations are the main culprit – however, transportation takes up a large share of the responsibility (averaging around 40%), especially for the non-SPM pollutants and has the potential to become the biggest problem , especially in the light of the fact that industrial development has been limited and controls on industry are well under way. Industrial emissions have stabilized or declined already (54, 55).

As regards health impacts, it is estimated by NEERI (National Environment Engineering Research Institute) that around 60% of Calcutta's residents suffer from air-pollution related respiratory disease. The number of patients with bronchial problems and allergic asthma has roughly doubled in the minutes, according to an opinion survey of a random sample of general practitioners.

Contributions of Various Modes.

In general, two-stroke scooters, motorcycles and autos constitute a major part of the vehicle fleet and are responsible for much of the emissions. They contributed to 44% of CO and 71% of HC emissions in 1995-6. Cars contributed to 53% of CO emissions, and buses to 33% of NOx emissions. [1] Buses contribute only 9% of TSP emissions.

As regards gasoline versus diesel vehicles, lead is emitted only by gasoline vehicles and hydrocarbon emissions are higher for gasoline. On the other hand, nitrous oxide , sulphur dioxide and TSP emissions are high for diesel vehicles (56).

Table 25 lists annual energy demand (in million tons of oil equivalent) by gasoline and diesel. This indicates that diesel constitutes a high percentage of demand, and this is expected to increase so that by 2010-11, diesel will constitute the greater percentage.

Table 25

Annual Energy Demand in Million Tonnes of Oil Equivalent

	1990/1	1995/6	2000/1	2005/6	2010/11
Gasoline	160	154	167	166	170
Diesel	94	106	135	156	173

Source : TERI website, vehicular air pollution.

Calcutta : Differences with Cities in U.S. / Europe

From the above discussion we can conclude that there are major differences between Calcutta and U.S. or European cities. The following lists major differences.

- Population density is much higher in Calcutta.
- The land percentage devoted to roads is very low, even lower than other Indian cities, at 4-6%.
- Congestion levels on the road are very high.
- The traffic is also erratic, with slow-moving vehicles inbetween fast-moving ones, and with little enforcement of traffic rules.

1 Two-wheelers are expected to contribute 64% of carbon monoxide and 85% of hydrocarbons by 2010-11, if there are no serious abatement measures. The contribution of cars to CO emissions is expected to decline to 33 percent.

- The potential to build more roads is low.
- The fleet distribution is biased towards two-wheelers but cars also contribute a large percentage. As for the developed countries, personalized modes constitute, , by far, the major chunk.
- However, buses satisfy 32% of travel demand and buses, trams, the metro and other rails and ferry contribute to over 50% of the demand.
- Average incomes are low, as reflected by the number of vehicles per 1000 persons (at 31). The upper and upper middle classes constitute a small percentage of the population.
- The purpose of travel appears to be much more work-based than otherwise, in contrast to U.S. cities.
- The residential pattern is largely non-suburban and mixed with other uses. Hence trip distances are much lower compared to the U.S. Those who travel from the suburban areas, moreover, usually take trains.
- There are certain differences in the purposes of non-work trips between Calcutta and other developed-country cities, due to differences in social behaviour.
- Fuel prices, as a percentage of incomes, are significantly higher compared to the U.S.
- Parking is not as controlled as in urban areas in developed countries and the cost of parking is not high.
- There is not such a strong bias against using public transport as in the developed countries.
- Government finances for air pollution abatement are limited.
- The wages of the police force and other enforcement workers may be increased.
- Labour is cheap and capital is scarce, compared to developed countries.
- There are strong political constraints for making travel more expensive for the lower income groups or for increasing the costs of public transport operators.

The implications of these differences will discussed in the next chapter.

Regulatory Measures in India and Calcutta

The Air (Prevention and Control of Pollution) Act was passed as late as 1981, allowing the Central Pollution Control Board to set national air quality standards and carry out related functions, and the State Pollution Control Board to petition local magistrates to restrain polluters from exceeding these standards. The State Board, moreover, has a number of other functions that are similar to the Central Board. In particular , the latter has to work in conjunction with the Central Government and the former with the State Government. The State Board , of course, is answerable to the Central Board. Hence there are many overlapping functions and there is a great deal of scope for greater clarity in terms of jurisdiction. Other organizations which are typically involved in regulatory functions are the courts, the Ministry of Petroleum and Natural Gas, the motor vehicles departments and the police department. Also, the State Board works under at least three organizations and therefore has limited powers (57).

The State Board is also limited by a paucity of funds. In 1987-88, it obtained a funding of only Rs. 4.5 million which rose to Rs 14.646 million in 1994-5[1]. However, interestingly, the Board had surpluses about half the time between 1987-88 and 1994-5. The reason, probably, is because the Board has operated in a very limited fashion, with nearly no attention given to motor vehicle pollution. Recent funding from Japan and the National Ambient Air Quality Monitoring (NAAQM) network has allowed the Board to set up more offices, a laboratory and more monitoring stations (58).

Very little has been done in the area of vehicular pollution, and nearly nothing for Calcutta. Much of the action in vehicular pollution regulation has concentrated on Delhi. A " White Paper on Pollution in Delhi with an Action Plan " has been written and partially `implemented.

Many of the bans and other rules are for Delhi. For example, from 31st December, 1998, there was a ban instituted on the separate sale of mobile oil in Delhi. A list of cities which have to have catalytic converters on four-wheeler gasoline vehicles during registration on or after the 1st of August, 1998 does not include Calcutta. Commercial vehicles older than 17 years have had their permits cancelled in Delhi, and operating vehicles have been impounded.. These vehicles are released if an undertaking is given to sell the vehicles *outside* Delhi. A scheme has also been developed for the purchases of new vehicles by the owners of the phased out vehicles (more than 15 years old) which includes (a) an exemption from sales tax at 8% and (b) a subsidy of 4% on the interest rates on loans. Bus terminals have been constructed in the peripheries, to prevent inter-state buses from entering the city. The number of outlets for CNG is proposed to be expanded from 9 to 80. Fuel supplied in Delhi is checked by authorities for adulteration (59, 60).

However, some of the regulations imposed nation-wide and in Delhi are bound to have some impact on Calcutta. The Central Motor Vehicles Rules of 1989 specified gross emissions standards for on-road vehicles and mass emission standards for all categories of new vehicles. Limits have been placed on carbon monoxide emissions for gasoline fueled cars, motorcycles and three-wheelers (see Table 26). Diesel smoke emissions are limited to 75 Hartridge units at full load. In 1992, diesel vehicles were controlled based on ECE R49. These limits are equivalent to ECE (15-04) but with test procedures adjusted to Indian driving conditions. Evaporative emissions, however, are not regulated.

Emission norms were made tighter in 1996. All two-stroke engines in two and three wheelers have to comply with the following (in grams/km.)

	CO	HC & NOx
Three wheelers	6.75	5.41
Two wheelers	4.50	3.50

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1 currently, a dollar is equal to around Rs. 44.

In 1984, NAAQM was established to monitor air qualities, and it has its monitoring stations in Calcutta, too. The national ambient air quality standards are given in Table 27. Correspondingly categories of ambient status are set up, as given in Table 28. By this categorization, Calcutta has critical values of SPM in residential areas, but moderate to low values for sulphur dioxide and nitrous oxides and Howrah, adjacent to Calcutta , has critical values of SPM, sulphur dioxide and nitrogen dioxide in residential areas. SPM values are "moderate " in the industrial areas of Howrah. Table 29 gives categories for the different pollutants in Calcutta.

Table 26

Exhaust Emission Standards for Gasoline-Fueled Vehicles, India (grams per kilometer)

Reference mass (kilograms)	Carbon monoxide	Hydrocarbons
Two-and three-wheel vehicles		
Less than 150	12	8
150-350	12+(18*(R-150)/200)	8+(4*(R-150)/200)
More than 350	30	12
Light-duty vehicles		
Less than 1,020	14.3	2.0
1,020-1,250	16.5	2.1
1,250-1,470	18.8	2.1
1,470-1,700	20.7	2.3
1,700-1,930	22.9	2.5
1,930-2,150	24.9	2.7
More than 2,150	27.1	2.9

R = Reference mass

Source : Faiz et al, 1996.

Table 27

National Ambient Air Quality Standards

Pollutant	Sulphur Dioxide (SO2)		Oxides of Nitrogen (NO2)		Suspended Particulate Matter (SPM)	
	*	**	*	**	*	**
Time Weighted Average	Annual Average	24-hours Average	Annual Average	24-hours Average	Annual Average	24-hours Average
Industrial Area	80 ug/m3	120 ug/m3	80 ug/m3	120 ug/m3	360 ug/m3	500 ug/m3
Residential Rural and Other Area	60 ug/m3	80 ug/m3	60 ug/m3	80 ug/m3	140 ug/m3	200 ug/m3
Sensitive Area	15 ug/m3	30 ug/m3	15 ug/m3	30 ug/m3	70 ug/m3	100 ug/m3

* Annual Arithmetic Mean of minimum 104 measurements in a year taken twice a week 24-hourly at uniform intervals.

** 24-hourly / 8-hourly values should be met 98% of the time in a year. However 2% of the time, it may exceeded but not two consecutive days.

Source : Ministry of Environment and Forests, NAAQMP, Home Page.

Table 28

Ambient Status
Annual Mean Concentration Range (ug/m ^{3})

Pollution level	Industrial		Residential	
	SO2 & NO2	SPM	SO2 & NO2	SPM
Low(L)	0-40	0-180	0-30	0-70
Moderate (M)	40-80	180-360	30-60	70-140
High (H)	80-120	360-540	60-90	140-210
Critical (C)	>120	>540	>90	>210

Source : Ministry of Environment and Forests, NAAQMP. Home Page.

Table 29

West Bengal Ambient Air Quality

	SO_2 1995		SO_2 1996		NO_2 1995		NO_2 1996		SPM 1995		SPM 1996	
	I	R	I	R	I	R	I	R	I	R	I	R
Calcutta	M	M	L	L	L	M	L	M	H	C	H	
Howrah	L	C		C	C	C		C	M	C	M	C

Note : I : Industrial Area R : Residential Area ; C : Critical L : Low M : Moderate
Source : Ministry of Environment and Forests. NAAQMP. Home Page.

Low-lead petrol of .15 grams per litre was introduced in the four major cities including Calcutta from June 1994. Unleaded petrol (less than .013 grams per litre) was introduced from April 1, 1995. From Sept.1, 1998, all retail outlets in Delhi began supplying only unleaded petrol, but the whole country is supposed to have been covered from April 1, 2000. Low sulphur diesel (with sulphur content of .5%) was supplied in all four cities from April 1, 1996. From April 1, 1999 diesel is supposed to have .25% sulphur throughout the country (61).

Committees have also been set up for a further tightening of emissions norms and for developing alternative fuels such as CNG , LPG and an ethanol - gasoline blend. The ministry of Petroleum and Natural Gas has recommended separate norms for cars fitted with catalytic converters, at 50% lower values compared to cars without them, as given in Table 30.

Table 30

Emission Standard for Petrol Driven Four-Wheelers

Pollutant	Without Catalytic Converter	With Catalytic Converter
CO (gm/Km)	8.68 – 12.40	4.36 – 6.20
HC + NO (gm/Km)	3.0 – 4.36	1.5 – 2.18
Total (CO+HC+NO)	11.68 – 16.76	5.84 – 8.38

Source : MOEF, India Annual Report 1998-99.

In Calcutta, Euro I standards are already in force and Euro II emissions norms are supposed to be initiated from April 1, 2000.Moreover, it was attempted to phase out taxis older than 17 years in 1999, but the attempt failed due to union-organised strikes. A decision on the phase-out age of buses, minibuses, trucks, vans and autorickshaws is to be taken in August, 2000. From August 1, restrictions on emissions levels by old vehicles (both public and private) are to be imposed and all vehicles will have to have " Pollution Under Control " certificates by that date (62).

Thus, in the last few years , some steps have been taken in the area of regulatory controls, although even here, Calcutta is far behind Delhi. Moreover, nearly nothing was been done in terms of economic measures or demand management. On the other hand, some steps in systems management have been taken and are planned such as more roads, connectors to the bypass, under passes and flyovers, one-way streets, and so on.

VIII

The Implicated Policy Package for Calcutta

Based on the essential features of the city (Section VII) and on the theory and practice of transportation policy for the control of vehicular air pollution (Sections II to VI), we may arrive at a set of recommendations for a suitable policy-frame for Calcutta.[1]

Firstly, it is clear that the indispensable core of any pollution control regime has to be a carefully-structured set of standards, accompanied by the regular inspection and maintenance of vehicles . India has already taken some steps in the direction of standard-setting and some form of inspection is also in force. However, a great deal needs to be done to enforce the regulations and run fool proof inspection and maintenance systems : the loopholes are obvious in Calcutta and also in the rest of India. We have seen that a privately contracted but centralized inspection system would be the best, with maintenance carried out by (separate) private garages. The costs can be recovered from the vehicle-owners, with a percentage going to the state government for coordinating the system. These costs depend on the nature and level of inspection : that can be kept moderate, so that costs are also moderate. Inspection costs, we have seen, have gone down significantly over the years, with technological developments. However, maintenance costs would not be so insignificant. The concern is not for owners of personalized modes, but for public vehicles - for greater costs would increase fares and that would be borne by the less affluent. Thus, implications in terms of public transit fares do have to be taken into consideration. It should also be kept in mind that the standards should be based on costs of enforcement and should therefore not be too stringent. They can be updated over the years, in accordance with technological developments that allow easier enforcement.

We have also discussed differentiated standards. The standards should definitely be different for different modes and fuels. Moreover, the equimarginal principle tells us that they should be more stringent for those who can abate more easily. Thus, the standards for older cars should be less strict. Also, vehicles which are used more and which are used in heavily congested areas should have stricter standards, as the damages created by these vehicles are greater. Thus one possibility, as a preliminary step, is to target public transits such as buses, autos and taxis for stricter enforcement given constraints on enforcement costs.

There have been aborted attempts in the city to phase out commercial vehicles older than 17 years. This, as we have seen, is a regressive policy and may not even be politically feasible. Another (more gradual) way of phasing out would be to incorporate this in the inspection and maintenance program, with prohibitive maintenance costs at a certain level of emissions. Alternatively, one may soften scrapping policies by providing benefits for the purchase of a new vehicle after scrapping the old one, such as sales tax exemptions. A payment may even be made

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1 These recommendations can, in part, be applied to other cities which have some of Calcutta's features.

for the old car, and finances for this may be collected by taking a deposit when a new car is purchased. However, fully compensating the vehicle-owner is impossible and hence if scrapping policies are implemented, care should at least be taken to base the scrapping age on average emissions of vehicles of different ages and on a concept of unacceptable emissions.

As regards technological aspects, the international nature of the car industry is clearly to India's advantage. There should be no problems in incorporating new low-emissions technologies in the production of new cars, if the government chooses to enforce this. The price increases implied by some of the *latest* technologies are prohibitive –we have looked at some of the *reasonable* technologies in Section VI . It is certainly imperative to look at what the other Asian counties are doing, and co-ordinate with them. Like these countries, India should concentrate on controlling two and three-wheelers and diesel-fueled engines. We must also keep abreast of developments in alternative fuel technologies that are taking place in the advanced nations. It is very necessary to explore the possibility of using CNG and LPG, which are cost wise most comparable to gasoline, for mass transit systems such as buses which have high mileages and are largely used in very congested areas. Gradually, India may even think of developing its own research institutes for pioneering work in the area of technologies suited to Asian conditions.

Whereas the latest technologies have easily been adopted for new cars, retrofitting old cars has been more difficult. The know-how for such retrofitting has to be updated and implemented in the private garages that carry out maintenance.

In general, the case for international co-operation in the field of technologies for the control of vehicular air pollution is very strong. In particular , a world-wide standardization in production is imperative. Other technologies such as for retrofitting, inspection and signalization should also be adopted at a faster pace.

Another indispensable feature of vehicular pollution control has to be the use of unleaded gasoline . It is imperative that leaded gasoline be totally removed from circulation. One major cost in completely shifting to unleaded gasoline is in developing sufficient refining capacity- but it this hurdle is overcome, the additional cost of unleaded over leaded is very little (Part VI). But the benefits of unleaded gasoline are so great that this has to be made universal , irrespective of cost.

The development of a data bank is of course imperative in order to take on a meaningful and effective policy package. This work, as mentioned earlier (Part IV), can be undertaken by a research institute, a government department , an NGO or some combination of organizations. Although setting up the data for the use of policy makers is most important, the involved-organization/s should also carry out policy-related analyses, using the data. Data collection and analysis are somewhat expensive, but this is an absolutely necessary feature of a pollution control regime. Such activities are currently sparse and sporadic and they have to be (at least) coordinated (if they cannot be brought under a single organization).

We now come to the other, perhaps less indispensable measures – mainly in the realm of economic measures (taxes, pricing, etc.) and Transportation Demand Management – TDM (and also Systems Management , TSM). Although, as we have seen, these measures are quite crucial, the way that these differ from the ones we have discussed so far is that one may pick and choose from them, depending on their relative costs and merits. Thus, policy structuring becomes particularly relevant when we come to *these* measures.

In fact, a number of factors favour economic measures such as taxes : they are efficient , they automatically ensure the equimarginal principle, they require less information , they encourage innovation (in the area of emissions control technologies). Most importantly, taxes or fines bring in net revenues which can be used for other kinds of pollution-abating activities. However, taxes are politically less feasible relative to standard-setting, subsidies or TDM. Given the numerous advantages of taxes, and given that taxes would primarily affect the more affluent vehicle-owners or industry, steps should be taken to introduce some taxes, perhaps initially at low rates. Possible taxes would be on fuel (differentiating between types of fuel), on new vehicles (where there may again be differentiation based on emissions levels), at the point of inspection or registration (emissions tax), or on the *production* of vehicles (again , based on emissions levels). Taxes would be financially more feasible and morally acceptable, relative to subsidies. It would , however, be important to evaluate the effects induced on employment (of workers in vehicles and fuel industries) and on consumers (in particular, users of public transport). Another factor that should be ensured without fail is to spend the tax revenues on other policies for air pollution abatement. This ensures that the cost incurred for air pollution abatement is re-injected into this sector so that there is no " social " cost for abatement.

The other ' market ' tool (apart from measures related to TDM, which I shall discuss subsequently) is Tradable Discharge Permits (TDP). These can be used for regulating the production of new cars or fuel by firms. It would be difficult to use them effectively to control the emissions by vehicle owners. Thus, the usefulness of TDPs appears to be limited.

As we have already discussed (sections IV, V and VI), TDM is important because it directly addresses the problem of reducing total VMT , and it is particularly relevant for Calcutta as, unlike cities in the U.S., the land-use pattern is not suburb-oriented, trips are largely work-based, fuel prices are high relative to incomes, road-space is limited and the bus system and other public transits are already extensively used – all of this discourages the excessive dependence on SOVs. What is necessary, for Calcutta, is really to discourage the *trend* in the direction of using personalized vehicles and also to not lose sight of the objective of minimizing the need to travel by motorized modes in all planning activities.

TDM, unlike the other tools, requires the state to bear some costs. However, some of the measures involve little or no cost, and many of the measures involve labour costs rather than capital costs - hence they are cheap and there is the added advantage of creating employment.

Of the various TDM measures, it has been seen that improving the mass public transit system, combined with well-enforced parking restrictions and prohibitive fines and charges is very effective – and this would be all the more effective for Calcutta , where public transit is well developed. When it comes to a choice between the various forms of mass transit (buses, trams, the metro, rail transport, ferry), however, the answer is not easy and would require specialized research. Rail systems and particularly underground rail systems are very expensive to set up and operate- but both the circular rail and the metro appear very crucial for Calcutta., given its tremendously limited road space. It would perhaps be best to give importance to all these systems, and in particular, look at the mass transit system as a whole, so that the problems of transferring and of access are extensively addressed. I have already mentioned the various features of improving mass transit (section IV) and have noted the fact that fare reductions have been seen to be less effective relative to improving the quality of service, especially in the long run. However, it would be useful to develop a variety of transit systems – having a broad range of fares. Some buses, for example, may be given luxury features such as air conditioning and comfortable seating, and highly priced. The private sector may be encouraged to provide such luxury bus services. Some measures have been taken in this direction, but there is a great deal of scope to intensify these measures and in particular, provide mass transit which closely substitutes SOVs. The reduction of waiting times (at bus stops) is also very crucial here. There is much scope to improve the circular and local railway, and the ferry system. I would like to stress that transit improvements would have even greater impacts if parking restrictions are much more severe than they currently are.

The other measure that would be very effective is reducing the work week to at most 5 days (if not 4) - Saturday is a working day at most work places. Also, land use management should be given much greater importance than has been previously – particularly for new developments. Greater care can also be given to already-developed areas, to ensure that various facilities are available in residential localities. Although there are strong limitations to changing the present land use structures, many possibilities would crop up if some care is devoted to this aspect. Another measure that has some potential is to make it mandatory for children to attend local schools – this would, however, have other major implications which cannot be discussed without elaborate investigation in the area of school education in Calcutta.

Measures such as ridesharing (carpools and vanpools), staggered work hours, congestion tolls, peak hour charges, AFZs, preferential lanes or parking and no-drive days based on license plate numbers may be looked into – there does not appear to be a strong applicability for Calcutta, but each of these should be given consideration and perhaps even be tried out to a small extent, to determine their effectiveness. It is important to note, especially in the context of Calcutta, that ridesharing facilities may be availed of by those who were earlier users of mass transit, thereby actually increasing emissions per individual.

Some of the TDM measures such as fringe-parking and bicycle and pedestrian facilities would be inapplicable for Calcutta, due to very high land price and low road space.

Of the tools in TDM that have been discussed, those that involve fines, tolls and charges are most cost-effective. The cost of operating these systems is recovered, and revenues collected – to be used for other measures. Some involve no cost - such as work-week reductions (assuming that production is not affected). Some other tools are labour-intensive and hence more feasible - eg. ridesharing programs. Also, ridesharing and some other measures, by saving on fuel use, have non-environmental benefits which must not be underrated. Transit improvements, unfortunately , can be quite expensive – but they also yield high benefits and are indispensable in high-density urban areas. The way out would be to fund transit improvements through taxation and other fines and tolls.

Transportation System Management (TSM) is another set of tools, closely connected to TDM, and important . The major elements of TSM are (a) smoothly moving traffic (achieved through traffic rule enforcement, advanced signalization, incident management , arrangements for bus stops, underpasses and overpasses, flyovers, etc.) and (b) new roads. The disadvantage of TSM lies mainly in the fact that reducing congestion and jams encourages the use of SOVs and increases VMT. New roads, in particular, induces the demand for SOVs. Also, some of the measures (especially involving the building of new structures) are very capital intensive and costly. Thus TSM should not be an objective for reducing air pollution, per se. On the other hand, the reduction of congestion and chaos on roads is an objective by itself, and TSM should be a major part of any urban transportation policy. If it benefits the environment (and apparently TSM sometimes improves the environment more than it deteriorates it), all the better. But it should be stressed that major construction projects should not be carried out in the name of air quality improvements.

Much of the policies discussed so far become meaningless without absolute enforcement. India should be having an advantage in this given that labour is cheap - but perhaps wages are too low and when it comes to deciding between employing more enforcement officials and building new flyovers, decisions are perhaps made in favour of construction projects which are visible and hence politically more attractive. The low wages also encourage corruption, which takes away the efficacy of inspection and traffic regulations. It is imperative, therefore, to address the question of enforcement, to employ more enforcement officials and pay them well.

Finally, as for other environmental policies, the involvement of the public is critical. It is , of course, important that the public is well formed regarding the facts and what is being done to abate air pollution. But it is also important to make the public aware of its moral responsibilities, and even to involve the public in decision-making. The extent to which the latter should be done, however, is debatable because of the costs of arriving at a consensus.

In sum, vehicular air pollution control in Calcutta requires regulations (in the form of standards, inspection and unleaded gasoline) – but moderation and differentiation should be exercised in determining emissions limits (with possible reductions in these limits in the longer run), combined, however, with absolute enforcement. In addition, a basket of other tools should be used, and demand management should be given far greater priority that it has been in the advanced nations. Severe financial constraints necessitate the use of taxes, fines and tolls, which can also fund other measures, coupled with the avoidance of capital-intensive measures.

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