A MULTIPLE-OBJECTIVES APPROACH TO ADDRESS MOTORIZED TWO-WHEELED VEHICLE EMISSIONS IN DELHI, INDIA

by

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ABSTRACT

Motor vehicle activity is growing and air quality is deteriorating rapidly in Indian and other less-industrialized country cities. The contribution of transport to air pollution is increasing. Motorized two-wheeled (M2W) vehicles, mainly powered by two-stroke engines, account for a significant proportion of motor vehicle activity and emissions. These issues are important because, in addition to local health and welfare impacts, they have important implications for energy security, acidification and climate change. The challenge in terms of M2W vehicles is to address their emissions while minimizing adverse policy impacts for vehicle users, since these vehicles provide mobility to millions.

The dissertation illuminates key aspects of the M2W vehicle air pollution problem, and reports on policy-relevant research related to M2W vehicle emissions in Delhi. It investigates contributory factors and the institutional setting, and explores the policy implications of critical vehicle user choices and perspectives. The dissertation proposes an analytic framework for effective policy-making and implementation, and multiple objectives and measures to characterize the impacts of policy alternatives.

Information sources include published and unpublished literature on various aspects of the problem, discussions with decision makers, industry representatives and researchers, and a questionnaire survey of, and in-depth interviews with, M2W vehicle users.

The dissertation demonstrates the importance of considering system-wide emissions due to vehicle activity, technology-human behaviour-political institution interactions, in-use realities and institutional constraints, and implementation issues including how vehicle users are affected by and respond to policies. In addition to these issues, the policy-analytic framework incorporates a wide range of policy impacts, and the concerns of various actors and affected groups, to address transport air pollution effectively and equitably over the long term.

It is argued that policy-making and implementation should be adaptive and flexible, and promote continual learning, for policy effectiveness. While considering implementation issues will lead to robust policies, policies that minimize reliance on expensive technologies and institutional mechanisms, and that are impervious to in-use realities and constraints, should be implemented. Since technological measures can be neutralized over time, and given multiple

transport impacts and constrained resources, the aim should be to achieve transport synergies, in addition to improving air quality.

Keywords: Urban Transport, Air Quality, Less-Industrialized Countries, Motorized two-wheeled vehicles, Policy Making and Implementation, Human Dimensions, Multiple Objectives.

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GLOSSARY

AIAM	Association of Indian Automobile Manufacturers, Mumbai and New Delhi, India
AIIMS	All India Institute of Medical Sciences, New Delhi, India
APM	Administered Pricing Mechanism
AQ	Air Quality Improvement
ASRTU	Association of State Road Transport Undertakings, New Delhi, India
BaP	Benzo(a)pyrene
BAU	Business-as-usual (scenario)
BC	British Columbia
BIS	Bureau of Indian Standards, New Delhi, India
CBA	Cost-benefit Analysis
CE	Cost-effectiveness
CFC	Chlorofluorocarbons
CIRT	Central Institute of Road Transport, Pune, India
CNG	Compressed Natural Gas
CoHB	Carboxyhaemoglobin
CoP	Conformity of Production
COPD	Chronic Obstructive Pulmonary Disease
CPCB	Central Pollution Control Board, New Delhi, India
CRRI	Central Road Research Institute, New Delhi, India
CSE	Centre for Science and Environment, New Delhi, India
CV	Contingent Valuation
DCB	Delhi Cantonment Board, New Delhi, India
DDA	Delhi Development Authority, New Delhi, India
DPCC	Delhi Pollution Control Committee, New Delhi, India
DTC	Delhi Transport Corporation, New Delhi, India
DUA	Delhi Urban Area
ECE	Economic Commission for Europe
EPEFE	European Programme on Emissions, Fuels, and Engine Technologies
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
ESI	Employees' State Insurance Corporation (India)
FE	Fuel Efficiency Improvement
FTP	Federal Test Procedure (US)
GEMS	Global Environment Monitoring System
GNP	Gross National Product
GoI	Government of India
GVRD	Greater Vancouver Regional District
GVW	Gross Vehicle Weight
HSU	Hartridge Smoke Unit
I&M	Inspection and Maintenance
IARC	International Agency for Research on Cancer, Lyon, France
IDRC	International Development Research Centre, Ottawa
IIP	Indian Institute of Petroleum, Dehra Dun, India

IIT Delhi	Indian Institute of Technology, Delhi, India
INR	Indian Rupee
IP	Interview Protocol
ITO	Income Tax Office, New Delhi, India
JNU	Jawaharlal Nehru University, New Delhi, India
JTW	Journey to Work
LCV	Light Commercial Vehicle
LIC	Less-industrialized country
LPG	Liquefied Petroleum Gas
M-O	Multiple-objectives
M2W	Motorized two-wheeled (vehicle)
M3W	Motorized three-wheeled (vehicle)
MCD	Municipal Corporation of Delhi, Delhi, India
MoEF	Ministry of Environment and Forests, Government of India, New Delhi, India
MoF	Ministry of Finance, Government of India, New Delhi, India
MoH	Ministry of Health, Government of India, New Delhi, India
MoI	Ministry of Industry, Government of India, New Delhi, India
MoPNG	Ministry of Petroleum and Natural Gas, Government of India, New Delhi, India
MoST	Ministry of Environment and Forests, Government of India, New Delhi, India
MQ	Survey Questionnaire
MRTS	Mass Rapid Transit System (New Delhi, India)
MTBE	Methyl tertiary-butyl ether
NAAQM	National Ambient Air Quality Monitoring Programme (India)
NAAQS	National Ambient Air Quality Standards (India)
NCR	National Capital Region (India)
NCTD	Government of the National Capital Territory of Delhi, New Delhi, India
NDMC	New Delhi Municipal Corporation, New Delhi, India
NEERI	National Environmental Engineering Research Institute, Nagpur, India
NGO	Non-governmental organization
NMT	Non-motorized transport
OCC	Oil Co-ordination Committee, Government of India, New Delhi, India
OECD	Organization for Economic Cooperation and Development
ORG	Operations Research Group, Baroda, India
PAH	Polycyclic Aromatic Hydrocarbons
persons/ha	persons per hectare
PKM	Passenger-kilometres
PM	Particulate Matter
ppm	parts per million
PUC	Pollution Under Control (Certificate) (New Delhi, India)
Q	Question
R&D	Research and Development
RFG	Reformulated Gasoline
RITES	Rail India Technical and Economic Services Ltd., New Delhi
RPM	Respirable Particulate Matter

RVP	Reid Vapour Pressure
SAE	Society of Automotive Engineers (USA)
SOF	Soluble Organic Fraction
SPM	Suspended Particulate Matter
SQ	Supplementary Questionnaire
TERI	Tata Energy Research Institute, New Delhi, India
TSM	Transport System Management
TSP	Total Suspended Particulates
TVS	T. V. Sundaram Iyengar Group of Companies, India
UBC	The University of British Columbia, Vancouver, BC
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
VKM	Vehicle-kilometres
VOC	Volatile Organic Compounds
WHO	World Health Organization
WTAC	Willingness to Accept Compensation
WTP	Willingness to Pay
% vol.	Percentage on a volume basis
µg/dl	Micrograms per decilitre
$\mu g/m^3$	Micrograms per cubic metre
µm	micrometre
°C	Degrees Celsius
O_3	Ozone
2-T	(Lubricant for) two-stroke spark-ignition air-cooled gasoline engines
cc.	Cubic centimetres
Cdn$	Candian Dollar
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
dB(A)	Unit of relative intensity of sound, using the A weighting network, which discriminates against low frequency sounds
g/km	Grams per kilometre
g/l	Grams per litre
g/m^3	Grams per cubic metre
g/pass-km	Grams per passenger-kilomtre
HC	Hydrocarbons
km	Kilometre
km/h	Kilometres per hour
km/l	Kilometres per litre
kPa	Kilopascal
mg/m^3	Milligrams per cubic metre
ml	Millilitre
N_2O	Nitrous Oxide
ng/m^3	Nanograms per cubic metre

NO_2	Nitorgen Dioxide
NO_x	Nitrogen Oxides
OH	Hydroxyl radical
Pb	Lead
PM_1	Suspended particulate matter of diameter 1 micrometre or less
PM_{10}	Suspended particulate matter of diameter 10 micrometres or less
$PM_{2.5}$	Suspended particulate matter of diameter 2.5 micrometres or less
SO_2	Sulphur Dioxide
SO_x	Sulphur Oxides
T_{90}	Temperature in degrees Celsius at which 90% of the fuel evaporates and is recovered in the distillation process
US$	United States Dollar

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CHAPTER I
INTRODUCTION

1.1 BACKGROUND, AND THE PUBLIC POLICY CHALLENGE

Global motor vehicle numbers and activity are growing rapidly. If present trends continue, the global motor vehicle fleet is likely to double from its 1990 level of around 700 million by 2020. While the OECD countries account for the bulk of global motor vehicle activity, much of the growth will likely be concentrated in the less-industrialized countries (LICs), including in Asia. Motor vehicle numbers are doubling every 7-10 years in many Asian LICs. By 2040, rapidly industrializing LICs could have as many vehicles as North America and Western Europe. An important characteristic of motor vehicle activity in Asian LICs is the predominance of motorized two-wheeled (M2W) vehicles (Faiz et al 1992; Sathaye, Tyler and Goldman 1994; Walsh 1991a; Walsh 1994).

Because of the concentration of motor vehicular and other energy-intensive activities in LIC megacities, air quality in these cities is deteriorating rapidly, and could soon rival Mexico City's, where levels of several air pollutants already exceed WHO limits by more than a factor of two. Further, because of the large populations of urban poor, who suffer from inadequate nutrition and limited medical care, significant health impacts ensue. The contribution of transport to air pollution in LIC cities is significant and growing (Brandon and Ramankutty 1993; CPCB 1995; CPCB 1996; CSE 1996; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman 1991; WHO/UNEP 1992).

The trends in motor vehicle activity and urban air quality in the LICs are abundantly evident in India. India's motor vehicle fleet increased from only 665,000 in 1961, and 5.4 million as late as 1981, to over 27 million in 1994. The fleet is likely in the range of 40 million as of 2000. M2W vehicles are the most rapidly growing vehicle type in India, and represent around 67% of motor vehicles nationally. India arguably has the largest population of this vehicle type of any country. In the Indian capital, Delhi, motor vehicles grew 20% annually in the 1970s and 1980s, as against a population increase of 5-6% per annum. While motor vehicle numbers no longer appear to be increasing at the same pace, they are still growing at around 8% per annum. In 1996, around 2.6 million motor vehicles were registered in the city.

Of these, about 1.7 million were M2W vehicles. If current trends persist, Delhi will likely have around 5.2 million motor vehicles by 2005. Around 3.4 millions of these will likely be M2W vehicles (AIAM 1994a; AIAM 1995; ASRTU/CIRT 1997; Faiz et al 1992; Mohan et al 1997; TERI 1997; WHO/UNEP 1992).

Air quality in Delhi is poor, and deteriorating. In particular, annual average suspended particulate (SPM) levels, which are strongly correlated with respiratory and cardiovascular diseases, have been routinely around five times the World Health Organization (WHO) guideline limit since the 1980s. Daily average SPM levels exceed WHO limits almost every day, with peak levels as high as 6-10 times the WHO limit at many sites. Daily average sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) levels exceed WHO guideline limits on several days of the year, at several sites. Ozone appears to be a major problem, especially in winter (CPCB 1995; CPCB 1996; CSE 1996; WHO/UNEP 1992).

The contribution of transport to air pollution is growing in Delhi, as in many other Indian and LIC cities (CPCB 1996; CSE 1996; Faiz et al 1992). Because M2W vehicles are used intensively, and are for the most part powered by highly polluting two-stroke engines, these vehicles play an important role in transport air pollution, particularly on a passenger-kilometre basis (ASRTU/CIRT 1997; Bose 1996; CPCB 1997; GoI/ESCAP 1991; IIP 1994; Shah and Nagpal 1997).

The rapid growth in motor vehicle activity in Delhi and other LIC cities has important implications for local well-being, in terms of air pollution, road safety, land use, access and mobility, and other transport impacts. This growth also has implications for regional and global issues such as energy security, acidification and climate change. While the OECD countries account for about two-thirds of global commercial energy consumption due to transport, their demand growth is expected to be flat or growing slowly. On the other hand, LIC transport energy demand, currently only around one-third that in the OECD, could increase as much as three times in as many decades. Transport already consumes around 45% of the world's oil, and is the fastest growing end-use category. India's and China's combined oil consumption accounts for 6.6% of the world's, but is increasing at 6.4% per annum, while world oil consumption is increasing at 1.5% per annum (Brandon and Ramankutty 1993; Flavin and Lenssen 1991; Grübler 1994; Holdren 1990; TERI 1997).

Air pollution due to M2W and other motor vehicles, and more generally, transport-energy-environment linkages in India and other LICs, are therefore issues worthy of public policy attention. M2W vehicles play an important role in transport air pollution in Delhi and other Asian LIC cities, but they also provide mobility to millions who have few other attractive options (Sathaye, Tyler, and Goldman 1994). Thus, the public policy challenge in terms of M2W vehicle emissions is to address the problem while minimizing adverse policy impacts for vehicle users. This challenge is made more daunting by the fact that transport air pollution is far more difficult to control than stationary source emissions, because it is more complex in its causes and effects, and involves a large number and variety of motor vehicles (Faiz et al 1992), and the choices of millions of vehicle users. Finally, the institutional setting for policy-making and implementation in the Indian and LIC contexts is characterized by serious technological, financial and administrative constraints (Author's survey and interviews 1997; Brandon and Ramankutty 1993; Douglass and Lee 1996; Faiz et al 1992; Hardoy, Mitlin and Satterthwaite 1992).

It is this challenge that provides the rationale for this dissertation, which focuses on policy analysis of air pollution due to M2W vehicles in Delhi. This focus is all the more relevant because the city's rapid growth in motor vehicle activity, particularly in terms of M2W vehicles, and its deteriorating air quality, are features shared by many other Indian and LIC cities.

1.2 RESEARCH OBJECTIVES AND APPROACH

This dissertation has two objectives. The first is to contribute to a more thorough understanding of, and to the academic policy analysis literature on, transport air pollution in the Indian and LIC contexts. The second objective is to inform policy-making and implementation for prevention and control of M2W vehicle air pollution in those contexts. The dissertation attempts to achieve these objectives by illuminating key aspects of the M2W vehicle air pollution problem, presenting an analytic framework for addressing the problem effectively, and reporting on policy-relevant research that the author conducted on M2W vehicle emissions in Delhi.

The dissertation addresses the following specific research questions:

- What are the technological, institutional, and vehicle user behavioural factors that contribute to air pollution due to M2W vehicle activity in Delhi?
- What is the institutional setting for prevention and control of transport air pollution in the Indian context? Who are the actors and what are their roles, responsibilities and interactions in terms of policy-making and implementation? What are the institutional barriers and constraints? What are the implications of all of the above for transport air pollution prevention and control in the Indian context?
- What is an appropriate analytic framework for thinking systematically about, and for enabling effective policy-making and implementation with regard to air pollution from M2W vehicles, given the characteristics of the Indian context?
- What are the important vehicle user preferences, choices, and motivations that influence M2W vehicle activity and air pollution in Delhi? What are M2W vehicle user perspectives on various current, proposed and possible policies, in terms of how they would be affected by and would respond to these policies? What measures would likely make these policies more attractive to users? What are the implications for policy-making and implementation, and how can policies be better designed in light of user preferences, choices and perspectives?
- What are appropriate objectives and measures on the basis of which to evaluate policies targeted at M2W vehicle emissions in the Indian context? In this regard, can tools employed with success in Western settings to clarify and structure public policy problems be used to achieve similar ends when applied to a highly complex issue such as transport air pollution in the LIC context?
- What are the broader implications of this study for transport air pollution prevention and control, urban transport, and urban environmental policy and planning in India?

The dissertation research focuses on M2W vehicles in Delhi, but aims to have relevance for transport air pollution generally in the Indian and LIC contexts. Following is a brief introduction to the approaches used to answer the research questions, and their contribution to fulfilling the dissertation objectives.

1.2.1 Contributory Factors

Transport air pollution is a complex and multi-dimensional problem. It is critically important to understand the various factors that contribute to the problem, in order to effectively address it. The dissertation analyses the factors that contribute to M2W vehicle air pollutant emissions in Delhi, and more generally, transport air pollution and energy consumption in India. This analysis can help identify policy levers to target key contributory factors, and make transport emissions and energy consumption measurement and modeling efforts more effective.

The dissertation addresses proximate technological as well as underlying institutional contributory factors. Since transport air pollution is a function of per-vehicle emissions as well as overall vehicle activity, factors that contribute to both of these components of the problem are addressed. Further, the dissertation focuses on system-wide air pollution due to M2W vehicle activity, not merely vehicle exhaust pipe emissions. Also, it addresses important contextual characteristics that critically influence emissions in the Indian context. Thus, technological-curative as well as preventive alternatives may be identified to address the problem comprehensively and effectively over the long term.

1.2.2 The Institutional Setting

The dissertation critically examines the institutional setting in relation to the transport air pollution problem in the Indian context. The actors whose roles, responsibilities and interactions are analyzed include key government agencies at the national and local levels, vehicle and fuel manufacturers, academic and research institutions, environmental NGOs, the courts and public interest litigators, and the media. This analysis can help identify critical institutional barriers and constraints, and mechanisms to overcome them.

The institutional setting is shown to be characterized by a multitude of actors with fragmented, overlapping, and conflicting roles and responsibilities, and by restricted financial, technological, and administrative resources. Actors' interactions have been characterized by conflict. Many current and proposed policies have not been thoroughly considered, in terms of the institutional support mechanisms necessary for their success, or their long-term consequences. The result is that many policies are likely to be costly and burdensome, yet

ineffective in addressing transport air pollution (Author's interviews 1997; CSE 1996; CSE 1997).

1.2.3 Policy Analytic Framework

Given the institutional setting, an analytical framework is needed for systematic thinking and effective policy analysis and implementation with regard to transport air pollution in the Indian context. This dissertation attempts to fulfill this need, by building on similar attempts in the current literature (Faiz et al 1992; Carbajo 1993; Shah, Nagpal and Brandon 1997), and by addressing their shortcomings.

A systematic methodology is proposed for estimating air pollutant emissions due to various policy alternatives. The methodology stresses the need to minimize system-wide emissions due to M2W vehicle activity, over the long term. It takes into consideration important in-use realities, urban transport issues, the inter-dependence between modes and pollutants, and vicious circles and side-effects. Issues that are typically relegated to the policy implementation phase are considered explicitly. So are data uncertainties and variabilities, based in part on informed expert judgments.

Welfare economists suggest cost-benefit analysis (CBA) as an ideal methodology for comparing policy alternatives (Carbajo 1993; Pearce and Markandya in Faiz et al 1992). The dissertation argues that operationalizing CBA would be problematic in the Indian context, because of the technical, conceptual and philosophical difficulties involved in the estimation and monetization of policy benefits. Instead, the framework proposes cost-effectiveness as a basis for estimating and valuing emissions impacts due to policy alternatives, with individual pollutants weighted to reflect their contributions to health, environmental and other impacts of concern. Further, because each policy can potentially have transport impacts other than those related to air pollution, and a range of cost and welfare impacts for different actors and groups, the framework proposes, based on the work of Edwards and von Winterfeldt (1987), Hobbs and Horn (1997), Keeney (1982, 1988a, 1988b, 1990, 1992), Keeney, von Winterfeldt and Eppel (1990) and Keeney and McDaniels (1992), that policy alternatives be evaluated in terms of multiple objectives reflecting these impacts and the diverse interests and concerns of various actors and affected groups.

1.2.4 Vehicle User Choices and Perspectives

Transport air pollution inevitably involves technological issues. At the same time, transport air pollution, and the effectiveness of prevention and control policies, are strongly influenced by vehicle user choices, and by how users are affected by and respond to policies. Indeed, some of the policy difficulties in the Indian context have come about as a result of these issues not having been adequately considered.

An investigation into these human dimensions would be useful in targeting critical user behavioural factors that contribute to transport air pollution. It would also be useful in developing policies that are attractive to users, and therefore have a greater chance of being effective in the long term. But neither the urban transport literature focused on the LIC context nor the environmental policy analytic literature related to transport air pollution (for example, Faiz et al (1992), RITES/ORG (1994), Shah, Nagpal and Brandon (1997)), pay much attention to vehicle user behavioural factors and perspectives as they specifically relate to transport air pollution and emission prevention and control policies.

This dissertation attempts to address these gaps. Based on information gathered from a questionnaire survey of, and in-depth interviews with M2W vehicle users in Delhi, the dissertation investigates important M2W vehicle user and user household preferences, choices and motivations that influence M2W vehicle activity and air pollutant emissions in Delhi. These preferences, choices and motivations relate to vehicle ownership, mode choice, daily travel, and vehicle purchasing, operation, maintenance, disposal and replacement. The dissertation also investigates user perspectives on various technological and regulatory policy alternatives targeted at M2W vehicle emissions, on public transit and bicycle commuting, and on measures that would make these policy alternatives and alternative modes more attractive to them. Finally, the dissertation explores the implications of the user choices and perspectives for policy-making and implementation, particularly in light of institutional capabilities and constraints.

1.2.5 Multiple Policy Objectives

Policies to address complex public policy problems such as transport air pollution involve environmental, health, socio-economic, safety and other implications for large sections of the

public and for future generations. They also involve multiple stakeholders, with multiple, conflicting interests and concerns. Gaining an understanding of these impacts, interests and concerns, and developing a broad range of policy objectives that reflect them, would be useful in terms of understanding the barriers to policy-making and implementation, and in designing policy packages that represent a win-win condition for all, thus enhancing chances of long-term policy success (Edwards and von Winterfeldt 1987; Keeney 1982; Keeney 1988a; Keeney 1992; Keeney and McDaniels 1992; Keeney and McDaniels 1999). Further, given the lack of effective co-ordination, and the tenuous linkages between the policy-analytic and decision-making communities in the Indian context (Kandlikar 1998), an integrative perspective on what is a multi-dimensional problem would be particularly valuable. Unfortunately, policy objectives for transport air pollution prevention and control are not well understood or articulated, and are therefore not considered in policy-making and implementation.

Analytical methods to clarify and structure public policy problems characterized by multiple stakeholders with multiple conflicting objectives are well established, and have been applied to a diversity of policy situations in Western settings. These problem-structuring tools of "value-focused thinking", which directly involve stakeholders to identify key public values, enable selection of alternatives that better serve these values (Keeney 1988b; Keeney, von Winterfeldt and Eppel 1990; Keeney 1992; Keeney and McDaniels 1992; Keeney and McDaniels 1999). This dissertation applies these tools to better understand the problem of M2W vehicle air pollution in the Indian context, and to identify and structure multiple objectives and measures on the basis of which to systematically create, evaluate, implement and monitor policy alternatives for long-term effectiveness.

Problem-structuring tools to clarify and structure public values have been used in only a few cases in the LIC context (Gregory and Keeney 1994; McDaniels and Trousdale 1999), but have not been applied, to the author's knowledge, to a highly complex situation such as the one this dissertation addresses. At any rate, this is perhaps the first attempt at developing multiple policy objectives related to transport air pollution in the Indian context. In addition to fulfilling an important policy-analytic need in relation to this problem in this context, the

dissertation also addresses the question of whether such tools can be applied to better understand and structure complex public policy problems in LIC contexts generally.

1.3 LEVEL OF ANALYSIS

Any research endeavour inevitably involves choices in terms of problem definition and boundaries, the various aspects of the problem that will be addressed, and policy alternatives that will be evaluated, among other issues. This dissertation is no exception, particularly since it addresses a highly complex, multi-dimensional problem like transport air pollution.

The first choice related to the component of the transport air pollution problem in the Indian context on which to focus. Note in this respect that transport air pollution prevention and control is itself only one part of the much larger problem of how to achieve a resource conserving, environmentally benign, safe, and socially just urban transport system in this context. While fully recognizing the important role of other motorized modes and transport system components, the decision was made to focus on M2W vehicles, based on their intensity of use, contribution to pollution on a passenger-kilometre basis, and their importance to millions of users, as already discussed. Also, it was reasoned that policies targeted at M2W vehicles would have relevance for M3W vehicles as well.

The second choice related to the aspects of the M2W vehicle emissions problem to address. It was decided that this problem would be addressed in its environmental, technological, socio-economic, human behavioural and political-institutional dimensions, in order to gain a thorough understanding of the problem, and to be better able to inform policy-making and implementation. The treatment of contributory factors, institutional setting, vehicle user choices and perspectives, and the policy-analytic framework and multiple objectives and measures as outlined above reflects this decision.

The third choice related to the contributory factors and policy alternatives on which to focus. There is a wide range of factors contributing to the per-vehicle emissions and vehicle activity components of the problem. Correspondingly, there is a wide range of technological, infrastructural, economic, regulatory and transport demand reduction policies that may be applied to address the problem. This dissertation focuses on technological factors and technological and regulatory policies, but recognizes the importance of, and discusses non-

technological factors influencing vehicle ownership and activity, and policies to address this component of the problem. Indeed, these factors and policies are considered throughout the dissertation, in each of the research tasks outlined earlier under Research Approach.

Thus, while the discussion of contributory factors and institutional setting focuses on vehicle and fuel technology, factors such as population growth, income, land use and housing location choice, sprawl and access for non-motorized modes, and transport infrastructure and public transit provision, and actors' roles and institutional constraints with respect to these factors are also addressed. Similarly, M2W vehicle user choices and perspectives are investigated with respect to technological and regulatory policies as well as public transit and bicycle commuting. Lastly, while the policy-analytic framework and multiple objectives and measures apply to technological and regulatory policies targeted at M2W vehicles, they also accommodate other policies. Further, they reflect the interdependence between modes, and between transport air pollution and other transport system impacts, including land use.

In summary, the research approach attempts to reflect the complexity and multi-dimensional nature of the M2W vehicle emissions problem, and integrates environmental policy-analytic, urban transport, engineering and planning perspectives. It is policy-relevant, and sensitive to the Indian context. It explicitly considers contextual capabilities and constraints, implementation issues, and the multiple conflicting interests and concerns of various actors and affected groups, in order to more effectively achieve its objective, which is to inform policy-making and implementation.

1.4 METHODOLOGY

This dissertation draws on published literature on a range of subjects including environmental policy, engineering, urban transport, and urbanization, reflecting the multi-dimensional nature of the transport air pollution problem. Documents relating to the state of vehicle and fuel technology and the urban transport system in the Indian context were also reviewed. In order to gain an understanding of policy-making and implementation processes, a wide range of published as well as unpublished written material, including pertinent environmental legislation, reports and position papers prepared recently by local and national government agencies, environmental NGOs and vehicle and fuel manufacturers and industry associations,

and transcripts of proceedings of Supreme Court public interest cases, were critically analyzed.

In addition to published literature and other secondary sources, the dissertation draws on in-depth interviews that the author conducted with various individuals interested in and/or knowledgeable about the range of issues involved, and representatives of institutions whose actions have an important bearing on transport air pollution in the Indian context. These individuals, listed in Appendix V, included decision makers in various relevant government agencies at the national and local levels, senior executives in the Indian M2W vehicle and fuel industries, and academics and researchers in the fields of environmental policy and urban transport.

The interviews focused on a wide range of issues, including technical and institutional factors contributing to transport air pollution; actors' roles, responsibilities and interactions; institutional barriers and constraints; considerations underlying current and proposed policies; and likely impacts of policies on vehicle users and industry. In addition to sharing their insights, the interviewees made available to the author the bulk of the documents referred to in the first paragraph in this section. As indicated, M2W vehicle user preferences, choices, perspectives and motivations were elicited by means of a questionnaire survey and in-depth interviews with M2W vehicle users in Delhi, in late 1997. The survey and in-depth interviews covered a wide range of issues, including those referred to under Research Approach.

The interviews, along with the information culled from the other sources indicated helped the author gain a comprehensive understanding of the transport air pollution problem in the Indian context.

1.5 STRUCTURE OF THE DISSERTATION

Each aspect of the M2W vehicle air pollution problem in the Indian context discussed earlier under Research Approach is treated separately and in depth in the following chapters. At the same time, an attempt has been made to maintain a logical flow from one chapter to the next.

Chapter II describes the problem that forms the focus of this dissertation. It presents a comprehensive picture of motor vehicle activity, and air pollution and its impacts in Delhi, and stresses the important role of M2W vehicles. The chapter presents a rationale for public policy

attention to, and outlines the larger context that needs to be considered in addressing, the problem. Chapter III discusses the technological, institutional and vehicle user behavioural factors that contribute to M2W vehicle air pollutant emissions in Delhi, and more generally, transport air pollution and energy consumption in India. Chapter IV discusses actors' roles, responsibilities and interactions, and institutional constraints and barriers, in relation to the various aspects of the transport air pollution problem discussed in Chapter III.

Chapter V proposes an analytic framework for systematic thinking and effective policy-making and implementation for addressing air pollution from M2W vehicles in the Indian context. Chapter VI describes the methodology for eliciting M2W vehicle user preferences, choices, perspectives and motivations by means of a questionnaire survey and in-depth interviews, and presents and discusses the results. The chapter then explores the implications of these results for policy-making and implementation. Chapter VII details the methodology for eliciting and structuring multiple policy objectives with respect to the issue at hand, and presents the results, in the form of a fundamental objectives hierarchy, measures, and a means-ends objectives network. Chapter VIII summarizes the implications of the dissertation research for transport air pollution prevention and control, and for urban transport and environmental planning, in the Indian context. The chapter also makes suggestions for further research.

CHAPTER II

THE TRANSPORT AIR POLLUTION PROBLEM IN DELHI, INDIA

2.1 INTRODUCTION

The purpose of this chapter is to present a rationale for public policy attention to air pollution from motorized two-wheeled (M2W) vehicles in Delhi, which is the dissertation focus. In order to achieve this purpose, the chapter discusses motor vehicle activity, and air pollution and its impacts, in Delhi. It stresses the role of M2W vehicles, which account for an increasingly important share of motor vehicle activity as well as transport air pollution. The dissertation focus is shown to be all the more relevant in light of the fact that Delhi's transport air pollution problem is shared by many other cities in India and other less-industrialized countries (LICs). Further, the growing importance of transport in India and other LICs in terms of global issues such as climate change, acidification and energy security is stressed. Finally, the public policy challenge is highlighted by situating Delhi's transport air pollution problem in the context of broader urban transport impacts. The chapter describes the problem that forms the focus of this dissertation, argues why it is worthy of urgent public policy attention, and outlines the larger context that needs to be considered in addressing the problem.

The information on which this chapter is based was culled from a wide range of secondary sources, many of which were identified during the course of meetings conducted by the author with decision makers in various relevant government agencies, representatives of vehicle and fuel manufacturing industries, and academics and researchers. These interviewees are listed in Appendix V.

2.2 URBANIZATION AND MOTOR VEHICLE ACTIVITY IN DELHI

Delhi has a history going back more than 2000 years. The city has been the capital of several kingdoms and empires. Delhi is today the third most populous city in India, after Calcutta and Greater Mumbai. The present-day union territory of Delhi, spread over 1,483 square kilometres, comprises the cities of Delhi, popularly known as Old Delhi, the capital of Muslim India from the 12th to the 19th centuries, and New Delhi, the capital of British India from

1912, and of the Republic of India since independence in 1947, and adjacent rural areas.[1] Delhi has been the dominant trading and commercial centre of northern India for centuries. The city is now a key transportation centre, with several national highways and railway lines passing through. Government and administrative services, industry and commerce, transportation, storage, distribution, and wholesale trading are the chief economic sectors (Encyclopaedia Britannica 1998; WHO/UNEP 1992).

In 1941, the number of people in the Delhi urban area was only 700,000, which is roughly the current population of several medium-sized Western cities. By 1991, Delhi's population had increased to 8.48 million, representing a 1100% increase over a mere half-century, and a doubling in less than twenty years, since 1971 (Figures 2.1 and 2.3).[2] If present trends continue, Delhi's urban population is likely to increase to around 13 million by 2001. According to the *Master Plan for Delhi*, Delhi's urban and rural population could together reach 15 million in the same year (DDA 1996; Faiz et al 1992; Midgley 1994; RITES/ORG 1994; Tiwari and Kale 1997; WHO/UNEP 1992).

Motor vehicle sales sky-rocketed in Delhi in the 1980s. In 1990, annual sales of motor vehicles were 370% higher than in 1980. But the rate of growth in Delhi's motor vehicle sales is tapering off. Annual motor vehicle sales in 1995 were only 19.4% higher than in 1990. Even so, over 550 motor vehicles of all types are sold daily in the city. Delhi accounted for 6.2, 18.1 and 5.1% of all-India sales of motor vehicles, cars and jeeps, and M2W vehicles respectively in 1995. Interestingly, Delhi's annual motor vehicle sales in 1995 equaled that in many large states such as Tamil Nadu (population 60 million). Car sales in the city exceeded those in any of the other Indian states, and were in fact three times that in Uttar Pradesh, the most populous Indian state (149 million) (AIAM 1994a and 1995; Encyclopaedia Britannica 1998).

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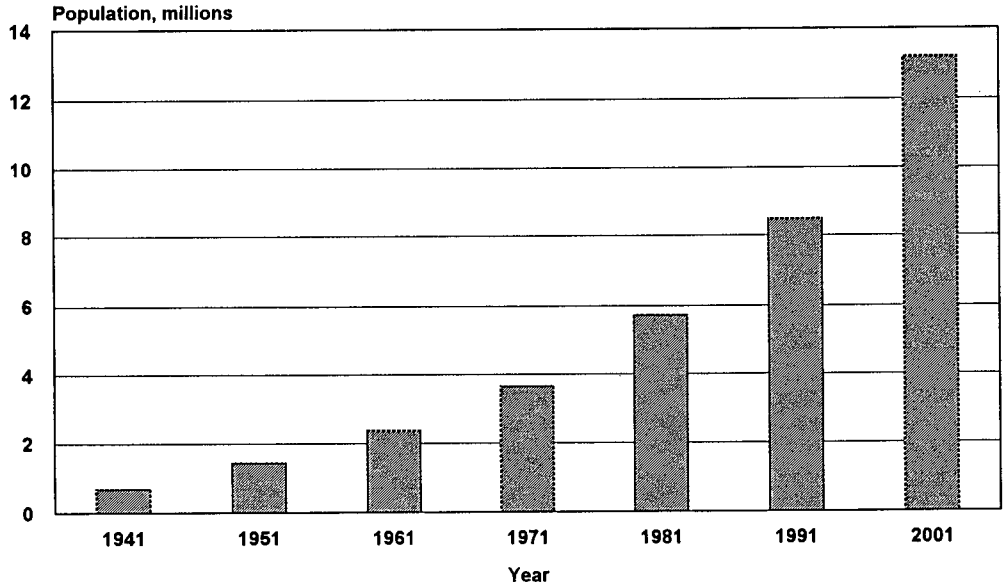
[1] While the area's economy and population are centred mainly in Old Delhi, government is concentrated in New Delhi. Old Delhi has nearly ten times the population density of New Delhi (Encyclopaedia Britannica 1998).

[2] This rapid surge in population was due to the massive influx of refugees during Partition (1948), and then the strong pull Delhi has exerted since the 1950s, because of the concentration of economic and political power and employment there (Misra et al 1998).

Figure 2.1 Population Growth, Delhi Urban Area

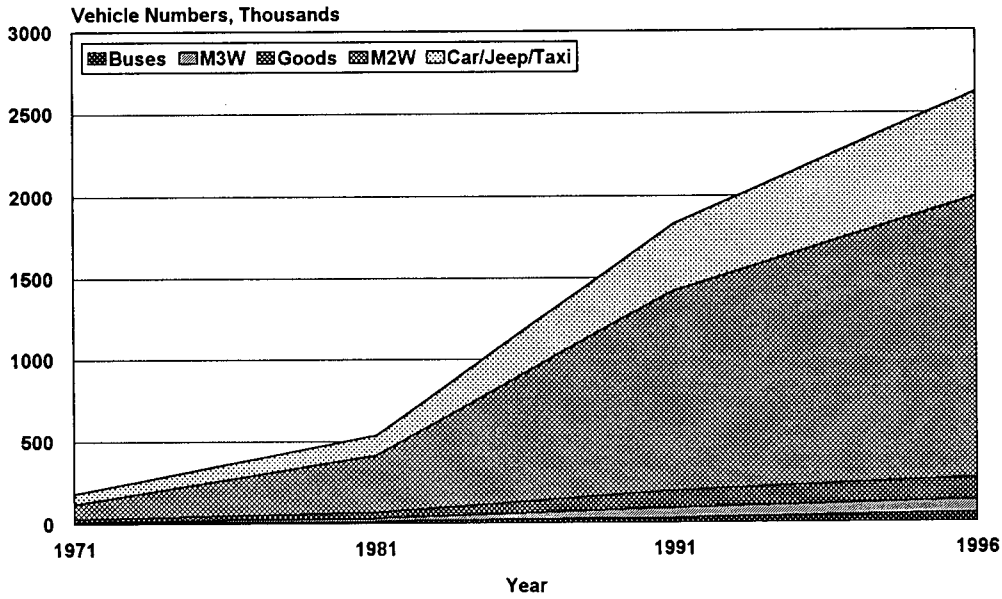
1941-2001



Sources: DDA 1996; RITES/ORG 1994 mgb99

Figure 2.2 Motor Vehicle Growth in Delhi

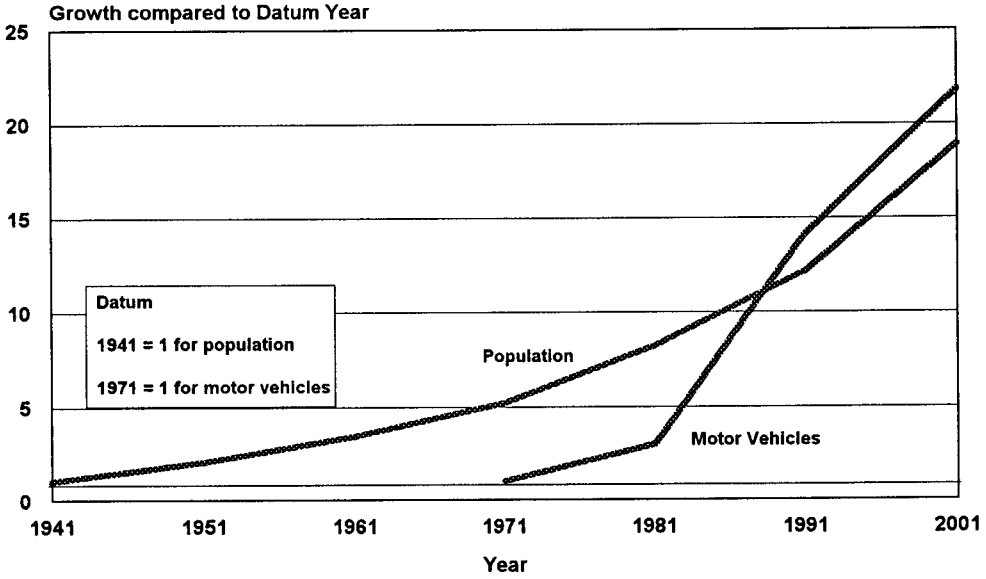
1971-1996



M2W/M3W = Motorized two-/three-wheeled vehicles. Sources: AIAM 1994a; CPCB 1997; Mohan et al 1997; NCTD 1997. mgb99

Figure 2.3 Population and Motorization Growth Rates in Delhi

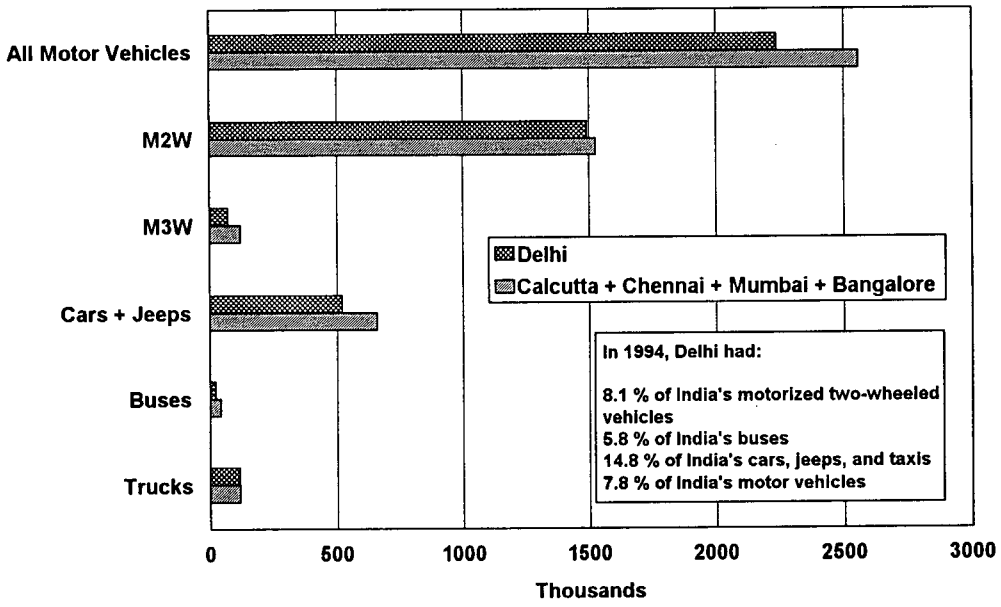
1941-2001



Motor vehicle population for 2001 estimated using average growth rate for 1990s. Sources: AIAM 1994a and 1995; CPCB 1997; DDA 1996; Faiz et al 1992; Mohan et al 1997; NCTD 1997; RITES/ORG 1994; WHO/UNEP 1992. mgb99

Figure 2.4 Delhi's Motor Vehicles Compared to Other Major Indian Cities

1994



M2W/M3W = Motorized two-/three- wheeled vehicles. Source: ASRTU/CIRT 1997. mgb99

Corresponding to the rapid growth in vehicle sales, Delhi's motor vehicle fleet grew at an annual rate of around 20% in the 1970s and 1980s (Figure 2.2). The figure shows that, astounding as Delhi's population growth has been, motor vehicle numbers have grown even more rapidly. While the city's population grew approximately 18-fold in 60 years, its motor vehicle population has grown more than twenty-fold in half the time.

Further, the growth rates for M2W vehicles and cars -- 24-25% in the 1980s -- have exceeded the overall motor vehicle growth rate. Motor vehicle numbers are not increasing at the same pace in this decade, but they are still growing at around 8% per annum. In 1996, around 2.6 million vehicles were registered in Delhi. Of these, 1.7 million (67%) were M2W vehicles. Additionally, 70,000 motor vehicles from neighbouring states were estimated to ply in Delhi daily (AIAM 1994a and 1995; CPCB 1997; Mohan et al 1997; WHO/UNEP 1992).

In 1994, the latest year for which data are available for all major Indian cities, Delhi had nearly as many motor vehicles as, and more M2W vehicles than, Calcutta, Chennai, and Greater Mumbai put together, plus Bangalore, perhaps the fastest growing Asian metropolis, and the second most motorized Indian city after Delhi (Figure 2.4). Delhi's motor vehicle fleet also exceeded that in every Indian state except Maharashtra and Gujarat. In 1995, Delhi accounted for 8.1% of motor vehicles, 7.8% of M2W vehicles, and 16.6% of cars registered nation-wide, with only a little over 1% of India's population. If current trends persist, Delhi will likely have around 5.2 million motor vehicles by 2005. Around 3.4 millions of these will likely be M2W vehicles (AIAM 1994a and 1995; ASRTU/CIRT 1997; Faiz et al 1992; Mohan et al 1997; TERI 1997).

To get a real sense of motor vehicle activity and its impacts, it is necessary to consider not merely motor vehicle *numbers*. While Delhi's motor vehicle numbers in 1995 had increased 3.4-5.2 times since 1981, depending on motor vehicle type, average trip lengths had increased 1.2-1.4 times (RITES/ORG 1994). Effectively, M2W vehicle and total motor vehicle kilometres in Delhi had increased 6.7 and 5.5 times in only 14 years (1981-1995), assuming *no increases in daily trips per mode* in the interval.

2.3 AIR POLLUTION AND HEALTH EFFECTS IN DELHI

2.3.1 Air Pollution in Delhi

One does not have to be an expert to know that Delhi's air quality is poor. It is patently obvious with every breath one takes. People complain of a sore throat, wheezing, and coughing. The newspapers regularly cover the problem, and attempts to address it. This author counted 22 news items, articles, and editorials on the subject in just three of Delhi's English language newspapers in six months in 1997. The city is blanketed in a haze for much of every day, particularly in winter. M2W vehicle riders wear masks. The leaves on the trees are covered with a thick coat of grime and soot.

But if "scientific" rather than merely anecdotal proof were needed, that is there too. Figures 2.5 to 2.10 show the evolving air quality situation in Delhi, compared to World Health Organization (WHO) guideline ambient air pollutant concentration limits. Appendix I compares the Indian NAAQS (national ambient air quality standards) with corresponding WHO, US and Californian limits. A detailed critique of the Indian NAAQS standards is also presented in Appendix I.[3]

Figures 2.5-2.10 are based primarily on Central Pollution Control Board (CPCB) and National Environmental Engineering Research Institute (NEERI) air quality data for Delhi.[4] CPCB and NEERI data are generally not comparable, because the measurement sites are different, measurements are carried out on different days, different methodologies are employed, and analysis is conducted in different laboratories. Discrepancies exist between

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[3] The gist of the critique is that the Indian NAAQS differentiate between "industrial", "residential" and "sensitive" areas. This differentiation is pointless in the Indian context, because supposedly industrial areas are also heavily populated, and a significant proportion of industries are located in residential areas. Further, the Indian NAAQS are either unnecessarily or unrealistically stringent in some cases, and too lenient in some others, as compared to WHO limits (see Appendix I).

[4] NEERI has been operating three United Nations GEMS (Global Environment Monitoring System) air quality monitoring stations in one industrial and two residential locations in Delhi since 1978. Sulphur dioxide (SO_2), suspended particulate matter (SPM), and nitrogen dioxide (NO_2) have been regularly monitored at these locations, except in 1988 and 1989, when monitoring was discontinued. Airborne lead levels were measured at the three NEERI sites in 1990. The CPCB initiated the National Ambient Air Quality Monitoring (NAAQM) programme collaboratively with the pollution control boards in the states in 1984. This programme currently involves 290 monitoring stations in 92 cities and towns. In Delhi, the CPCB commenced air quality monitoring at five stations in 1987. As at 1996, CPCB gathered SO_2, SPM and NO_2 data from five stations in industrial, and four stations in residential, areas. According to Cropper et al (1997), CPCB have been directly operating six stations since 1987. CPCB added three more in 1990, and these are operated on their behalf by NEERI.

NEERI and CPCB data for the same year, and between these and reports in various other sources.[5] Further, neither NEERI nor CPCB monitored carbon monoxide (CO), ozone (O_3) or PM_{10} (suspended particulate matter (SPM) below 10 microns diameter) on a regular basis, at least during the period covered in Figures 2.5-2.10.[6] Even those pollutants monitored by the CPCB are not monitored continuously, or even regularly, contrary to requirements stipulated in the Indian NAAQS. Thus, while the data for six Delhi sites in 1993 in CPCB (1996) were based on measurements on 69-79 days, those for the three other sites were based on measurements on only 21-23 days (Brandon and Hammonn 1995; CPCB 1995 and 1996; Shah and Nagpal 1997; WHO/UNEP 1992).

With those caveats, let us now turn our attention to the annual average sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and SPM levels in Delhi from 1978, presented in Figures 2.5-2.7. In addition to the annual averages for all sites, the maximum annual average recorded for each year is also presented, along with the area type at which the maximum occurred. For the sake of consistency, the CPCB data shown from 1990 onward is for the same three sites as for the NEERI data from 1978.

While annual average SO_2 levels appeared to be rising in the early 1980s, and even exceeded the applicable WHO limit of 50 $\mu g/m^3$ in 1984-1986, they are now below this limit. Similarly, annual average NO_2 levels have been generally below the Indian NAAQS standard of 60 $\mu g/m^3$ for residential areas until the early 1990s (there is no WHO annual average standard for NO_2). However, CPCB data for 1994 and NEERI data for 1996 appear to indicate an increasing trend (and even exceedence above the Indian NAAQS limit for industrial areas in 1996). It is therefore not possible to say anything conclusive about NO_2 trends in Delhi. However, if NO_2 levels are indeed increasing in Delhi, it would not be surprising, considering the rapidly increasing motor vehicular activity.

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[5] CPCB data for different cities cannot be compared, since the monitoring is conducted by the various state pollution control boards, and a large number of personnel and equipment types are involved in sampling and chemical analysis (CPCB 1996). There is a dire need for consistent air quality measurement and reporting, not just in Delhi, but across the country, to enable reliable comparisons and effective monitoring and control action.

[6] Though NEERI had apparently commenced measuring PM_{10}, CPCB had not (CPCB 1995 and 1996; Shah and Nagpal 1997; WHO/UNEP 1992).

Most importantly, annual average SPM levels, which are strongly correlated with respiratory and cardiovascular diseases, have been routinely exceeding the WHO limit of 60-90 $\mu g/m^3$ by as much as five times, and even the Indian NAAQS standard of 360 $\mu g/m^3$ for industrial areas, since the early 1980s. Incidentally, the CPCB itself designates 210 $\mu g/m^3$ as "critical" (and 70-140 $\mu g/m^3$ as "moderate") (CPCB 1996), on what grounds precisely is not clear. The one reported annual average PM_{10} figure, for 1992 (in Brandon and Hommann 1995), is 181 $\mu g/m^3$, measured by NEERI. This level is nearly 2.5 times higher than even the WHO annual average limit for *total* SPM, let alone the WHO 24-hour limit for PM_{10} (WHO/UNEP 1992).[7]

Airborne lead levels do not appear to be measured on a regular basis in Delhi. The annual average (as measured by NEERI) was reported as being around 0.5 and 0.27 $\mu g/m^3$ in 1990 and 1992, and 0.20 $\mu g/m^3$ in 1996/97 (Brandon and Hommann 1995; MoEF 1997b; WHO/UNEP 1992). Annual average lead levels are below the WHO limit, and appear to be declining, likely due to the progressive reduction of lead in Indian gasoline (Appendix IV).

As already mentioned, CO levels are not monitored on a regular basis. But annual average CO was measured at the ITO crossing, one of Delhi's busiest traffic centres, from 1990 (MoEF 1997b). This data shows a rising trend, from 2.7 mg/m^3 in 1990, to 5.6 mg/m^3 in 1996. But these figures are below even the WHO 8-hour limit (WHO/UNEP 1992).

The annual average values, serious as they are in the case of health-critical air pollutants such as SPM, hide site-to-site variations. Annual average SO_2 levels at all measurement sites are below the applicable WHO limit generally, but those at specific industrial and even residential sites regularly exceed it (Figures 2.5 and 2.8). While the annual average SPM levels at all sites have been routinely exceeding the WHO limit by five times since the early 1980s, as noted, those at specific industrial and even residential sites have been as high as 6-10 times the WHO limit (Figures 2.7 and 2.9). There are also important seasonal variations.[8]

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[7] PM_{10} is suspended particulate matter below 10 micron diameter. It is also referred to as thoracic PM (Faiz et al 1992; GVRD 1996; WHO/UNEP 1992). Though PM_{10} is not measured, it may be calculated because it is estimated to be 0.50-0.60 of SPM by mass for Delhi (Cropper et al 1997). The WHO 24-hour PM_{10} limit is 70 $\mu g/m^3$. The Californian 24-hour PM_{10} standard is only 30 $\mu g/m^3$ (WHO/UNEP 1992).

[8] Seasonal variations in air pollutant concentrations in Delhi are a function of the local climatic features there. While the city's annual mean temperature is around is 25°C, the summers are extremely hot and dry, with temperatures as high as 47°C in June. In winter (November-February), temperatures dip as low as 3°C. While the heavy monsoon rains from June to October have a scrubbing effect, strong pre-monsoon westerly winds

Finally, to gain an appreciation of the acute exposures in Delhi, let us consider the short-term (24-hour, 8-hour and 1-hour) concentrations of various pollutants (Figures 2.8-2.10). The 24-hour average SO_2 and NO_2 levels were above the corresponding WHO limits for many days in 1994 at several sites in Delhi, including at residential sites. 24-hour average SPM levels exceeded the corresponding WHO limit on a daily basis. In fact, the 24-hour WHO limit was exceeded by even the monthly average SPM levels every month in 1993 and 1994 (the years for which the author has data for all months), at all of the CPCB measurement sites, both industrial and residential. Peak 24-hour average SPM levels were 6-10 times the WHO limit at many sites (Figure 2.9).[9] In a 1997 study by Cropper et al (1997), the authors found that daily levels exceeded (by several times) the WHO limit 97% of days. The WHO limit they considered was 150-230 $\mu g/m^3$, not 120 $\mu g/m^3$, which should apply in Delhi's case, since SO_2 is also present (WHO/UNEP 1992). According to Priti Kumar et al (1997), the highest 24-hour average SPM levels recorded in the three years preceding 1994 were as high as 2338, 2340 and 1227 $\mu g/m^3$.

8-hour and 1-hour CO levels were found to be within WHO guidelines, when averaged over various locations. At the busy ITO traffic junction in 1984, 8-hour average CO levels were around 5.5 mg/m^3, as against the WHO limit of 10 mg/m^3. However, the peak hourly concentration was 29 mg/m^3, as against the WHO 1-hour limit of 30 mg/m^3 (CPCB 1995). Short-term CO levels have very likely increased dramatically since 1984 at several sites in Delhi, as motor vehicle activity has grown rapidly, with important implications for the thousands who eke out a living daily on the street, including police personnel and street vendors.

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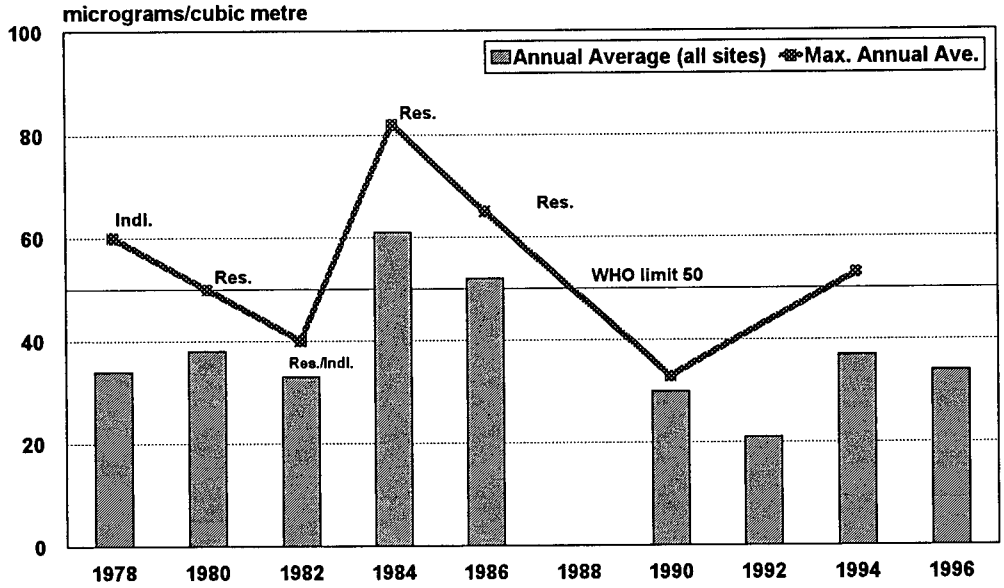
bring in large concentrations of SPM from the Thar Desert, and re-suspend it for long periods. Winters are characterized by frequent calms and temperature inversions which restrict mixing heights and thus pollutant dispersal and dilution. SO_2 levels typically peak in winter, due to increased coal burning for space heating, and NO_2 levels peak in October-November when maximum insolation occurs (Faiz et al 1992; WHO/UNEP 1992).

[9] Once again, it should be noted that CPCB measurements were conducted only a few days each month, and for only 16 hours each day (CPCB 1995 and 1996).

Figure 2.5 Annual Average Sulphur Dioxide Levels in Delhi

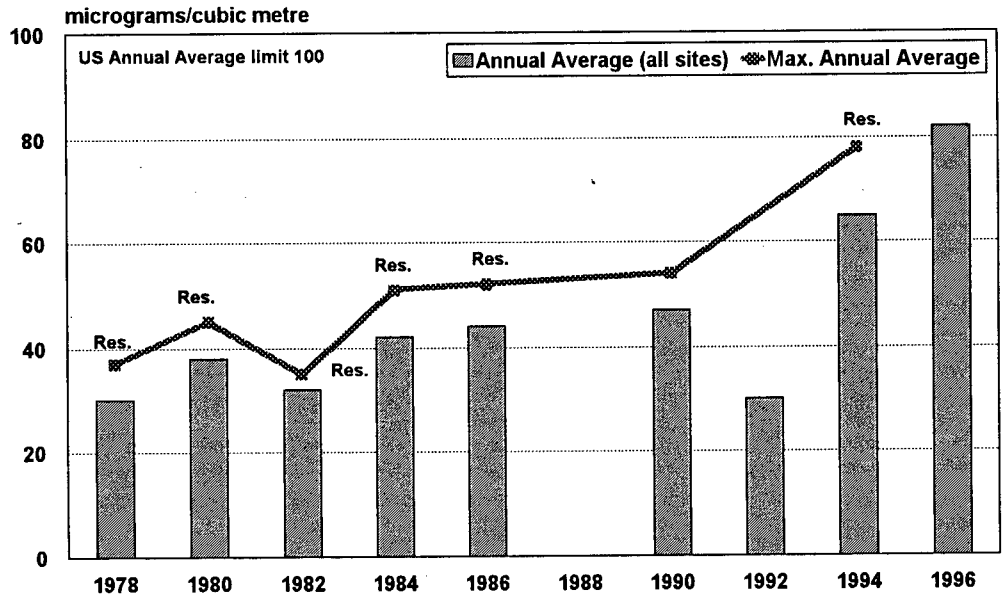
1978- 1996



Indl. = Industrial site; Res. = Residential site. Sources: CPCB 1997; NEERI data from AIAM 1997a and WHO/UNEP 1992. mgb99

Figure 2.6 Annual Average Nitrogen Dioxide Levels in Delhi

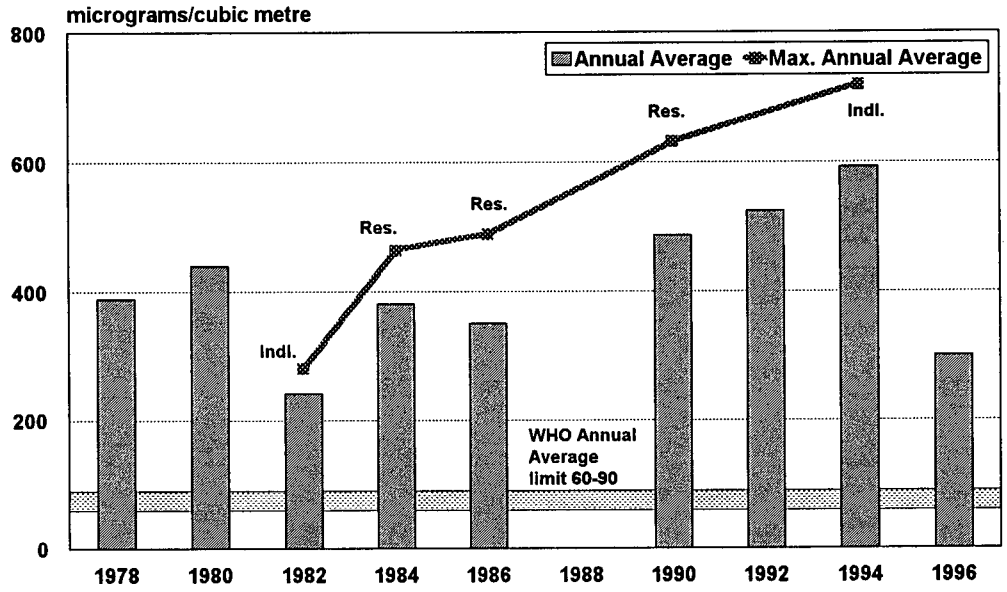
1978-1996



Indl. = Industrial site. Res. = Residential site. Sources: CPCB 1997; NEERI data from AIAM 1997a and WHO/UNEP 1992. mgb99

Figure 2.7 Annual Average Particulate Levels in Delhi

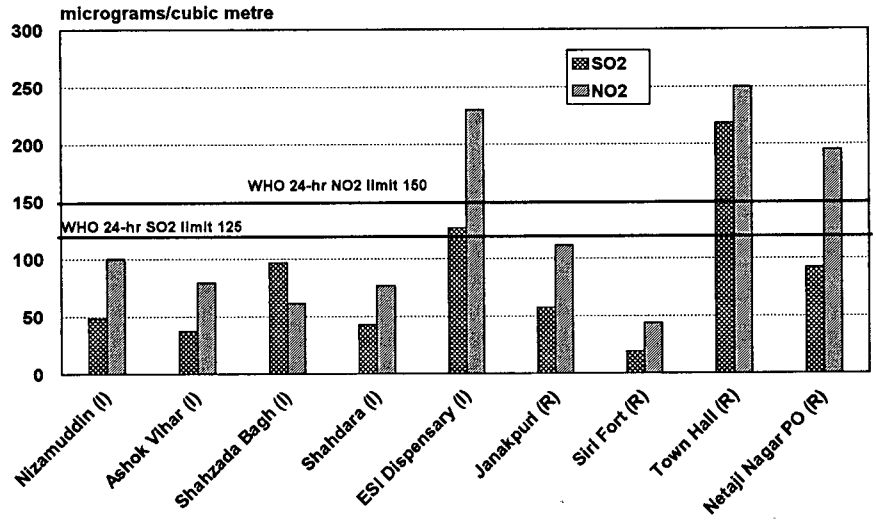
1978-1996



Indl. = Industrial site. Res. = Residential site. Sources: CPCB 1997; NEERI data from AIAM 1997a and WHO/UNEP 1992. mgb99

Figure 2.8 Peak 24-hour Sulphur and Nitrogen Dioxide Levels

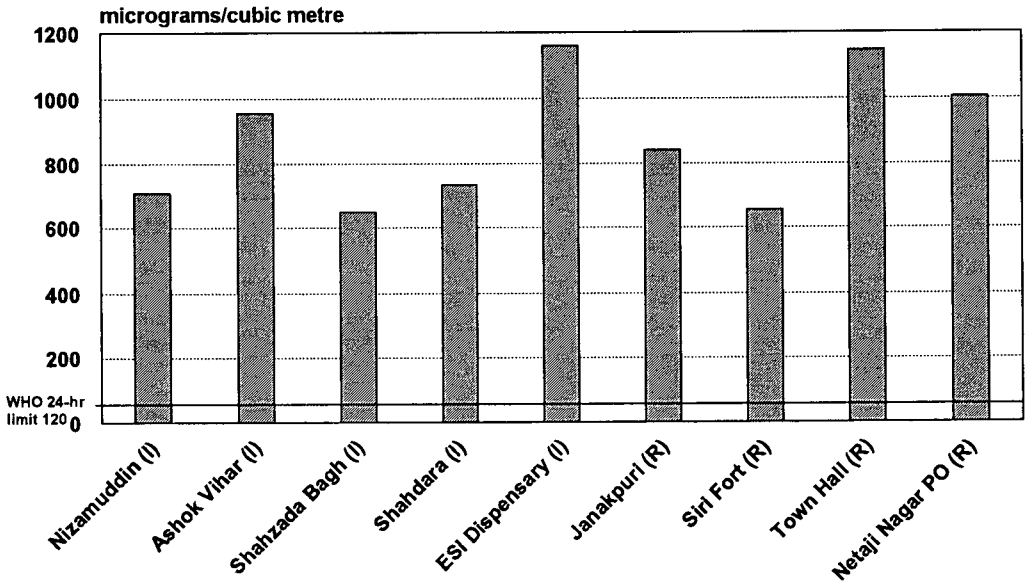
at Various Sites in Delhi, 1994



(I) = Industrial areas. (R) = Residential areas. Source: CPCB 1996. mgb99

Figure 2.9 Peak 24-hour SPM Levels

at Various Sites in Delhi, 1994

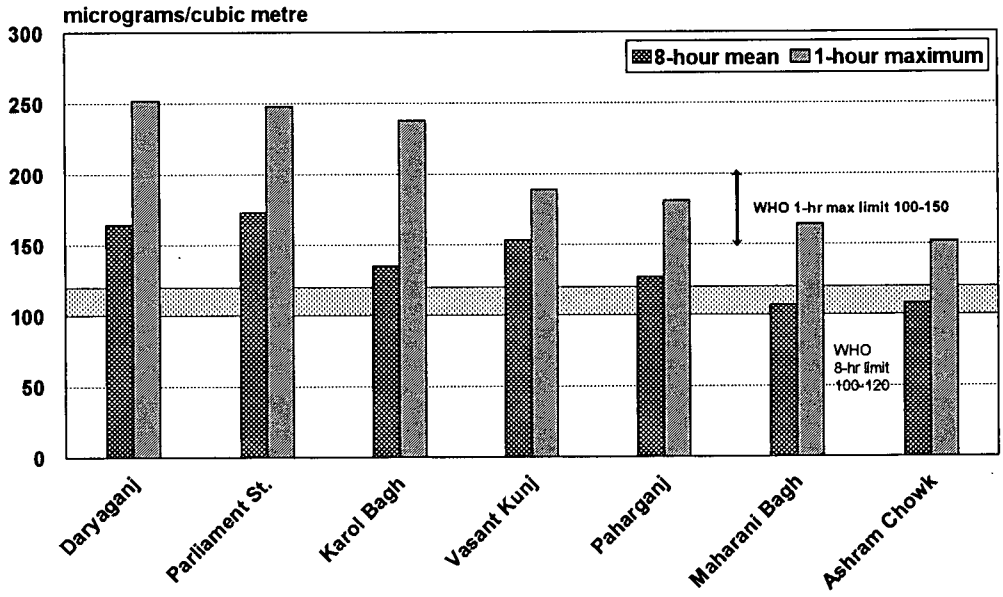


(I) = Industrial areas; (R) = Residential areas. Source: CPCB 1996.

mgb99

Figure 2.10 8-hour Mean and 1-hour Maximum Ozone Levels in Delhi

1997



Source: Roy Chowdhury 1997.

mgb99

The only recent study on ozone (O_3) in Delhi was conducted by the Central Road Research Institute (CRRI) at seven sites in the winter of 1993. WHO 8-hour limits were exceeded at most locations (Figure 2.10). The peak 1-hour levels across all sites averaged 203 $\mu g/m^3$, with the peaks in areas with heavy traffic like Karol Bagh, Daryaganj and Parliament Street 30-40% in excess of the WHO 1-hour limit. Studies conducted by the Jawaharlal Nehru University (JNU) and the Tata Energy Research Institute (TERI) in 1989-90 had shown peak levels of 256 $\mu g/m^3$, well above the WHO 1-hour limit (CSE 1997; Roy Chowdhury 1997). Delhi's smog could simply be reduced visibility due to increased SPM, but the city has the potential for photochemical smog, because of growing transport and other emissions, and a climate favourable to O_3 formation, particularly in winter, which is when NO_x levels are high, and inversions occur (Faiz et al 1992; WHO/UNEP 1992).

To summarize the air quality situation in Delhi: annual average CO and SO_2 levels appear to be within WHO limits. So are annual average NO_2 levels, but they may be increasing (not surprisingly, given the rapid increase in motor vehicle activity). Airborne lead levels appear to be declining generally, likely due to lowered lead levels in gasoline and the introduction of unleaded gasoline, but appear to be high at isolated sites. One cannot be sure if this is due to non-transport sources. Most importantly, annual average SPM levels, which are strongly correlated with respiratory and cardiovascular diseases, have been routinely around five times the WHO limit since the 1980s. In terms of short-term exposure, daily average SO_2 and NO_2 levels exceed WHO limits on several days of the year, at several sites. 24-hour average SPM levels exceed WHO limits nearly every day of the year, with peak levels as high as 6-10 times the WHO limit at many sites. Based on a limited study, O_3 appears to be a major problem, especially in winter, exceeding 8-hour and 1-hour WHO limits at several sites.

It is often reported in the media, as in the *Toronto Star* (1997), that Delhi has the world's fourth worst air pollution. This ranking is immaterial. For example, Delhi could be far more polluted than presently, and be ranked the twentieth most polluted city globally. Regardless of such rankings, one can get a sense of the seriousness of Delhi's air pollution problem by considering that, while the great historical air pollution disasters, in London (in the winters of 1955-1960), and in New York (1953-1964) were characterized by 24-hour SPM concentrations of 1200-3250 and 500-1000 $\mu g/m^3$ respectively, and excess mortalities of 5-

30% (Smith 1994), Delhi's *annual* average SPM levels are themselves routinely close to 400 $\mu g/m^3$, and daily averages range between 500 and over 1000 $\mu g/m^3$ at several sites on many days in the year.[10] Further, Delhi's peak O_3 levels of 250 $\mu g/m^3$ at some sites (Figure 2.10) are half the peaks in Los Angeles (Lents and Kelly 1993), which has nearly four times the motor vehicles.

2.3.2 Air Pollutants and their Health Effects

The air pollutants discussed so far -- CO, NO_2, SO_2, SPM, Pb, and O_3 -- have health effects that range from irritation of eyes and mucous membranes and aggravation of asthma and bronchitis, to damage to circulatory, kidney and nervous systems, and cancer. These health effects are discussed in detail in Appendix II. Of primary concern in terms of health effects are particulates, in particular PM_{10} (and $PM_{2.5}$).[11] PM_{10} and $PM_{2.5}$ are dangerous because they remain suspended longer than larger particles (5-15 days for PM_1), and penetrate deeper into, and take longer to be cleared from, the respiratory tract.

Transport-generated SPM is associated primarily with uncontrolled diesels, but gasoline vehicles including two-strokes, which power the majority of Indian M2W vehicles, are an important source as well. The bulk of transport-generated SPM is in the PM_{10} range. Indeed, motor vehicles contribute significantly to PM_{10} and $PM_{2.5}$ emissions, and proportionately more to these fractions than to total PM. Further, transport PM_{10} consists of a solid carbonaceous core on which unburned HCs, sulphuric acid, sulphates, nitrates, and known carcinogens and/or mutagens such as benzo(a)pyrene and polycyclic aromatic hydrocarbons (PAHs), also transport-generated, adsorb. Transport-generated particulates also contain respirable lead (from leaded gasoline) and other metals (Faiz et al 1992; GVRD 1995; GVRD 1998; Walsh 1991a and 1994; Wijetilleke and Karunaratne 1997).

Epidemiological studies worldwide have consistently shown that non-accidental deaths and other health end-points, including hospital admissions for chronic respiratory, cardio-vascular and acute respiratory diseases, are closely linked to ambient TSP, PM_{10}, $PM_{2.5}$, and particulate

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[10] Interestingly, all of the historical air pollution disasters and episodes of high air-pollution related excess mortality (Smith 1994) seem to have occurred in the winter months.

[11] $PM_{2.5}$, suspended particulate matter of diameter below 2.5 μm, is referred to as fine particulates (GVRD 1998).

sulphates, in addition to SO_2 and O_3. Particulates are closely linked to various health-points even when no SO_2 is present. TSP levels below 100 $\mu g/m^3$ were once considered harmless, but linking data from the great air pollution disasters and studies relating to levels below 120 $\mu g/m^3$ showed no sign of either any threshold or saturation in the dose-response relationship over a range of more than two orders of magnitude from levels in the tens of $\mu g/m^3$. Infants are particularly vulnerable. A study in Brazil in the late 1980s found that the risk for pneumonia deaths, a major component of infant mortality in the LICs, was substantially greater than that for adult mortality, because of the sensitivity of children, and the intimate link between particulates and this end-point. Finally, PM_{10} and $PM_{2.5}$ are even more strongly correlated with health end-points than TSP. Californian and Canadian studies have found that 85% of air pollution health effects were attributable to PM_{10} (Dockery et al 1993; Fazio 1997; Smith 1994; Walsh 1994a and 1994b).

Another transport air pollutant of concern in the Indian context is lead. Nearly all lead in gasoline is released to the atmosphere, mainly as inorganic lead salts (chlorides, bromides and sulphates) and oxides in aerosol form, all in the PM_{10} range, but mostly as fine particulates. There is a significant relationship between lead in gasoline, airborne lead, and blood-lead. While high concentrations can lead to anaemia, hypertension, heart attacks, strokes, kidney failure, massive and permanent brain damage and death in adults, even low blood-lead levels induce neurological damage and lowered learning ability in children. Infants and children under five are at high risk of excessive lead exposure, because they take in dust and soil through normal mouthing habits.[12] In this connection, it is worth noting that about 10% of transport-generated lead is deposited within 100 metres of roadsides, where children frequently play in the LICs. A study in Mexico City, where gasoline vehicles account for the bulk of airborne lead, revealed that children who lived in low traffic areas had a significantly lower blood-lead level than those living close to main roads (CPCB 1992; CSE 1996; Driscoll et al 1992; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman 1991; Romieu et al 1992; Wijetilleke and Karunaratne 1997).

[12] Maternal lead can be transmitted to the fetus via the placenta at blood lead levels as low as 10 $\mu g/dl$, thus affecting gestational age, birth weight, and mental development (CPCB 1992; CSE 1996; Faiz et al 1992; Wijetilleke and Karunaratne 1997).

The economic and social costs of the health effects of lead can be significant. Exposure to even low lead levels can cause neurological and other adverse effects in children, and can persist irreversibly into adulthood even after exposure ends (CPCB 1992; Wijetilleke and Karunaratne 1997). This fact is pertinent in the Indian context, since gasoline lead levels have been lowered and unleaded gasoline introduced only in 1995. Lead levels prior to 1995 were high (at least 0.56 g/L since 1971) (BIS 1995a; CSE 1996; Appendix IV). Indeed, high ambient lead levels were observed even as late as 1992, in areas of heavy traffic in Delhi (CPCB 1992). Lastly, note that a lot of human activity occurs, and food is cooked and eaten, in such areas.

As discussed in the previous section, Delhi appears to have an ozone problem, which is likely to intensify with time. North American, European, and Japanese studies have shown that O_3 is related to mortality independently of particulates, and to hospital admissions for chronic and acute respiratory and cardio-vascular diseases (Bates 1994; Brandon and Hommann 1995; CPCB 1992, 1995 and 1996; CSE 1996; Faiz et al 1992; Roy Chowdhury 1997; Wijetilleke and Karunaratne 1997; WHO/UNEP 1992).

While attention is typically focused on conventional (regulated) pollutants in vehicle exhaust, there are several other transport-generated air pollutants with serious health and other effects, from other vehicular and transport system sources. Metals in motor vehicular exhaust, as well as from clutch, brake and tyre abrasion, include aluminium, arsenic, beryllium, cadmium, chromium, cobalt, manganese and nickel. Many of these metals are known or suspected mutagens and carcinogens. While asbestos-free materials are now the norm for brakes and clutches in the West, asbestos, implicated in mesothelioma, a cancer of the peritoneum with an extremely poor prognosis and long latency periods, continues to be used in these applications in Indian vehicles. Asbestos and other metal emissions from motor vehicles are commonly in the respirable range (Author's interviews 1997; Bates 1994; CSE 1996; Government of Canada 1991; Faiz et al 1992; IARC 1989; Walsh 1991a; Whitelegg 1993). These emissions may be particularly relevant in the case of M2W vehicles, because they tend to be used to maneuver through high traffic areas, with consequently excessive brake and clutch use.

Benzene, a crude oil constituent, occurs in exhaust and due to fuel evaporation. Refinery processes to compensate for lead removal increase levels of this and other high-octane HCs (such as toluene and xylene, which cause neurological, kidney and liver damage). Short-term exposure to benzene in high concentrations causes respiratory tract inflammation and lung hemorrhaging, and can even be lethal, but the main concern is its linkage to adult leukemia and lung cancer. Other effects include central nervous system damage and birth defects. WHO specifies no safe limit for benzene in air. Benzene levels in gasoline were not controlled until very recently (BIS 1995a; Appendix IV), and are even now considerably higher than those in gasoline in the OECD countries (BIS 1995a; Calvert et al 1993; Mercedes Benz 1997). Aldehydes are another important exhaust product. Though diesels produce them at a greater percentage of total HC, gasoline vehicles produce them too.[13] Formaldehyde is particularly concerning, because of its photochemical reactivity, and possible carcinogenicity. As will be discussed in subsequent chapters, aldehyde emissions will likely increase in the Indian context, due to the addition of oxygenates to gasoline, to be allowed from 2000 (BIS 1995a; CSE 1996; Government of Canada 1991; Faiz et al 1992; Walsh 1991a and 1994; Wijetilleke and Karunaratne 1997).

Fuel additives can have significant impacts of their own. Lead "scavengers" such as ethylene dichloride and dibromide added to leaded gasoline to prevent excessive lead deposits are a concern, because these are emitted in the form of inorganic lead chlorides and bromides in fine PM form. Ethylene dibromide is potentially carcinogenic (Faiz et al 1992; Walsh 1991a).[14]

Finally, there are important contextual factors that would likely exacerbate pollution impacts in India. The effects of air pollutants in combination may be far more serious than

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[13] Diesels emit many toxic air contaminants, such as 1,3-butadiene, dioxins and dibenzofurans, polycyclic aromatic hydrocarbons (PAHs) including benzo(a)pyrene (BaP), and PAH derivatives, such as 3-nitro-benzo(a)pyrene, a powerful mutagen. Atmospheric reactions form new species. 1,3-butadiene can react with OH radicals and ozone to form formaldehyde. In short, transport can contribute significantly to air toxics and associated health risks. In 1990, transport air toxics, including PM, 1,3-butadiene, benzene, and formaldehyde, caused 54-58% of all air toxic related US cancers (Finlayson-Pitts and Pitts 1986; Williams 1989; Walsh 1991a and 1994; Wijetilleke and Karunaratne 1997). Indian data on air toxics is sparse. BaP levels in Delhi were 30-750 ng/m^3 in 1990 (Agrawal 1997; Biswas and Dutta 1994).

[14] This is an example of how, in solving one problem, others may be created. Additionally, ethylene dichloride and dibromide also form acids, causing engine and exhaust system rusting and reduced engine oil life. Similarly, calcium and barium additives in diesel suppress visible black smoke, but can significantly increase the PAH content and mutagenicity of SOF, and particulate sulphate emissions (Faiz et al 1992; Walsh 1991a).

singly. Particulate effects are enhanced if high PM_{10} levels are associated with high SO_2, NO_2, and ozone levels, increasingly the situation in Delhi and other Indian cities. Further, in the Indian context, large numbers of people (including infants, the old and the infirm) live and work road-side. This situation, coupled with the fact that air pollution is typically higher in high-traffic areas than farther away, causes much larger exposures for a large number of people than for the general urban population.[15, 16] Recall in this context that CO levels at traffic junctions such as ITO reach 10 mg/m^3 over extended periods, and peak as high as 29 mg/m^3, daily, and that daily average NO_2 levels are high, and are likely increasing, at several sites. Recurrent exposure to high NO_2 levels is more harmful than continuous exposure to lower concentrations (Barde and Button 1990; Brandon and Hommann 1995; CSE 1996; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman 1991; Romieu et al 1992; WHO/UNEP 1992; Wijetilleke and Karunaratne 1997).

Pollution exposure and impacts also depend on activity levels. SPM deposition depends not only on particle size but also on breathing effort. Larger particles are deposited in the exothoracic part of the respiratory tract, and PM_{10} in proximity to the fine airways with normal nasal breathing, but mouth breathing typical of physical activity increases tracheo-bronchial and pulmonary deposition.[17] Finally, there are synergies between pollution, poverty and nutritional deficiency. For example, diets deficient in calcium, vitamin D, iron and zinc increase lead absorption (CSE 1996; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman 1991; Romieu et al 1992; Wijetilleke and Karunaratne 1997).

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[15] Ambient measurements such as those conducted at fixed stations by CPCB in Delhi – high as they are for some pollutants -- may actually be under-estimating the risk for a large number of vulnerable people. This may be less of a problem with O_3, which tends to disperse broadly, as opposed to lead and SPM (WHO/UNEP 1992; Wijetilleke and Karunaratne 1997).

[16] Interestingly, though, motor vehicle occupants may be at most risk to air pollutants. Air pollution levels inside cars, particularly in terms of CO and VOCs, can be up to five times higher than background concentrations, and much higher than levels to which pedestrians and cyclists are usually exposed (Taylor and Fergusson 1998). Because of the generally poor condition of vehicles, including exhaust system fracture, and the stop-and-go traffic (common in the Indian context), very high, even lethal concentrations of CO could accumulate inside vehicles (Wijetilleke and Karunaratne 1997). Studies in Delhi show that M2W and M3W vehicle riders are exposed to much higher PM and CO levels than car and bus riders (TERI 1997b).

[17] In this regard, note that, while 240 $\mu g/m^3$ is the USEPA limit for short-term O_3 exposure, lung function is adversely affected in the young if they exercise for six hours at 160 $\mu g/m^3$ (Wijetilleke and Karunaratne 1997).

2.3.3 Studies linking Air Pollution and Health and Economic Costs in Delhi

No systematic Indian epidemiological study linking air pollution and health effects exists to the author's knowledge. Brandon and Hommann (1995) of the World Bank made rough estimates of the health and economic costs of air pollution in 36 Indian cities including Delhi. They used annual average air pollutant concentrations from NEERI and CPCB, dose-response data from US studies, and various conversion factors based on GNP-, medical cost-, and wage-ratios.[18] They concluded, based on the air quality in 1992, that there are around 7500 premature deaths, and four million hospital admissions and illnesses requiring medical treatment annually due to air pollution exceeding WHO limits in Delhi, at an economic cost of around US$ 100-400 million. Airborne lead exposure in Delhi was estimated to be responsible for around 41,194 hospital admissions and medical treatments, costing US$ 267,000-667,000, plus US$ 1.5-3.7 million to remedy "children's IQ points loss". The premature deaths, hospital admissions and economic costs in Delhi constituted 19, 20, and 20-30% of the corresponding totals for all 36 cities. More than 95% of the health damage due to air pollution in the 36 cities was estimated to be due to PM_{10} and SO_2, with the remainder due to high lead levels (Brandon and Hommann 1995).[19]

Cropper et al (1997) recently conducted a study relating daily PM levels to daily deaths in Delhi in 1991-1994. Mortality data were obtained from the New Delhi Municipal Corporation (NDMC), which has a large number of hospitals. 25% of Delhi's mortalities occur in the NDMC.[20] Daily mean TSP, SO_2 and NO_x, based on CPCB data, were found to be strongly related to cardiac and respiratory diseases. As already indicated, average annual TSP was five times the WHO limit, and daily TSP exceeded the WHO 24-hour limit 97% of the time, during 1991-1994. Surprisingly, the percentage mortality increase in Delhi was found to be only one-third that in the US studies for the same TSP increase. Thus, while applying US

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[18] The study also estimated the health and economic costs of water and industrial pollution, soil degradation, and deforestation (Brandon and Hommann 1995).

[19] Wijetilleke and Karunaratne (1997) observe, in commenting on such studies, that the actual effects of SO_2 may be underestimated, because typically, sulphates, formed by transformation to acid aerosols, are counted as particulates. Thus, some benefits from reducing PM should properly be attributed to SO_2. This point is valid, but only if fuel sulphur is also reduced. However, there is no question that reducing SO_2 (and lead, which as we have seen, is in the PM_{10} range) will also reduce PM, and more specifically, PM_{10}.

[20] The study was based on deaths in NDMC hospitals only, because NDMC was the only jurisdiction with a detailed computerized data base (Cropper et al 1997).

PM_{10}-non-trauma death dose-response coefficients to Delhi, as Brandon and Hommann (1995) did, predicted 7500 premature deaths, Cropper et al, based on actual Delhi data, estimated only 3430 premature deaths, for the same PM_{10} levels (Brandon and Hommann 1995; Cropper et al 1997).

The above discrepancies highlight the difficulties in transferring dose-response functions from North American and European epidemiological studies to the LIC context. For a variety of reasons including higher pollution levels and exposure, greater diffusion of outdoor air indoors, and a higher percentage of people in marginal health due to lower living standards and poor nutrition, one would have expected that using US or European dose-response functions would underestimate health effects in the LIC context (Brandon and Hommann 1995; Wijetilleke and Karunaratne 1997). Thus, Brandon and Hommann's predicted effects should have been lower than Cropper et al's, but the reverse is the case.

There are several possible reasons why PM in Delhi has a smaller effect than in the USA. Delhi's PM may be larger in size, and a larger proportion may be natural rather than combustive in origin. But Delhi's PM_{10}/TSP ratio is only slightly smaller than the US cities average, and its annual PM_{10} is well above even the WHO 24-hour limit, as discussed. The most likely reason is that in Delhi, people die at younger ages and from different causes. While over 70% of all US deaths occur after 65, over 70% of Delhi's occur before 65, with 20% occurring before age five. Further, while 46% of all non-trauma US deaths are due to cardio-vascular disease, which is strongly associated with air pollution, both cardio-vascular and respiratory deaths account for only 24% of non-trauma deaths in Delhi (infectious diseases account for as many as 20%). But PM have a smaller impact even on cardio-vascular and respiratory deaths in Delhi. This may be because pneumonia, which has a weaker association with PM than say chronic obstructive pulmonary disease (COPD), comprises a larger fraction of respiratory deaths in Delhi. Also, in the USA, the impact of PM is significant for deaths after, not before, 65. In Delhi, the peak impact occurs in the 15-44 age group, with significant effects also for the 5-14 group (Cropper et al 1997).

But this does not mean that PM is not a health hazard in Delhi. The dose-response relationship is flatter than in the USA, but this is likely because other diseases claim Delhi-ites sooner. Further, if *life-years lost rather than lives lost* is the criterion, Delhi's situation is

more serious. Because the largest impacts there occur in the 15-44, as opposed to the 65 plus age group in the US, more life years will be lost in Delhi on average than in the US, for each air-pollution related death (Cropper et al 1997).

In any case, medical professionals report that respiratory diseases are increasing rapidly in Delhi, and that five of its 13 millions, including 40% of its children, suffer from them. In a study of 10,000 5-16 year-old school children, Dr. Chhabra of the Patel Chest Institute found that 12% had asthma. Including those who showed symptoms in the past, the figure was closer to 17%. Asthma attacks are reportedly becoming more frequent and severe, including in children, with 5% being fatal compared to only 2% a few years ago. Not surprisingly, traffic policemen are particularly vulnerable. Studies show a greater susceptibility to lung disorders, and significantly larger proportions of decreased lung capacity and abnormal COHb among them as compared to office workers (Basu 1997; Chhabra 1997; CSE 1996; Priti Kumar et al 1997; Roy Chowdhury 1997).[21]

2.4 THE ROLE OF TRANSPORT IN DELHI'S AIR POLLUTION

Figure 2.11 traces the contribution of transport to air pollutant emissions in Delhi over time, and from different information sources (Brandon and Ramankutty 1993; CSE 1996; Faiz et al 1992; WHO/UNEP 1992). Figure 2.12 shows the contribution of transport and other sectors to emissions in the most recent (1996) CPCB emissions inventory (CSE 1996).

There are serious discrepancies between the CPCB inventory and that in Faiz et al (1992). Besides, it is unclear what methodology was used in each case. Given the rapid growth in motor vehicle activity in Delhi, it is surprising that while the contribution of transport to HC appears to be increasing, its contribution to CO and NO_x is not (Figure 2.11). Further, while it is unsurprising that power generation and industry account for the bulk of SPM and SO_2, it is surprising that the contribution of transport, particularly to SPM, is decreasing, as the CPCB data for 1996 appears to suggest, given that transport energy consumption is increasing rapidly, and no control actions have been taken in that sector. There is a need for a reliable

[21] Dr. Naresh Trehan of Delhi's Escorts Heart Institute can apparently identify Delhi inhabitants easily; while patients from outside have pink lungs, those from Delhi have black ones (CSE 1996).

inventory of emissions from transport and other sectors.[22] Regardless of the discrepancies, however, the figures show the predominance of motor vehicles in terms of CO, HC and NO_x. The role of motor vehicles, even in terms of SPM and SO_2 is growing with time (Faiz et al 1992).[23]

The rapid growth in Delhi's motor vehicle activity since the 1970s, particularly in terms of M2W vehicles, has been discussed. The majority of Delhi's M2W (and M3W) vehicles are powered by highly polluting two-stroke engines.[24] Many of the city's buses (all diesel-operated), and goods vehicles (predominantly diesel-operated), are of old vintage and poorly maintained, and are gross polluters, particularly in terms of PM.

Though vehicular emission standards have been progressively tightened in the 1990s (Appendix III), and those related to M2W vehicles proposed for 2000 are some of the strictest in the world, many in-use M2W and M3W vehicles, and also cars, particularly those manufactured prior to 1991, pollute heavily (AIAM 1994a, 1995 and 1997; CSE 1996; Faiz et al 1992; Faiz et al 1996; Shah and Nagpal 1997; Narayana 1994).

Two-stroke engines are preferred for M2W and M3W vehicles because they are simple in design, have high power/swept volume and power/weight ratios, and are relatively inexpensive to own, operate, maintain and service. But since exhaust and intake events occur simultaneously in two-strokes, 20-30% of the fuel-air charge escapes unburned through the exhaust. Further, lubricating oil is added to the fuel to lubricate engine parts, since the fuel-air charge is drawn through a "dry" crankcase. The oil is "lost" due to combustion, but does not burn completely. These factors in combination result in high HC and PM emissions (Faiz et al 1992).[25]

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[22] WHO/UNEP (1992) also remarks on discrepancies between the NEERI and CPCB emissions inventories. Apart from many other problems that will be discussed shortly (and in subsequent chapters), the CPCB transport emissions inventory (CSE 1996) likely accounts only for emissions from vehicular exhaust, not from other vehicular and transport system sources.

[23] It is certainly interesting that air quality monitoring in Delhi should have started around the time motor vehicles began to grow rapidly.

[24] While all the M2W vehicles are gasoline powered, 97% of Delhi's M3W vehicle fleet are. Many para-transit vehicles also employ two-stroke engines (Cervero 1997; Faiz et al 1992; MoEF 1997b).

[25] Though catalytically controlled spark-ignition (gasoline) vehicles emit 50-80 and 100-120 times less PM than light- and heavy-duty diesels respectively, spark-ignition PM can be significant where poor maintenance or engine wear lead to high oil consumption, and/or where (as in two-strokes), oil is mixed with the fuel. Further, inorganic lead salts are an important exhaust component on engines operated on leaded gasoline, as

Fuel and lubricating oil quality also contribute significantly to the air pollution problem. Their quality is being improved in a phased manner (BIS 1995a; Appendix IV),[26] but lead content was as high as 0.56 g/L in 87 octane (and 0.8 g/L in 93 octane) gasoline until 1995. Similarly, gasoline and diesel sulphur were as high as 0.2 and 1% by weight respectively until 1995 (BIS 1995a; BIS 1995b).[27] Fuel and lubricating oil adulteration are also an important factor, particularly in the case of M3W and commercial vehicles (Raje and Malhotra 1997).

Table 2.1 compares the exhaust emission factors measured on in-use M2W and M3W vehicles, cars and urban buses in the early 1990s (IIP 1994; Shah and Nagpal 1997). These measurements are relevant even today because many vehicles from that period are likely still operational (of course, fuel and oil quality have improved since then).[28] M2W and M3W vehicles carrying just 1-2 persons produce higher CO and HC and one-fourth the PM per kilometre relative to a bus (Table 2.1), despite the bus having a much larger, more powerful engine, and carrying over 40 people. Effectively then, in terms of CO and HC, Delhi now has more than two million buses, each of which carries only 1-2 people.

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already noted. Finally, the mutagenicity of gasoline soluble organic fraction (SOF) per unit mass is greater than for diesel SOF (Faiz et al 1992; Lowenthal 1994; McClellan 1986; Walsh 1991a and 1994).

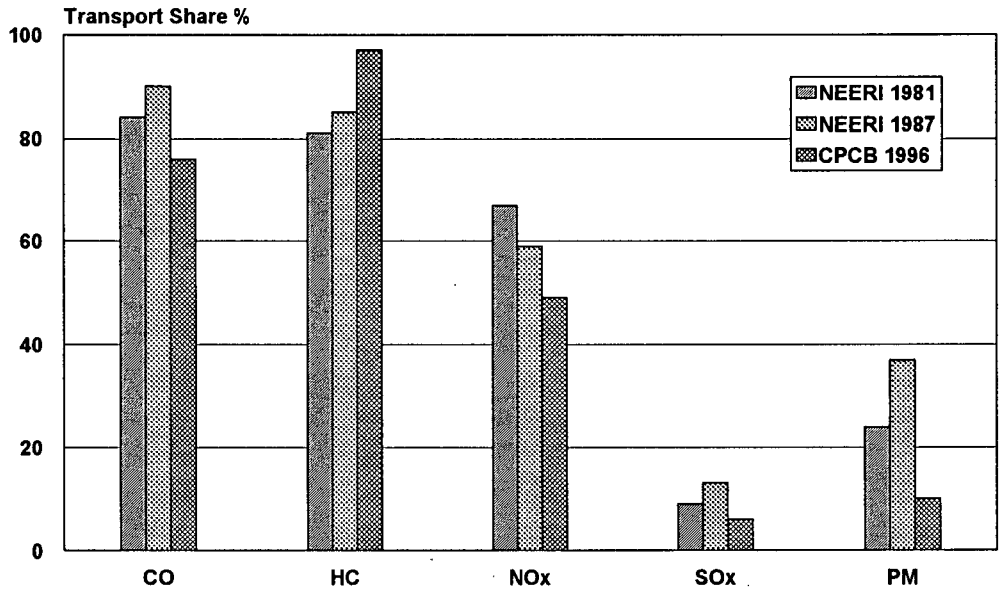
[26] Governments, both at the national and local levels, have instituted or are contemplating several measures in addition to progressively stringent vehicle emission standards and fuel and lubricating oil quality improvements (Appendices III and IV). These measures include enforcement of in-use emissions standards in Delhi (and in some other Indian cities), by means of a road-side no-load pollution check, on the basis of which a "Pollution Under Control" sticker is issued, scrappage of old vehicles in a phased manner in Delhi, alternative fuels, and the introduction of a mass rapid transit system (MRTS) in Delhi and some other cities (CSE 1996 and 1997; MoEF 1997b; NCTD 1997a, b and c).

[27] Fuel sulphur is an important component of exhaust PM. While approximately 98% of diesel sulphur is emitted as SO_2 and 2% as particulate metal sulphates, the latter can contribute up to 14% of diesel PM mass. Further, sulphur oxides from diesels may undergo reactions in the atmosphere to form acidic sulphates and sulphuric acid (Faiz et al 1992; Lowenthal 1994; Pierson 1988; Truex et al 1980).

[28] However, there are many data gaps, uncertainties, and discrepancies in Indian emission factors (Bose 1996; IIP 1994; NCTD 1996; AIAM 1997a). Some data (NCTD 1996) simply reproduces 1973 USEPA data for US vehicles. The IIP (1994) data, perhaps the most dependable, presents actual emission measurements on used vehicles. But this is not without its problems either. These problems are detailed in Chapter III. Table 2.1 is based on IIP (1994) data, supplemented with average PM values for M2W and M3W vehicles, and buses, from Shah and Nagpal (1997). They quote data from South and South-East Asia showing PM emission factors ranging from 0.2 g/km to as high as 2 g/km in poorly maintained M2W and M3W two-stroke vehicles using poor quality lubricating oil, and from 0.75 g/km to 8 g/km in "smoke belcher" buses.

Figure 2.11 Transport Share of Air Pollutant Emissions in Delhi

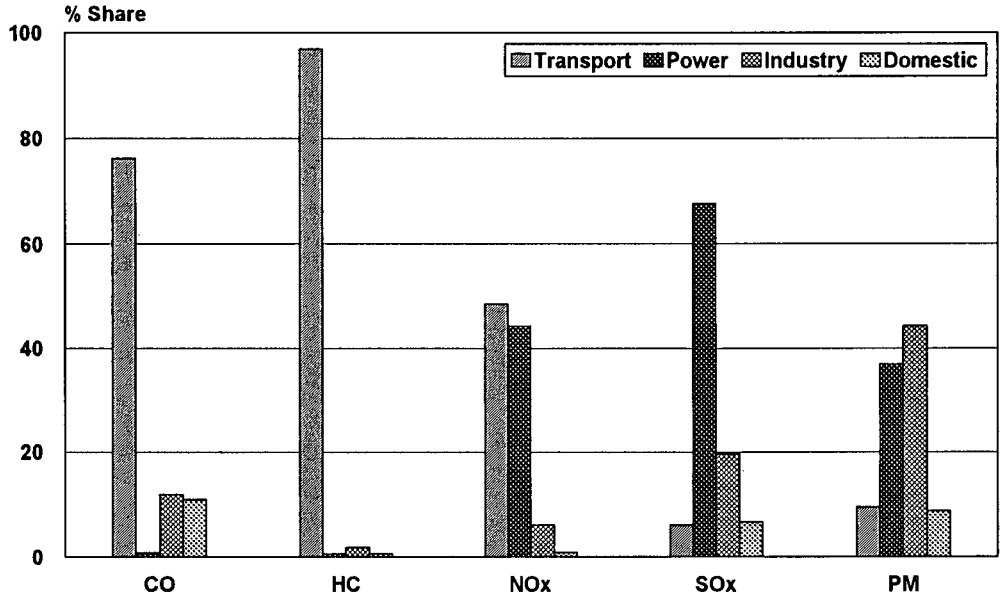
Data from NEERI and CPCB, 1981-1996



NEERI - National Environmental Engineering Research Institute. CPCB - Central Pollution Control Board.
Sources: Brandon and Ramankutty 1993; CSE 1996; Faiz et al 1992; WHO/UNEP 1992. mgb99

Figure 2.12 Air Pollutant Emissions Inventory for Delhi

CPCB, 1996



CPCB - Central Pollution Control Board. Source: CSE 1996 mgb99

Table 2.1 In-Use Indian Motor Vehicular Emission Factors

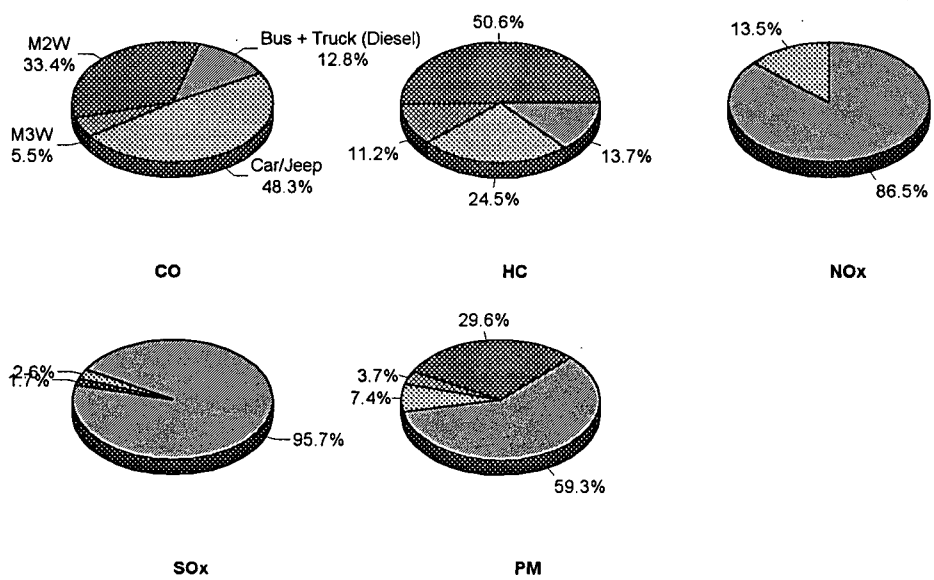
Modal Comparison

Emission Factors, g/km	M2W	M3W	Car	Bus
CO	6.5	8.6	24.9	5
HC	3.9	7	5	2.1
NOx	0.03	0.26	2.01	9.7
SO2	0.013	0.029	0.053	1.44
PM	0.5 (Range 0.2-2)	0.5 (Range 0.2-2)	0.33	2 (Range 0.75-8)

M2W/M3W = Motorized two-/three-wheeled vehicles. Sources: Bose 1996; Shah and Nagpal 1997; IIP 1994. mgb99

Figure 2.13 Motor Vehicular Exhaust Emissions in Delhi

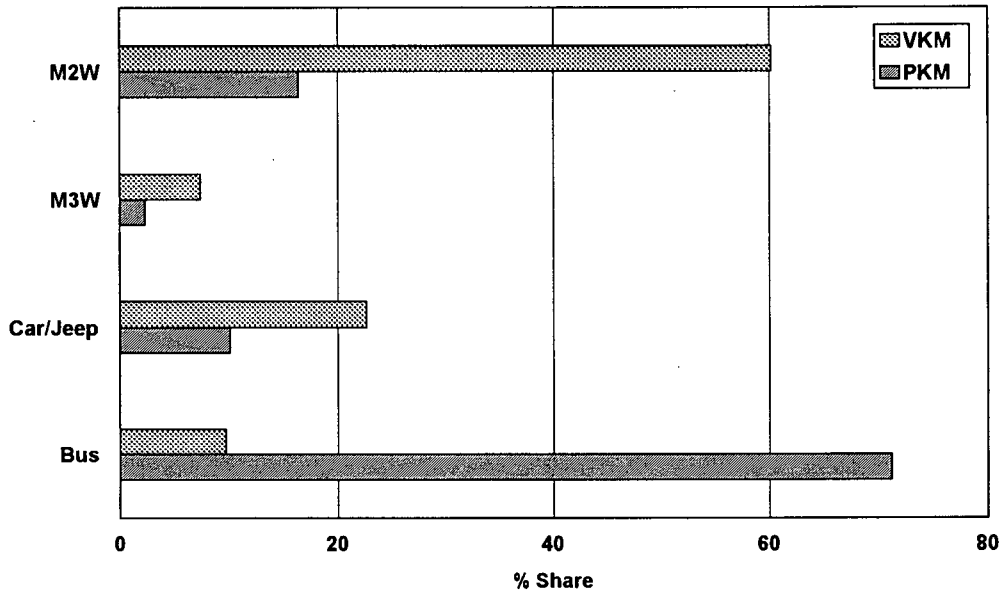
Modal Shares



M2W/M3W = Motorized two-/three-wheeled vehicles. Calculations based on data drawn from ASRTU/CIRT 1997; Bose 1996; CPCB 1997; IIP 1994; Shah and Nagpal 1997. mgb99

Figure 2.14 Passenger Motor Vehicular VKM and PKM in Delhi

Modal Comparison



VKM - vehicle-kilometres; PKM - passenger-kilometres. M2W/M3W = Motorized two-/three-wheeled vehicles. Calculations based on vehicle population, daily kilometre, and occupancy data from ASRTU/CIRT 1997; Bose 1996; CPCB 1997; GoI/ESCAP 1992. mgb99

Table 2.2 Emission Factors for In-Use Indian Cars and Buses

Compared to M2W Vehicle

Index: M2W = 1	Car, g/veh-km	Car, g/pass-km	Bus, g/veh-km	Bus, g/pass-km
CO	3.8	2.3	0.8	0.03
HC	1.3	0.8	0.5	0.02
PM	0.7	0.42	4	0.15
NOx	67	41.1	323.3	12.3
SO2	4.1	2.5	110.8	4.1

M2W = Motorized two-wheeled vehicle. Calculations based on data from ASRTU/CIRT 1997; Bose 1996; CPCB 1997; IIP 1994; Shah and Nagpal 1997. mgb99

Because of their exceedingly high emissions per vehicle-kilometre, and the fact that they are used intensively, M2W vehicles account for significant proportions of CO, HC and PM exhaust emissions from motor vehicle activity in Delhi (Figure 2.13). Their contribution is marginal only in terms of NO_x and SO_x, for which buses (and other diesel-powered vehicles) are primarily responsible.[29]

Further, buses account for only around 10% of vehicle-kilometres, but 71% of passenger-kilometres, in motorized passenger vehicles in Delhi. On the other hand, M2W vehicles account for 60% of vehicle-kilometres, and only 16% of passenger-kilometres, in such vehicles (Figure 2.14). Thus, on an emissions per passenger-kilometre basis, M2W vehicles produce roughly 33, 50 and 7 times the amount of CO, HC, and PM, and one-fourth the SO_x, that buses do (Table 2.2).

To conclude this section, the share of transport is high in terms of CO, HC and NO_x emissions in Delhi, and its role in terms of SPM and SO_2 is growing with time. Further, the share of transport in high traffic areas, where large numbers of people live and work, is considerably higher than on a city-wide basis, thus causing significant exposures and health risks. M2W vehicles are an important transport source of CO, HC and PM, particularly on an emissions per passenger-kilometre basis. While not ignoring the key role of diesel vehicles, particularly in terms of NO_x, SO_x and PM, this fact highlights the need to direct public policy attention to M2W vehicle emissions in Delhi (and in the Indian context generally).

2.5 DELHI'S MOTOR VEHICLE ACTIVITY AND AIR POLLUTION IN A WIDER CONTEXT

So far, we have discussed air pollution and its local health effects in Delhi, and the increasingly important role of transport in general, and M2W vehicles in particular. In order to more strongly justify public policy attention, Delhi's transport air pollution problem is shown to be shared by many other Indian and LIC cities in the following discussion. Further,

[29] It must be stressed that all the calculations in this section focus on exhaust emissions alone. In addition to the other problems, Indian transport emissions inventories (such as that conducted by CPCB -- CSE 1996) do not appear to take into account crankcase and evaporative emissions, which are likely significant in the Indian context, nor PM due to brake, clutch and tyre wear, and re-suspended dust. Emissions from these sources would need to be included for a truly comprehensive accounting of transport emissions.

transport air pollution and energy consumption have many non-health welfare effects, locally as well as regionally and globally. The growing role of transport in India and the other LICs in terms of climate change, acidification and energy security is discussed. Finally, Delhi's transport air pollution problem is placed in the context of broader urban transport and urbanization impacts, as a means of highlighting the public policy challenge.

2.5.1 Motor Vehicle Activity and Urban Air Pollution in India and Other LICs

Delhi is by no means unique, either in terms of rapid growth in motor vehicles, or the predominance of M2W vehicles. Motor vehicle growth has been at least as rapid in other Indian cities. Between 1971 and 1995, motor vehicle numbers increased more rapidly in Ahmedabad, Bangalore and Chennai than in Delhi. In fact, Chennai's motor vehicle fleet increased from only 120,000 to 768,000 in that period. While M2W vehicles form 67% of Delhi's motor vehicle fleet, they represent 70-80% of the fleet in Ahmedabad, Bangalore, Chennai, and Hyderabad. Only Calcutta and Mumbai have a low percentage (43%) in this respect (ASRTU/CIRT 1997).

In India as a whole, motor vehicle numbers increased from only 665,000 in 1961, and 5.4 millions as late as 1981, to over 27 million in 1994 (Figure 2.15). At 8% pa (per annum) growth, this number could touch 43 million by 2000 (AIAM 1994a; TERI 1997a). As in Delhi, M2W vehicles are the most rapidly growing vehicle type country-wide (44% pa in the 1980s). M2W vehicles represent nearly 80% of all motor vehicles produced and sold, and 67% of those registered, nationally. India arguably has the largest population of this vehicle type of any country. Even in 1988, India accounted for only 0.04% and 1.3% of the world's cars and trucks/buses, but 8.4% of global M2W (and M3W) vehicles (AIAM 1994a and 1995; ASRTU/CIRT 1997; Faiz et al 1992; TERI 1997a).

The motor vehicle trends in India are shared by many other Asian LICs. While the growth in motor vehicles is rapid globally, it is most so in Asia, as markets become saturated in the OECD, and production moves to large untapped markets in Asia, where policies now encourage investment. Though Asia accounts for a small proportion of the global fleet, motor

vehicles are doubling every seven years in many of its nations.[30] By 2040, rapidly industrializing LICs could have as many vehicles as North America and Western Europe (Champagne 1998; Faiz et al 1992; Mohan, Tiwari and Kanungo 1997; Walsh 1991a and 1994).

South and East Asia collectively had only 8.5% of the world's motor vehicles, but 36% of its M2W and M3W vehicles, in 1988. M2W and M3W vehicles make up more than 50% of the fleet in Bangladesh, Thailand, Malaysia, Indonesia and Taiwan. In Bangkok, M2W vehicles increased three-fold in just six years from 1980, and might reach three million by 2000, if trends follow those in Taipei, where each household owns at least one such vehicle (Faiz et al 1992; Poboon et al 1994).

As in the Indian context, motor vehicle activity in other LICs is characterized by restricted technological, financial and administrative resources for manufacturing and maintaining clean vehicles and fuels, providing transport infrastructure, public transit and transport system management, and for policy-making and implementation. Also, unlike in the West, motor vehicle activity in the LICs is typically concentrated in one or a few major cities. In Iran, Korea, Mexico, Philippines, and Thailand, the capital cities account for 40-50% of national automobile fleets (Faiz et al 1992; Faiz and Aloisi de Larderel 1993; Sathaye, Tyler, and Goldman 1994; Shalizi and Carbajo 1994; WHO/UNEP 1992).[31]

The role of the LICs is currently not significant in terms of global motor vehicle numbers and motor vehicular CO, HC and NO_x emissions (10-25%), but their share of these pollutants, and of global motor vehicular SO_2 and PM, already considerable (40-60%), is expected to grow significantly, even with progressive controls. The OECD, on the other hand, will likely experience reductions (Faiz et al 1992; Walsh 1994).[32]

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[30] Motor vehicle numbers increased from a mere 40,000 in 1971 to nearly 400,000 in 1993 in Bangladesh, and from 177,000 in 1970 to 1.24 million in 1995 in Sri Lanka, thus giving an annual growth rate of 40 and 25% in the two countries (Mohan, Tiwari and Kanungo 1997).

[31] This concentration is more accentuated for cars than for other modes, reflecting the concentration of economic power. While 76% of Thailand's M2W vehicles were registered outside Bangkok, only 23% cars were. India is in a much better position. 35% of its motor vehicles operate in 23 metropolitan centres. However, Bangalore, Delhi, Calcutta, Chennai and Mumbai jointly account for 17% of the national motor vehicle fleet (ASRTU/CIRT 1997; Sathaye, Tyler, and Goldman 1994).

[32] M2W vehicles (mostly in the LICs), will likely contribute significantly to increased HC emissions globally, and trucks will be a rapidly growing contributor to global NO_x and PM (Walsh 1994).

The share of transport in air pollution in LIC cities is significant and growing. The concentration of national motor vehicular activity in these cities is certainly a factor. Air pollution in many LIC (including Asian) cities, already serious, could soon rival Mexico City's, where levels of several air pollutants already exceed WHO limits by more than a factor of two. 12 of the 15 cities globally with the highest SPM levels, and the six with the highest SO_2 levels are in Asia (these include Delhi, Beijing, Calcutta, Jakarta, Shanghai, Seoul, Manila, and Bangkok).[33] Lead levels have been high in many Indian (and Asian LIC) cities, with blood lead three times that in the OECD. Respiratory diseases, the second commonest cause of death in children under five in the LICs, kill more than four million globally annually (Agrawal 1997; Brandon and Ramankutty 1993; Faiz et al 1992; Faiz and Aloisi de Larderel 1993; Smith 1988 and 1994; Walsh 1994; WHO/UNEP 1992).[34]

2.5.2 Transport, Energy Security, and Climate Change

Delhi consumes nearly 10% of the nation's gasoline, 3.3% of its diesel (and 4% of its petroleum products), with only 1.4% of its population. Annual growth rates for these categories range from 5-8%. Nationally, industry continues to consume the largest share (50%) of India's commercial energy, whereas transport consumes around 24% (as opposed to 5% in China). However, energy intensity is reducing in the former, and increasing at 7% annually in the latter sector, less rapidly than in only the domestic sector. Further, as in other countries, transport is a major consumer of petroleum products (44 and 51% in 1985 and 1995) (Brandon and Ramankutty 1993; GoI/ESCAP 1991; TERI 1997a).

Diesel is the principal Indian petroleum product consumed (43%, as against 6% for gasoline), the primary source of transport energy (75%, as against 25% for gasoline) and the fastest consumed petroleum product since the 1970s (11.8% annually, as against 6% for gasoline). But passenger movement by private modes (predominantly urban and gasoline-powered), currently only 20% of passenger movement by road, is likely to increase much

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[33] Monthly SPM and SO_2 maxima in Calcutta are 891 and 300 $\mu g/m^3$, and annual average SPM levels as high as 1000-1700 $\mu g/m^3$ have been recorded at traffic junctions (Priti Kumar et al 1997).

[34] It is not merely major Indian and LIC cities that have severe air pollution. Air pollution and per capita air pollution effects are significantly higher in secondary Indian cities than in Delhi. Over 90% of CPCB stations nationwide record annual SPM levels exceeding the WHO standard, with SO_2 levels doing likewise in many cities (Brandon and Hommann 1995; CPCB 1992 and 1996).

faster (13% annually) than by public modes. Also, freight is expected to grow slowly. As a result of these trends, gasoline consumption in transport will likely increase twice as rapidly as diesel. Incidentally, M2W vehicles already consume nearly 50% of Indian gasoline. In 2009, gasoline will likely contribute one-third and diesel two-thirds, of transport energy (GoI/ESCAP 1991; Faiz et al 1996; TERI 1997a).

If motor vehicle activity trends persist, transport energy demand will increase dramatically. This trend will likely have significant energy and political security implications.[35] Petroleum product consumption increased three times between 1970 and 1990 (Figure 2.16). The gap between local oil production and refining capacity and demand is rising rapidly, and has to be met through imports. India's vulnerability to world oil prices and crises is borne out by the fact that while imports increased 9% annually in the 1970s, their cost increased 389%. The net oil import bill as a percentage of net export earnings increased from 8% in the 1960s, to over 30% and 75% in 1973/74 and 1980/81 respectively, and currently stands at 32%.[36, 37] The future is worrisome, given rapid demand growth, and the possibility that Indian oil reserves will last only 25 years at current production levels (GoI/ESCAP 1991; TERI 1997a).

At the global level, transport already consumes about 25% of commercial energy, and is the fastest growing end-use category. The OECD, with 15% of world population, accounted for nearly two-thirds of global commercial energy consumption for transport in 1995, but its demand over the next two or three decades is expected to be flat or growing slowly. In contrast, transport energy demand in the LICs, now around one-third that in the OECD countries, could increase two to three times in as many decades. This has serious security implications, since transport already consumes around 45% of the world's oil. India's and China's combined oil consumption accounts for only 6.6% of the world's, but is increasing at 6.4% annually, while world oil consumption is increasing at 1.5%.

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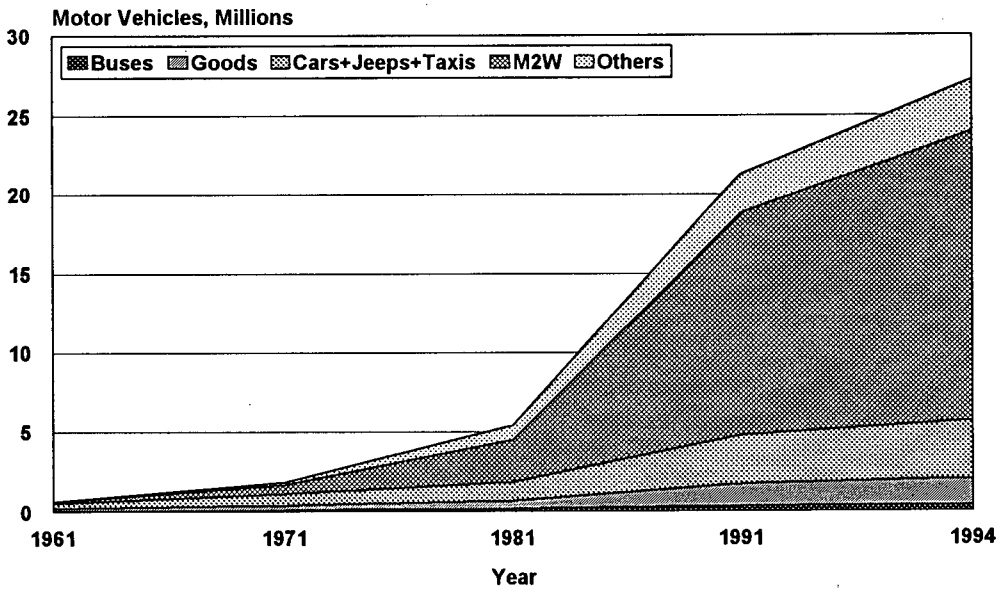
[35] Energy consumption is increasing rapidly in all sectors. It is currently doubling every 12 years in India (and Asia), as opposed to 28 years globally (Brandon and Ramankutty 1993).

[36] Besides, oil imports alone account for nearly a quarter of all Indian imports (Nag 1997).

[37] The predominant role of diesel in Indian transport is of concern because of its implications for air pollution health effects. Further, diesel accounts for 62% of petroleum imports, which are vulnerable to price fluctuations, and it has also been heavily subsidized (GoI/ESCAP 1991; Nag 1997; TERI 1997a).

Figure 2.15 Motor Vehicle Growth in India

1961-1994

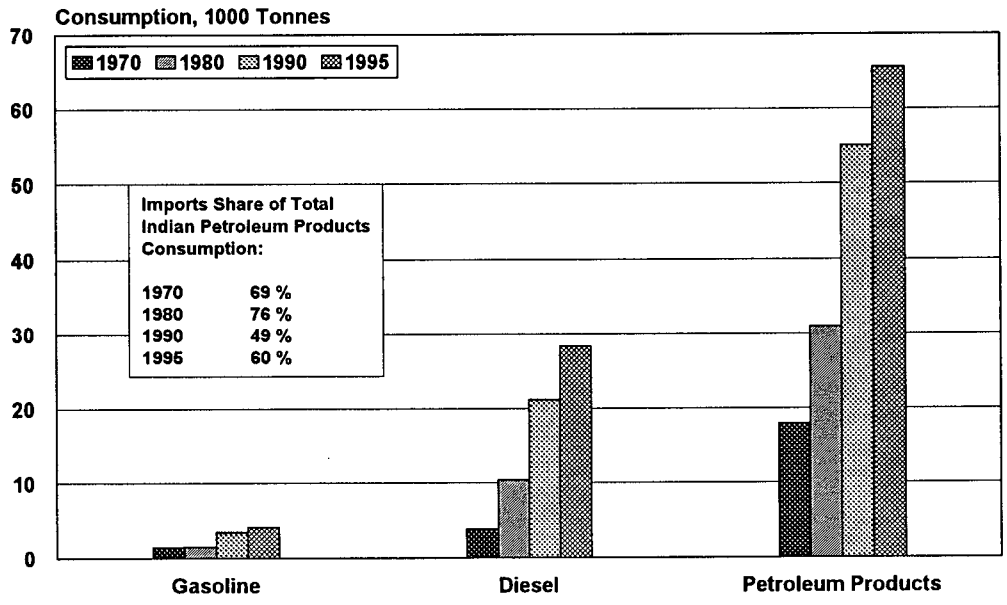


M2W = Motorized two-wheeled vehicles. Sources: AIAM 1994a; TERI 1997a.

mgb99

Figure 2.16 Petroleum Products Consumption in India

1970-1995



Source: TERI 1997a.

mgb99

At this rate, two-thirds of global oil will likely have to come from the politically volatile Middle East, as against only 26% in 1991. If, as some scenarios suggest, the global fleet grows to five billion motor vehicles by the end of the 21st century, transport alone would require, even with efficiency improvements, up to 50% more than the present total oil consumption world-wide (Flavin and Lenssen 1991; Grübler 1994; Holdren 1990).

The rapid growth in motor vehicle activity and transport energy demand also have important implications for climate change. Globally, motor vehicles contribute significantly to emissions of gases implicated in climate change, including CO_2 and CFCs (the two major climate change gases),[38] tropospheric O_3, nitrous oxide, methane, and CO. Transport accounts for around 14% of CO_2 and 25% of CFC emissions globally, and around 15% of all global warming. The share of non-OECD countries, including the LICs, is only 33 and 10% of global motor vehicle generated CO_2 and CFCs respectively. However, with rapid growth in motor vehicle activity, CO_2 emissions from global transport will likely be two-thirds above current levels by 2030, with nearly half coming from non-OECD countries. In these countries, transport CO_2 emissions could increase thrice in as many decades, even with fuel economy improvements.[39] Of course, even with this increase, their share will barely equal that of the OECD.[40]

2.5.3 Regional Acidification and Tropospheric Ozone

Acidification results from SO_2 and NO_x being transported by prevailing winds and returned to earth in wet or dry form. Typically, sulphuric acid makes up 60-70% of total acidity, and nitric acid the balance. While transport contributes insignificantly to SO_2, its contribution to NO_x is

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[38] CFCs are not caused by M2W vehicles, the focus of this study. Indeed, CFCs are not normally associated with transport. However, CFCs from motor vehicle air-conditioning, and other automotive systems, are a major contributor to overall CFC emissions. A significant contributor to climate change, CFCs are also predominantly responsible for stratospheric ozone depletion (Faiz et al 1992; Government of Canada 1991; Walsh 1994).

[39] Cars will likely dominate in terms of CO_2. However, heavy-duty trucks, accounting for under 10% of the global fleet but almost 20% of motor vehicle-kilometres, and 25% of CO_2 from road transport, will be a rapidly growing contributor, due to minimal fuel efficiency improvements. By 2030, they will likely be the dominant vehicular CO_2 source (Faiz et al 1992; MacKenzie and Walsh 1990; Walsh 1991a).

[40] Thus, as Faiz et al (1992) point out, policy in most LICs would be driven by energy conservation, rather than global environmental, considerations.

substantial. O_3 and its precursors (a growing problem in Delhi and other LIC cities) also travel great distances, so that high levels can occur far from major sources. For example, while O_3 levels exceed WHO limits by up to 9% within Delhi, they typically do so by 20% outside (Faiz et al 1992; Roy Chowdhury 1997; Walsh 1994).

Local and regional impacts due to acidification and ground level O_3 (and PM) include damage to soils, vegetation and crops, and forest and aquatic ecosystems, groundwater pollution due to toxic metal leaching, impaired visibility, metal corrosion, and structural damage to buildings and monuments (the Taj Mahal is a prominent victim). Acidification and O_3 effects in the LICs, particularly in Asia, are increasing rapidly. India and China are particularly prone to high emissions and depositions.[41] While this is the case, even low O_3 levels can seriously diminish crop yields. More importantly, O_3 appears to affect tropical crops more severely than US and European ones. While damage is estimated to be 10% in the USA (except for sensitive crops in California), it could be 40% for wheat, soybean, rice and groundnut in the North Indian bread-basket states of Punjab and Haryana (Brandon and Ramankutty 1993; Faiz et al 1992; Roychowdhury 1997; Walsh 1994).

2.5.4 Other Impacts of Motor Vehicle Activity and Urbanization

This dissertation focuses on transport air pollution. However, it is important to keep in mind that while air pollution might be the most widely felt impact of motor vehicle activity, there are other important transport impacts, and that air pollution is inextricably linked with them.

Delhi's (and India's) road safety record, already among of the world's worst, are deteriorating steadily. In 1993, Delhi accounted for 19% of all road accidents, and 36% of all resulting mortalities, in 12 major Indian cities (interestingly, Calcutta and Bombay had more accidents, but far fewer mortalities). Nationwide, road accidents are the primary cause of accidental deaths. They caused 54,058 and 60,595 mortalities in 1990 and 1993 respectively, as many as in North America, and with a fraction of its motor vehicle activity. While car occupants accounted for only 12% of Delhi's road accident fatalities in 1994, pedestrians, cyclists and M2W vehicle users accounted for 42, 14 and 27% (AIAM 1995; ASRTU/CIRT

[41] Asia's SO_2 emissions, mainly from coal-fired power plants and industry, but also domestic sources, could easily exceed the OECD's by 2010 (Brandon and Ramankutty 1993).

1997; Mohan and Tiwari 1997; Mohan, Tiwari and Kanungo 1997; Stackhouse 1995; TERI 1997a).[42, 43]

Peak-hour speeds are dropping with growing motor vehicle activity, and now average 10-20 km/h in Delhi, Bombay, Calcutta and many other Asian LIC cities.[44] Besides causing time and productivity losses, congestion significantly exacerbates air pollution and energy consumption (Brandon and Ramankutty 1993; CSE 1996; Faiz et al 1992; Sathaye, Tyler, and Goldman 1994; Poboon et al 1994). Since congestion involves a large number of vehicles moving in a "stop-and-go" fashion over narrow corridors, the net result in terms of *local pollutant levels* is bound to be dramatic.

As motor vehicle activity, sprawl, and accommodation of motor vehicles feed on each other, NMVs become less viable, and access and mobility for pedestrians, NMV users, and for those too poor to afford even the least expensive modes, suffers. Even in Delhi, around 50% of the population lives in slums, and many residential households do not possess even bicycles. The trend in the LICs has been a significant reduction in non-motorized vehicle (NMV) shares. In Delhi (Figure 2.17), bicycle trips dramatically reduced from 36 to 7% of trips by all mechanical modes between 1957 and 1994. In the western Indian city of Pune, households with bicycles fell from 61 to 29%, while those with M2W vehicles rose from 17 to 41%, between 1982 and 1989 (Hillman 1990; Whitelegg 1993; Midgley 1994; Pendakur 1987 and 1988; Replogle 1992; RITES/ORG 1994; Sathaye, Tyler, and Goldman 1994).

Though generally overlooked, transport wastes include used crankcase oils, lubricants, transmission and brake fluids, coolants, automobile batteries and acids, filters, tyres and solvents generated during vehicle operation, maintenance, servicing and disposal. Many of these wastes are hazardous, contain carcinogens and/or neurotoxins, and when disposed of

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[42] Other LIC countries show a similar trend. In Bangladesh, Sri Lanka, and Thailand, 53-72% of such fatalities are pedestrians and NMV users. In the USA, by contrast, less than 20% are pedestrians or cyclists. In Sri Lanka, Malaysia and Thailand, M2W vehicle users account for 34-57% of road fatalities. The high shares of NMV and M2W vehicle users in countries like India are of course due to their high shares in travel activity. Additionally, there is little separation between motorized and non-motorized modes and sidewalk activity, and traffic regulations are hardly enforced (Mohan and Tiwari 1997; Mohan, Tiwari and Kanungo 1997). Finally, M2W vehicles are unstable, and are rendered more so by being used to carry passengers and/or goods.

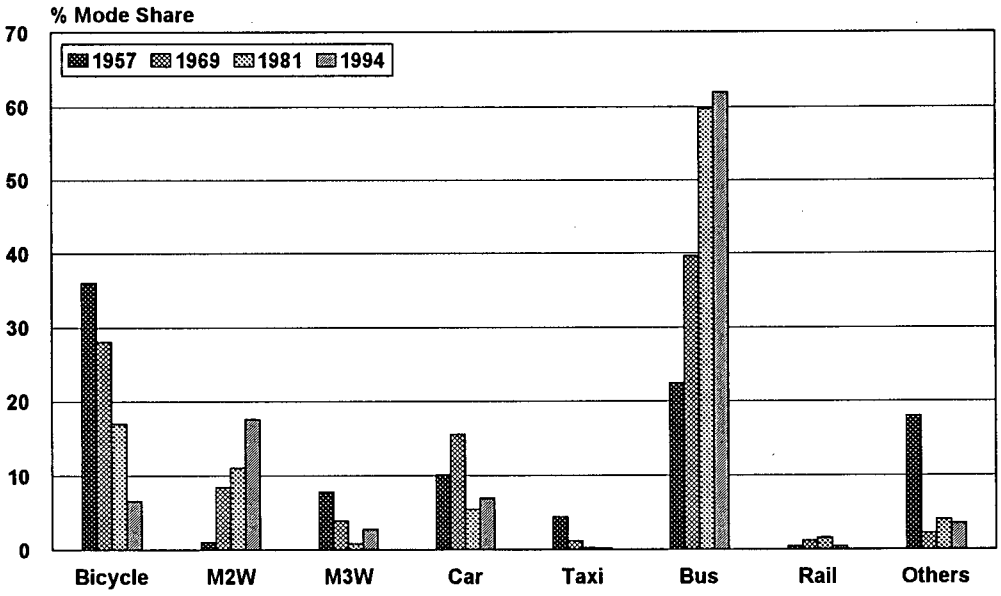
[43] In addition to the disproportionate representation of pedestrians and cyclists, there is also a dramatic skew in terms of gender. More than 80% of Indian road fatalities are male (Mohan, Tiwari and Kanungo 1997).

[44] However, we must be careful when comparing average speeds in different contexts, because the share of walking and non-motorized trips, which of course lower average speeds, can vary widely across contexts.

indiscriminately (there are virtually no controls in the Indian context), can either persist in the air, water or soil, or be absorbed by the lower organisms, and travel up the food chain. As the number of under-ground fuel storage tanks increase with growing motor vehicle activity, so will the likelihood of leakage and contamination of ground water (California Environmental Protection Agency 1988; Government of Canada 1991).

Figure 2.17 Mechanical Mode Share Changes in Delhi

1957-1994



M2W/M3W = Motorized two-/three-wheeled vehicles. Source: RITES/ORG 1994. mgb 99

Traffic noise, including that due to frequent horn usage (because of the chaotic traffic), is high, and increasing. Levels of the order of 80 dB(A), typical of road traffic, can induce both physiological as well as psychological effects (Barde and Button 1990). Finally: associated with high motor vehicle activity levels is the operation and maintenance of various facilities such as traffic control, policing, and street maintenance, activities that are resource-intensive and which require transport systems of their own.

Transport is by no means the only source of air pollution, and neither is outdoor urban air pollution the only air pollution problem. The burning of fuelwood and other 'traditional' fuels by the vast majority for cooking and space heating creates indoor PM levels of 6000 $\mu g/m^3$,

and health impacts far more severe than in even the most polluted urban environments. Not only the vast majority of rural inhabitants, but also a significant number of low-income urban households, rely on these fuels.[45, 46] Thus, the urban poor receive very high PM exposures from city-wide as well as indoor sources (Brandon and Ramankutty 1993; GoI/ESCAP 1991; Priti Kumar et al 1997; Smith 1988 and 1994; TERI 1997a).

Neither air pollution nor the other transport impacts discussed are the only serious urban problems in Delhi and other Indian and LIC cities. Water pollution due to ineffective sewage and human waste disposal, and other effluents, is perhaps the most widespread urban environmental problem in India (and Asia). Coupled with inadequate and overcrowded housing and poor solid waste disposal, water pollution causes water and vector borne diseases that are responsible for millions of mortalities and morbidities annually, mainly among children. It is worth noting in this connection that water pollution alone accounts for 59% of total health impacts due to environmental pollution in India, as against only 14% for air pollution. Infectious and parasitic diseases account for 18-19% of all deaths in India, and 27% of deaths among children under five, and are increasing rapidly. Thus, the scale and range of problems in Indian (and LIC) cities is massive, and many of these do far greater, and more easily preventable, damage to human health than air pollution, important as that is (Brandon and Ramankutty 1993; Brandon and Hommann 1995; Hardoy and Satterthwaite 1991; Mohan, Tiwari and Kanungo 1997).

2.6 SUMMARY AND CONCLUSIONS

Motor vehicle activity is increasing rapidly in Delhi. Also, Delhi's air quality is poor, and deteriorating. The contribution of transport to the city's air pollution is significant and

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[45] In India, these fuels even now account for 75% of total household energy use (90 and 40% in rural and urban areas), and over one-third of final energy consumption, with coal, soft coke, and charcoal accounting for another 24%. In addition to adverse health impacts, these fuels are a major cause of deforestation. Also, for example, burning dung instead of using it as fertilizer deprives the soil of nutrients (Brandon and Ramankutty 1993; GoI/ESCAP 1991; TERI 1997a).

[46] In the Indian context, the effect of high particulate levels is exacerbated by widespread smoking, which affects non-smokers only marginally less than it does smokers. Also, the growing electrical power shortage has resulted in increased use of portable generators, many of which are powered by two-stroke gasoline and diesel engines (CSE 1996). Though generators may not be significant in terms of total pollution load, they tend to be used over prolonged periods daily in residences and other enclosed areas such as markets, and are therefore of concern in terms of total human exposure and health impacts.

growing. M2W vehicles account for the lion's share of the city's motor vehicle activity. Because of this fact, and their exceedingly high emission factors, M2W vehicles contribute significantly to transport air pollution, particularly on a per passenger-kilometre basis. At the same time, M2W vehicles provide affordable mobility to millions who have few other attractive options.

Transport air pollution poses a particularly difficult public policy challenge. It is an externality that transport system users impose on non-users, as opposed to congestion, which primarily affects users, who at least benefit from motor vehicles (Hanson 1992; MacKenzie et al 1992; OECD 1992). In Indian cities, a majority of the non-users are poor and enjoy none of the benefits of motor vehicles, while involuntarily bearing the brunt of its impacts. Chronic health and welfare effects of long term exposure to multiple transport pollutants may be far more serious than those due to acute episodes involving stationary sources, and are far more difficult to document and quantify. Besides, pollutant emissions from a large number and variety of motor vehicles are far more difficult to control than from stationary sources (Faiz et al 1992). Finally, transport is arguably the most complex sector in terms of human behavioural issues. In the case of M2W vehicles in India, the additional challenge is how to address their emissions while minimizing adverse policy impacts for vehicle users. It is this challenge, and the challenge that transport air pollution poses generally, that provides the rationale for this dissertation.

Delhi's rapid growth in motor vehicle activity, particularly in terms of M2W vehicles, and its deteriorating air quality, are features shared by many other Indian and LIC cities. Transport emissions, already significant in terms of the rapidly worsening urban air pollution in the LICs, will likely become even more so. Additionally, transport energy demand in the LICs could increase as much as three times in as many decades.

Addressing transport-energy-air pollution linkages in India and other LICs is therefore important, in terms of local well-being as well as regional and global issues such as energy security, acidification and climate change. Focusing on M2W vehicle emissions in Delhi, as this dissertation does, is all the more relevant in light of the above considerations.

The effort to address transport air pollution must recognize that air pollution is by no means the only important transport impact. Neither is transport the only source of air

pollution. Further, neither transport air pollution nor the other transport impacts are the only serious urban problems in Delhi and other Indian and LIC cities. Lastly, the Indian and LIC contexts are characterized by multiple urgent demands on meagre technical, financial and administrative resources.

CHAPTER III
TRANSPORT AIR POLLUTION IN INDIA: A DISCUSSION OF CONTRIBUTORY FACTORS

3.1 INTRODUCTION

In order to gain a good understanding of, and to effectively address, any problem, it is important to investigate the various factors that contribute to it. This is particularly true of complex and multi-dimensional public policy challenges such as transport air pollution. In Chapter II, reference was made to some of the critical factors contributing to air pollutant emissions from M2W and other vehicles in Delhi, including outdated vehicle technology, poor vehicle maintenance, poor quality fuel and oil, and fuel and oil adulteration. But there are many other contributory factors. Also, addressing the transport air pollution problem in India requires an understanding of important contextual characteristics that critically influence emissions.

This chapter discusses in some detail the complex of inter-locking factors that contribute to M2W vehicle air pollutant emissions in Delhi. This discussion can help identify policy levers to target key contributory factors. Just as importantly, it can help identify factors that are impervious to policy interventions, and must therefore be accepted as constraints. Lastly, identifying critical contributory factors will help in making transport emissions and energy consumption measurement and modeling efforts more effective.

While the discussion focuses primarily on M2W vehicles in Delhi, it is relevant to the overall transport air pollution and energy consumption problem in India. Further, while the proximate causes of the problem are technological, the more fundamental causes are non-technological and institutional, and must be considered for long-term policy effectiveness. Institutional factors are discussed in this chapter, but are treated in greater detail in Chapter IV, which addresses the institutional setting for policy-making and implementation with regard to this problem in the Indian context. Vehicle user behavioural factors play a crucially important role in influencing transport air pollutant emissions. Reference is made to some key user behavioural factors, but they are discussed in detail in Chapter VI, which focuses on M2W vehicle user preferences, choices and motivations,

and their perspectives on how they would be affected by, and would respond to various policy alternatives. Since transport air pollution is a function of both per-vehicle emissions, as well as overall vehicle activity, the chapter addresses factors that contribute to both of these key components of the problem. The advantage of this approach is that technological-curative as well as preventive alternatives may be identified, for long-term effectiveness. Indeed, the chapter focuses on air pollutant emissions transport system-wide due to M2W vehicle activity, rather than merely from vehicle exhaust.

3.2 METHODOLOGY

The discussion in this chapter draws on published literature on a range of subjects including environmental policy, engineering, urban transport, and urbanization, reflecting the multi-dimensional nature of the transport air pollution problem. Documents relating to vehicle and fuel technology and the urban transport system in the Indian context that the author culled during the course of his field work in late 1997 are also referred to. Additionally, the chapter draws on in-depth interviews with various individuals interested in and/or knowledgeable about the range of issues involved, and representatives of institutions whose actions have an important bearing on transport air pollution in the Indian context. These individuals included decision makers in various relevant government agencies at both the national and local levels, vehicle and fuel industry representatives, academics and researchers,[1] and last but not least, M2W vehicle users. Combining information from these diverse sources helped the author gain a comprehensive understanding of the various contributory factors and their interactions, and how the situation is evolving and is likely to continue to evolve over the coming years.

[1] A list of these interviewees is provided in Appendix V. Interviewees' informed consent was obtained prior to interviews being conducted. The interview protocol, and the Informed Consent Form (Appendix VI), were approved by the Behavioural Research Ethics Board of the UBC Office of Research Services and Administration. One of the conditions of this approval was that the identity of interview participants would be kept confidential. It is for this reason that, while their information and insights were of immense value to the author, interviewees are not explicitly acknowledged. For the questionnaire, interview protocol and Informed Consent Form relating to the survey of, and in-depth interviews with M2W vehicle users, see Appendices VIII-XI.

3.3 FACTORS CONTRIBUTING TO M2W VEHICLE AIR POLLUTANT EMISSIONS IN THE INDIAN CONTEXT

Before we discuss factors contributing to M2W vehicle air pollutant emissions, it is useful to note that it is exposure to air pollution, not merely air pollutant emissions, that determine health and welfare impacts. In turn, exposure is a function of local pollutant concentrations, duration of exposure, and the number of people exposed (Faiz et al 1992). However, air pollution impacts are not a function of exposure only. Also important are factors such as nutrition quality, and level of physical activity during exposure, as noted in Chapter II (CSE 1996; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman, 1991; Romieu et al 1992; Wijetilleke and Karunaratne 1997). While all of the above factors in combination determine susceptibility to health impacts, access to quality health care influences the ability to cope with impacts, once they occur. Factors such as nutrition quality and access to quality health care are strongly related to income. And so, one might argue, are the level of physical activity to earn a living and housing location, both of which can strongly influence exposure. In short, income may likely be an important determinant of air pollution exposure and impacts.

Factors such as topography, ventilation (and in turn, wind transport, dispersion and inversions), weather (in terms of precipitation), and vegetation have an important bearing on air pollutant concentrations, apart from transport and other emissions (Faiz et al 1992).[2] Delhi's SPM concentrations would be a lot lower, for example, if its rainfall were distributed more evenly over the year. The point of the foregoing is that, while the best line of action is of course to minimize emissions in the first place, measures such as housing away from areas of high local pollutant concentrations, improved nutrition, and access to good quality health care would also help.

3.3.1 Vehicle Technology

In general terms, Indian motor vehicle technology is decades behind global practice. 1950s and 1960s vintage vehicles, with considerably lower fuel economy than OECD vehicles,

[2] As Faiz et al (1992) point out, though air pollutant emissions in Santiago, Chile are only 10% of those in Sao Paulo, Brazil, the severity of pollution episodes in Santiago equal those in Sao Paulo.

continue to be manufactured in India and other LICs. This situation is changing, however, as more recent model vehicles are entering the Indian market with economic liberalization (Faiz et al 1992; Champagne 1998).[3,4]

Two-stroke engines power the bulk of Indian M2W vehicles, as indicated in Chapter II. M2W vehicles powered by four-stroke engines are expected to grow in prominence, as industry increasingly relies on this technology, among other options, in response to the stringent emission standards scheduled to come into force in 2000 (Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; MoST 1996).[5] Until recently, however, four-strokes have accounted for only 10-15% of annual M2W vehicles sales, and thus constitute only a small proportion of this fleet in India. In 1997, there were around eight M2W vehicle models that were powered by four-stroke engines in the Indian market (Narayana 1994).[6]

Table 3.1 compares the in-use fuel economy and exhaust emissions of Indian M2W vehicles with their two-stroke European counterparts in the early 1990s. This comparison is relevant, because many M2W vehicles from that period are likely operational on Indian roads. It appears from the figure that even in the early 1990s, Indian M2W vehicles were

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[3] For example, fuel injection is beginning to replace carburetion in cars, as emission standards become more stringent, and three-way catalytic converters, which require fuel injection for optimum effectiveness, become necessary in order to achieve those emission standards. Catalytic converters were mandated on all new cars in the major Indian cities in 1995, along with the introduction of more stringent emission standards (Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; Faiz et al 1992; MoST 1996).

[4] Fuel economy data on Indian vehicles is sketchy, particularly for vehicles other than M2W and M3W vehicles. Where fuel economy data is presented, test conditions are rarely indicated. Average fuel economy for new Indian cars (including recent models) appears to be around 13 km/l on the Indian driving cycle, compared to around 11 km/l in Europe for both urban and highway driving, and 17 km/l in-city in North America (AIAM 1994b and 1997b; Environment Canada 1998; Faiz et al 1996; IIP 1994).

[5] Four-stroke engines deliver one power stroke for every two revolutions of the engine crankshaft, as opposed to two-strokes, which deliver a power stroke every revolution. The problem of fuel-air charge escaping unburned through the exhaust is eliminated on four strokes. Also, four strokes employ crankcase lubrication. HC, CO and PM emissions are reduced significantly, and fuel economy is considerably improved, compared to two-strokes. However, four strokes are larger (and heavier) for the same power output, and more expensive than two strokes. This is precisely why two-strokes are preferred for small M2W vehicles (Faiz et al 1992 and 1996).

[6] M2W vehicles sold over the last 30 years, and manufactured to this day, in India and other LICs, were developed in the 1960s by the Japanese, Italians and others. At the time, there was understandably no great interest in either emissions or fuel economy, and most such vehicles under 200 cc capacity were two-strokes. Only Honda offer a variety of four-strokes with displacements below 200 cc, and Kawasaki and Yamaha have a few models (Duleep 1994). Not surprisingly, all the motorcycle models offered by Hero-Honda in India are four-strokes (so is the Kawasaki-Bajaj 4s) (AIAM 1994b and 1995).

considerably superior to their European counterparts.[7] However, it should be noted that the Indian driving cycle, which was used to generate the data for Indian M2W vehicles in Table 3.1, is based on, but is not identical to, the ECE (Economic Commission for Europe) cycle, which itself reportedly underestimates emission factors by 15-25% with respect to more realistic driving at the same average speed.[8] Further, while the ECE cycle requires starting vehicles after a six hour soak at 20-30 °C, the Indian cycle was run on warm vehicles until recently, and could have underestimated CO and HC on this score alone (AIAM 1996a; Calvert et al 1993; Faiz et al 1992; Faiz et al 1996; IIP 1994; Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; MoST 1996).[9] Finally, it is not clear to what extent the Indian M2W vehicle data (or for that matter, the European data) in Table 3.1 were representative of in-use fuel and oil quality, and vehicle operation and maintenance. Actual emission factors for Indian M2W vehicles could therefore be higher than the numbers shown in Table 3.1.

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[7] The fuel economy of Indian two-stroke and four-stroke M2W vehicles, and two-stroke mopeds, averaged 54, 73 and 61 km/l respectively on the Indian driving cycle, on the tests by IIP (1994). However, fuel economy figures reported during the author's user interviews averaged 35 km/l for two-strokes. This matches very well the 35 km/l figure quoted in Duleep (1994). The fuel economy figures for European and US M2W vehicles average 20-25 km/l, and 42 km/l on European mopeds (Faiz et al 1996).

[8] Even the US FTP driving cycle, perhaps the most representative cycle in terms of accelerations and transients, likely underestimates CO and HC (and also NO_x), because the maximum speed and acceleration levels are lower than those achieved in reality (Faiz et al 1992; Faiz et al 1996). Calvert et al (1993) estimate that this underestimation could be as much as two times. The ECE cycle is far less representative of actual driving than the US FTP, involving as it does steady state conditions linked by uniform speed changes, and much lower maximum speed and acceleration levels than the US FTP. Additional driving cycles have been developed to make both the US FTP and ECE cycles more representative of reality. In the latter case, an extra urban driving cycle has been added to account for much higher speeds outside urban areas. Further, in order to account for the enhanced CO levels at low temperatures, the US FTP procedure has recently been modified to include a CO emissions test at -7 °C in addition to the existing 20-30 °C. The ECE cycle on the other hand continues to be run with the vehicle started at 20-30 °C (Faiz et al 1992; Faiz et al 1996). The Indian driving cycle involves a lower maximum speed than even the ECE cycle, on which it is based, which is reasonable given Indian conditions, but also lower acceleration levels (AIAM 1996a). Note that the extra urban driving cycle is not included in the ECE or the Indian driving cycles in the case of M2W vehicles.

[9] Cold start was made a requirement in the Indian emission standards from April 1998 for M2W and M3W vehicles, and from April 1996 for light-duty diesel vehicles (Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; MoST 1996). However, there is no clear specification of the temperature at which the emissions test is to be started, or of the soak time. Since the Indian driving cycle is based on the ECE cycle, it may be assumed that test vehicles are to be soaked for six hours at 20-30 °C before starting, which are the ECE requirements (Faiz et al 1996).

In addition to the above issues, it should be noted that there are no evaporative controls on the fuel distribution system, or on vehicles except cars produced from 1996 (MoST 1996). Indian gasolines have a wide volatility range, with a high maximum value (BIS 1995a), as will be discussed in a subsequent section on fuel and oil quality. The vast majority of gasoline vehicles on Indian roads are carbureted, not fuel-injected (AIAM 1994b and 1995). These facts, along with India's high ambient temperatures, which can reach 45°C in Delhi in the summer, heighten the potential for evaporative emissions, which are rich in reactive hydrocarbons that participate in the formation of tropospheric ozone.[10]

Table 3.1 In-use Indian M2W Vehicle Fuel Economy and Exhaust Emission Factors

Compared to Europe, Early 1990s

	Fuel Economy, km/l	CO, g/km	HC, g/km	NOx, g/km
M2W Vehicle, India	54	6.5	3.9	0.03
Europe, 2s >50 cc, Urban	25	22	15.1	0.1

M2W Vehicle = Motorized two-wheeled vehicle; 2s = Two-stroke. Sources: Bose 1996; Faiz et al 1996; IIP 1994; Shah and Nagpal 1997. mgb00

Evaporative emissions increase exponentially with increasing volatility and ambient temperatures. These emissions can be as high as 20-32% of total HC emissions on uncontrolled vehicles, and even higher on hot days.[11] Also, evaporative losses are a

[10] Evaporative emissions comprise diurnal or 'breathing' losses due to expansion and contraction of gasoline in the fuel tank with changes in air temperature, 'hot soak' emissions from the carburetor bowl when a warmed up engine is shut down, running loss emissions due to vapour generated in fuel tanks during vehicle operation, and re-fueling emissions. Hot soak emissions do not occur in sealed fuel systems, such as those used with fuel injection systems (Calvert et al 1993).

[11] Ambient temperature and altitude play an important role in transport energy and air pollution. Elevated ambient temperatures and altitude would tend to increase evaporative emissions. Additionally, these two factors affect engine power, and therefore fuel efficiency, as air density reduces with increasing ambient temperature and altitude. Unless equipped with electronic air-fuel ratio control, or unless adjustments

significant source of vehicular benzene emissions. Evaporative emissions per kilometre from M2W vehicles can be as high as 40% of that in an uncontrolled car (Calvert et al 1993; Faiz et al 1992; Faiz et al 1996). In view of the foregoing, evaporative emissions from M2W vehicles can be significant in the Indian context (in addition to their high exhaust emissions). Recall in this connection that in Delhi, M2W vehicles account for around 2.7 times the vehicle-kilometres as cars. Indeed, M2W vehicle-kilometres are around 1.5 times the total vehicle-kilometres by all other motorized passenger transport modes in Delhi (Figure 2.14 in Chapter II).

Table 3.2 Evolution of Indian M2W Vehicle Exhaust Emission Standards Compared to Taiwan

M2W Vehicle (g/km)	India 1991	Taiwan 1991	India 1996	Taiwan/ Thailand 1994	India 2000	Taiwan/ Thailand 1997 (Proposed)
CO	12-30	3.75	4.5	1.5	2	0.75
HC	8-12					
HC + NOx		2.4	3.6	1.6	1.5	0.8

M2W Vehicle = Motorized two-wheeled Vehicle. Sources: CMV (Amendment) Rules 1995; CSE 1996; Faiz et al 1996; MoST 1996. mgb00

Engine crankcase emissions can also be substantial. This source accounts for 13-25% of total VOCs on uncontrolled gasoline powered cars (Faiz et al 1992). These emissions

were made to suit the higher altitude, engines would consume more energy and produce higher exhaust emissions for the same performance as at sea level (Calvert et al 1993; Faiz et al 1992). In terms of health impacts, increased emissions at altitude would likely be coupled with the effects of altitude on the human respiratory system. In the Indian context, this is of concern in the case of Bangalore, which is situated at an elevation, and is also the most motorized city after Delhi (ASRTU/CIRT 1997).

were mandated to be controlled, commencing in 1996, but only for cars, not for M2W and M3W vehicles or diesels (Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; MoST 1996). As more M2W (and M3W) vehicles fitted with four-stroke engines begin to be produced in response to more stringent emission standards, crankcase emissions will gain in prominence as far as these vehicles are concerned. Crankcase HC emissions can be as high as 20% of exhaust HC emissions on four-stroke M2W vehicles (Hare et al 1974).[12]

All in all, in-use emissions from the vehicle as a whole could be considerably higher than would appear to be the case for Indian M2W vehicles from Table 3.1. Moreover, what makes M2W vehicles so important in terms of urban transport air pollution in the Indian context is the fact that these vehicles are used in large numbers for daily commuting, unlike in Europe and North America. Besides, many M2W vehicles in Europe and North America are large-displacement, high-powered machines. Therefore, let us compare Indian M2W vehicle emission factors with those in Taiwan and Thailand, countries which have similar M2W vehicle ownership and usage characteristics as India. This may be done by tracing the evolution of M2W vehicle emission standards in these countries since the early 1990s (Table 3.2). As may be seen from this table, the emission standards for Indian M2W vehicles have improved vastly over just nine years, but have been inferior to those for their Taiwanese and Thai counterparts, until very recently. Even the Indian standards proposed for 2000 are not as stringent as those proposed for 1997 in Taiwan and Thailand, the most stringent globally except for Swiss mopeds. Besides, there were no cold start requirements in the Indian emission standards until recently, whereas the standards in Taiwan and Thailand follow the ECE cycle, which calls for a starting temperature of 20-30 °C. And the maximum speed in the Indian driving cycle is lower than in the ECE cycle (AIAM 1996a; Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; Faiz et al 1992 and 1996; MoST 1996).[13] Further, Conformity of Production (CoP) limits, which specify the maximum allowable deviation from standards for production lots,

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[12] Even so, HC emissions from exhaust as well as crankcase on four-strokes would be considerably lower than exhaust HC emissions from two-strokes (Hare et al 1974).

[13] However, there are no M2W vehicle emission standards that are more stringent than the 2000 (and even the 1996) Indian standards, with the exception of those in Taiwan and Thailand, and for Swiss and Austrian mopeds. (Central Motor Vehicles (Amendment) Rules 1995; CSE 1996; Faiz et al 1992 and 1996; MoST 1996). Note also that the 1997 standards for Taiwan and Thailand are only proposed figures.

were as high as 25 and 33% for CO and HC from Indian M2W vehicles in 1991, and were brought down to 20% for CO and HC+NO_x in 1996 (Appendix III). Finally, unlike for vehicles in the USA, no clear stipulations as to emissions durability appear to have been made, nor are any emissions warranty or vehicle recall requirements imposed on manufacturers (MoST 1996).[14] Consequently, there is little if any incentive for manufacturers to design and maintain vehicles for emissions durability.

The upshot of all of the foregoing is that, while Indian M2W (and other vehicle) emission standards have become increasingly stringent, in-use emissions per vehicle-kilometre from the vehicle as a whole on even recent model Indian M2W vehicles could be considerably higher than the emission standards would seem to indicate. This situation is rendered all the more likely because of in-use vehicle operation and maintenance realities, which we discuss below.

Before doing so, note that while we have been focusing on the engine and exhaust system, vehicle components such as transmission, brake and tyre are also important in terms of transport air pollution and energy (Alberta Energy 1988; Duleep 1994; Faiz et al 1996). In this connection, recall from Chapter II that asbestos continues to be used for vehicle brakes and clutches in Indian vehicles, because it is 40% less expensive than alternative materials.

3.3.2 Vehicle Operation, Maintenance and Disposal

Vehicle user choices and behaviours play a key role in transport emissions, and also in efforts to prevent and control them. This issue is discussed in considerable detail in Chapter VI, so only some brief points will be made here, with regard to vehicle operation and maintenance. Driving behaviours such as "jack-rabbit" starts and stops can increase emissions dramatically (Faiz et al 1992). Many M2W vehicle users interviewed by the author reported frequent fuel refills, and oil-fuel ratios not always as per specification,

[14] In the USA, clear emissions durability requirements, emissions warranties, in-use surveillance, and vehicle recall have been implemented in addition to emission standards. Emissions durability requirements have been extended from 80,000 to 160,000 km. Such requirements have not been incorporated even in the European standards. In Taiwan, M2W vehicle emissions durability requirements of 6,000 km have been in force since 1991, and were upgraded to 20,000 km from 1998 (Faiz et al 1992 and Faiz et al 1996).

with significant implications for evaporative and exhaust PM emissions (Author's user interviews 1997).

Coupled with the high motor vehicle activity rates in the Indian (and LIC) context is the high average fleet age because of low scrappage rates, and poor maintenance. Several studies worldwide have shown that maintenance is a significant factor in vehicular emissions. Among uncontrolled vehicles, HC and CO emissions between properly and poorly adjusted engines can vary by a factor of four or more. CO emissions can increase as much as 400% due to normal drift between services. Factors such as faulty ignition which have considerable scope to occur in the Indian context, can affect emissions durability.[15] This is particularly so in the case of technologies such as catalytic converters, which are entering the Indian market in response to more stringent emission standards. A damaged catalytic converter can increase HC and CO by 20 times, and NO_x by 3-5 times. Data from South and South-East Asia show that PM emissions can increase ten-fold in poorly maintained M2W and M3W two-stroke vehicles using poor quality lubricating oil (Shah and Nagpal 1997).[16] Finally, while average emissions typically increase with age, US studies have shown that 20% of recent model vehicles are "super emitters" (Calvert et al 1993; Faiz et al 1992 and 1996).

One would expect good vehicle maintenance, given low labour and high fuel costs in the Indian context (Duleep 1994). However, many M2W vehicle users interviewed by the author (see Chapter VI) reported maintaining their vehicles themselves, or using the services of local mechanics, and only when absolutely unavoidable. Further, spurious spares are commonly used. Quality spares in India are expensive, in part because of high sales taxes (Author's user interviews 1997; Duleep 1994). Obviously, apart from user knowledge and skills, user incomes strongly influence vehicle operation, maintenance and

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[15] Faulty ignition is common on M2W and M3W vehicles in the Indian context. Spark plugs on these vehicles are highly susceptible to malfunctioning, because of dirty operating conditions, poor air filtration, and poor maintenance. Misfiring can give rise to high HC and CO emissions (Faiz et al 1992).

[16] In diesels, damaged fuel injection systems can increase PM at least 20 times. 6% of buses (and 22% of trucks and 37% of LCVs) in Delhi were found to have a free-acceleration smoke reading of 85 HSU (Hartridge Smoke Units), corresponding roughly to 8 g/km PM. 37% of buses, 62% of trucks and 57% of LCVs registered over 65 HSU (Faiz et al 1996; IIP 1994).

disposal choices. At any rate, these choices exacerbate the effect of vehicle (and fuel) technology.[17]

3.3.3 Ineffective Monitoring and Enforcement

Poor vehicle maintenance is also enabled by largely ineffective monitoring and enforcement in the Indian context. A more detailed discussion is presented in Chapter IV, but briefly, this is because inspection of in-use emissions in Delhi (and other Indian cities), which is conducted in a decentralized fashion and is riddled with corruption, is burdensome for users, who therefore find ways and means of circumventing and/or subverting the testing process (CSE 1996; Priti Kumar 1997). Moreover, the testing procedure is itself problematic. Only CO emissions are measured at idle on gasoline-powered M2W and M3W vehicles and cars (MoST 1996). These tests can identify gross malfunctions on uncontrolled, carbureted vehicles, but correlate poorly with real-life emissions, particularly for HC and NO_x, and give rise to false passes and failures, on vehicles with electronic fuel injection and catalytic converters (Faiz et al 1996).

3.3.4 Congestion, and Road Availability and Condition

As noted in Chapter II, congestion is increasing rapidly, as a result of rapid motorization, in Delhi and other Indian and Asian LIC cities. Peak-hour speeds now average 10-20 km/h in many of these cities (Brandon and Ramankutty 1993; CSE 1996; Faiz et al 1992; Sathaye, Tyler and Goldman 1994; Poboon et al 1994). As far as Delhi is concerned, the average speed for all trips is reported to be only 10.7 km/h (RITES/ORG 1994). However, a careful examination of the data reveals that speeds for motorized modes, which are key in terms of transport air pollution and energy consumption, are higher – 19.7, 17.8, and 12.1 km/h for cars, M2W vehicles, and buses.[18] Further, while the average

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[17] Poor maintenance is not unique to M2W and other personal motorized modes. Buses and other commercial vehicles in Delhi are for the most part owned by a large number of private parties, who have little ability or incentive to invest in proper maintenance (especially given lax inspection), let alone improved vehicle technology. Even the 15% or so of Delhi's buses operated by the Delhi Transport Corporation (DTC), the state-owned public bus transit operator in Delhi, are poorly maintained (ASRTU/CIRT 1997; Chima 1997; Duleep 1994; Gambhir and Narayan 1992).

[18] The average speed for all trips is much lower than for motorized modes, because walking accounts for as many as 32% of trips in Delhi (RITES/ORG 1994).

speed (presumably for motorized modes) is reported to be only 10-15 km/h in the central area, it is 25-40 km/h on arterials (CSE 1996).

Emissions of all gasoline engine pollutants, except for NO_x, increase dramatically at low speeds.[19] Excessive idling and jerky "stop-and-go" operation due to congested traffic, too many intersections, and poor TSM (transport system management) further aggravate emissions. A French study showed that CO and HC emissions per vehicle-kilometre increase by around 200%, and fuel consumption and CO_2 emissions by around 260%, in congested flow as opposed to smooth flow (Joumard 1990 in Faiz et al 1992). So, congestion further exacerbates the effects of vehicle and fuel technology, and the vehicle user behaviours discussed above.

Vehicle driving behaviour is of course influenced by user choices, knowledge and skill, but also by the level of congestion, which in turn is determined by road availability in relation to vehicular activity, the level of modal separation, and the effectiveness of TSM and traffic regulations enforcement, factors over which vehicle users have no control. Another factor is the presence of travel peak periods. But travel peaks become irrelevant when road availability is the constraining factor, in which case congestion is likely to be a round-the-clock, or at least a day-long, phenomenon.

While the road and highway system is inadequate nationally,[20] Delhi does not suffer from a lack of roads. The city has an extensive road network of over 21,000 kilometres (12-feet width), with 800 km of 30-metre plus width roads. Indeed, Delhi has the highest road density per square kilometre in India, and a higher road length per capita than most countries in Europe and Asia (Mohan et al 1997; TERI 1997a). Notwithstanding this fact, and the point made earlier about the speeds for motorized modes in Delhi, congestion is increasing, and is likely to continue to do so, along with increased motor vehicle activity.

So far in this section, we have been discussing the importance of transport system characteristics such as road availability, modal separation, TSM, and traffic regulations

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[19] Engines (and for that matter, vehicles as a whole) are typically designed to operate over a wide speed range. If, as is reasonable to expect, the bulk of passenger vehicles in Indian cities are operated at low to medium speeds (because of congestion), and rarely if ever out of town, it may be worthwhile considering optimizing fuel efficiency and emissions selectively for the low and medium speed range.

[20] India has only around one million kilometres of surfaced roads, with the remainder being unsurfaced (TERI 1997a).

enforcement. As far as transport infrastructure is concerned, it is not only these factors, but also the quality of roads, that plays an important role in transport energy consumption and emissions. First, unsurfaced roads increase re-suspended PM emissions, which can contribute significantly to total transport PM (and PM_{10}) inventories (Bhattacharyya 2000; CSE 1996; GVRD 1995). Second, and more importantly, the low load-bearing capacity of Indian roads have a profound impact on overall fleet fuel efficiency and emissions. This is particularly so for commercial vehicles, which account for the lion's share of transport energy consumption in the country, as discussed in Chapter II. Vehicle size critically influences fleet fuel efficiency. The larger the vehicle size, the higher the potential overall transport fuel efficiency on a per unit payload basis, because payload increases faster than empty vehicle weight. Because of the low load-bearing capacity of Indian roads, vehicles of no more than around 15 ton gross vehicle weight (GVW) can be used, as opposed to the 40 ton GVW vehicles commonly seen on roads in USA, Canada, and other OECD countries. This constraint, along with the varying speed/load conditions typical of travel on Indian roads, leads to fleet fuel efficiencies half of those in the OECD on a ton-kilometre basis, and much higher emissions per ton-kilometre and road and vehicle maintenance and operating costs (Duleep 1994; Faiz et al 1996).[21]

3.3.5 Fuel and Lubricating Oil Quality

The health and welfare effects of fuel quality parameters such as lead, sulphur, and benzene content were discussed in Chapter II. Apart from these effects, fuel lead and sulphur degrade catalytic converter effectiveness by forming deposits on, and blocking exhaust gas access to, the catalyst. As little as a single tank of leaded gasoline can cause permanent catalyst damage. On the other hand, fuel sulphur causes reversible catalytic performance deterioration (Faiz et al 1992). Other gasoline quality parameters that have a significant bearing on exhaust and evaporative emissions and atmospheric reactivity

[21] Further, engine and vehicle technologies such as turbochargers and aerodynamic improvements, which have the potential to provide significant fuel economy and emissions benefits, are not cost-effective in the Indian context, because these benefits are obtained at sustained high speeds, a difficult proposition on Indian roads, and also since diesel is heavily subsidized (ASRTU/CIRT 1997; Brandon and Ramankutty 1993; CSE 1996; Duleep 1994; Faiz et al 1996; TERI 1997a).

include fuel volatility, aromatic, olefin and oxygen content, and distillation and deposit-control characteristics (Faiz et al 1992 and 1996; Calvert et al 1993; Raje and Malhotra 1997).

Until 1995, lead content in Indian gasoline was as high as 0.56 g/L (in 87 octane), and sulphur content was as high as 0.2% (2000 ppm) by weight.[22] Benzene, a known carcinogen, was not controlled at all (BIS 1995a). With rapidly deteriorating urban air quality, fuel quality improvements have been implemented in a phased manner, as shown in Appendix IV, and as discussed in a subsequent paragraph. In 2000, unleaded gasoline is expected to be available country-wide. Gasoline benzene content is expected to be controlled to 5% by volume country-wide, and to 3% in the four major cities. Gasoline sulphur is expected to be lowered to 0.1% (1000 ppm) by weight, for unleaded fuels. Simultaneously, improvements have been proposed in deposit control and fuel volatility (BIS 1995a).[23]

The above improvements in the quality of Indian gasoline represent a significant advance over the situation that prevailed in 1995. Even so, Indian gasoline continues to be considerably inferior to that presently available and likely to come on stream shortly in Europe and the USA (Table 3.3). In addition to the stringent controls on sulphur, benzene and fuel volatility in US and European gasolines (Table 3.3), aromatic and olefin content are also controlled (Calvert et al 1993; Faiz et al 1996; Mercedes Benz 1997). These fuel quality differences can have significant air quality implications. In terms of gasoline sulphur, for example, an increase from 100 to 900 ppm by weight can produce a 13-14% deterioration in catalytic converter performance (Faiz et al 1992). The author learned from his interviews that many vehicles with fuel injection systems being imported into India have encountered problems with fuel injector blockage because of poor deposit control on Indian gasolines.

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[22] Lead content was 0.8 g/L in 93 octane gasoline. Such high levels of lead were necessitated in part because knock susceptibility, and thus octane requirement, increases with increased engine operating temperatures and deposit accumulation (Faiz et al 1992). Both of these factors are common in the Indian context.

[23] Diesel sulphur, an important contributor to PM, was as high as 1% (10,000 ppm) by weight until recently. It was brought down to 0.25% (2500 ppm) in Delhi and its neighbourhood in 1996, and country-wide in 1999 (BIS 1995b; Appendix IV). By comparison, diesel sulphur levels are below 100 ppm in many European countries (Mercedes Benz 1997).

Unleaded gasoline (0.013 g/L lead) was introduced for new four-wheeled gasoline-powered vehicles with catalytic converters in Delhi and the three other major metropolitan centres in 1995, and in all other state capitals and major cities in late 1998. As already indicated, unleaded gasoline is expected to be available country-wide in 2000. Thus, only about 10-20% of gasoline sold in Delhi was unleaded from 1995 until recently. The fuel for M2W and all other gasoline-powered vehicles (the overwhelming majority of vehicles on the road), has been 0.15 g/L lead gasoline, which was introduced in the four major cities in 1994. Unleaded gasoline is understood to have been restricted to new four-wheeled vehicles with catalytic converters, because of concerns about the high levels of benzene in unleaded gasoline going into the atmosphere untreated in vehicles without catalytic converters. However, it is also the case that it has been a challenge for Indian refineries to produce adequate quantities of unleaded gasoline, while also controlling important fuel quality parameters such as octane rating, benzene and other aromatics, volatility, and gumming properties (CSE 1996; Faiz et al 1996; Hari 1994; Raje and Malhotra 1997).

There was no fuel price differential between leaded and unleaded gasoline in India, unlike in Mexico, when unleaded fuel was introduced in 1990 (Humberto Bravo et al 1991). Mis-fueling vehicles with catalytic converters with leaded gasoline was therefore not likely to occur on this account within Delhi and the other major cities. However, mis-fueling was certainly a possibility on new cars with catalytic converters operating both within and outside major cities until 2000, on account of the widespread availability of leaded fuel outside the cities. This possibility raises doubts about the effectiveness of catalytic converters, particularly given the largely ineffective I&M regime. Indeed, it is reported that many vehicles with catalytic converters in Delhi have failed the in-use emissions test (CSE 1996).[24]

[24] However, as noted, no-load in-use emissions tests are unreliable on vehicles with catalytic converters. Since unleaded gasoline is expected to be widely available nation-wide effective 2000 (Appendix IV), the possibility of catalytic poisoning due to misfueling with leaded fuel will not be an issue after this date. Also, since benzene levels are going to be controlled simultaneously, the use of unleaded fuel in vehicles without catalytic converters will not be an issue either, at least as far as benzene is concerned.

Table 3.3 Quality of Indian Gasoline

Compared to California and Europe

	India pre-1995	India 2000	California RFG 1996	ACEA Recommendation post-2000
Lead, g/L max.	0.56/0.80 (87/93 Octane)	0.013		
Sulphur, ppmw max.	2000	1000	30	30
Benzene, % vol. max.	no limit	5	0.8 (1 -- USA)	1
RVP, kPa @ 38 deg C, max.	35-70	35-60	47 (summer); 54/62 (USA)	58

RFG -- Re-formulated gasoline; ACEA -- European Automobile Manufacturers' Association; ppmw -- parts per million by weight; RVP -- Reid Vapour Pressure; kPa -- Kilopascals. Benzene level in Thai gasoline 3.5% vol. since 1993; US RVP 49.6/55.8 in areas with serious air pollution problems. Sources: BIS 1995a; Calvert et al 1993; Faiz et al 1996; Mercedes Benz (1997). mgb00

The implementation of the phased two-gasoline policy may therefore also have contributed to transport emissions. Further, some experts believe that restricting unleaded gasoline to vehicles with catalytic converters was a wrong policy, because lead is less preferable than benzene in terms of health effects (Friedrich and Walsh 1997). According to Weaver (1995), though, a two-gasoline policy is a good transitional measure, with a tightly controlled low-lead fuel for older vehicles, and less tightly controlled unleaded gasoline for newer vehicles. The first 0.1 g/L lead provides the largest octane boost, with diminishing returns thereafter, and the quickest and most economical way to reduce lead emissions generally is to reduce lead content of all gasoline grades as much as possible, rather than to have vehicles without catalytic converters use unleaded fuel. This helps conserve limited unleaded gasoline supplies for vehicles with converters, and reduces the price differential between leaded and unleaded gasolines, thus reducing the incentive to misfuel such vehicles. While this is precisely the approach adopted in India, low-lead

gasoline for the majority of vehicles was by no means tightly controlled in terms of other fuel parameters (BIS 1995a).[25]

Finally, lubricating oil quality has important implications for transport PM and HC emissions, particularly in the case of two-stroke engines fitted on M2W and M3W vehicles, in which the oil is "lost" due to combustion, but does not burn completely.[26] Additionally, phosphorus and other oil additives coat and poison catalytic converters (Faiz et al 1992 and 1996). Two-stroke lubricating oils in India are proposed to be made phosphorus-free from 2000 (BIS 1996).

3.3.6 Fuel and Oil Pricing and Adulteration

In the Indian context, the problem of poor quality fuel and oil is further exacerbated by fuel and oil adulteration. M3W vehicle operators, who typically do not own their vehicles, commonly adulterate their gasoline with as much as 30% kerosene, and even solvents. To guard against the resulting wear and tear, they mix as much as 10% of lubricating oil, the principal source of PM emissions in two-strokes. Lubricating oil, sold loose mainly for use in M2W and M3W vehicles, is also adulterated (Raje and Malhotra 1997).

Adulteration is enabled principally by the fact that kerosene (and diesel) have been heavily cross-subsidized by gasoline, as a part of the administered pricing mechanism (APM). In the case of kerosene, subsidization is justified on the grounds that this fuel caters for the energy needs of lower income urban households. Kerosene retailed at INR (Indian Rupees) 2.60 per litre in Delhi in 1995, as compared to gasoline at INR 17 per litre. Given this price differential, operators find it attractive to adulterate gasoline with kerosene, rather than using straight gasoline, even though frequent piston changes are necessary. Diesel is adulterated with kerosene as well, though the diesel-kerosene price differential is not as great as that for gasoline-kerosene (in Delhi in 1995, diesel retailed at INR 7 per litre)[27] (TERI 1997a). Adulteration is likely at least as much of a problem in

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[25] The two-gasoline policy also involves the added cost of duplicating storage, delivery and distribution facilities (Weaver 1995).

[26] In diesels, lubricating oil can contribute up to 2-48% of exhaust PM mass, and up to 88% of mutagenic and/or carcinogenic diesel particulate SOF (Pierson 1988; Truex et al 1980; Lowenthal 1994).

[27] Similar disparities exist in other Asian countries, including Pakistan, Thailand, Indonesia and China, particularly for gasoline and kerosene. But the disparity for gasoline has been by far the highest in India.

smaller cities and towns. In Bhopal, for example, 90% of dealers reportedly sell adulterated fuel, despite random checks and punitive measures by district authorities (Kumar et al 1997).

Fuel and oil adulteration, and factors such as excessive oil usage in M3W vehicles, have a significant impact on transport emissions, not to mention fuel economy and engine life. As noted earlier, such in-use realities are not reflected in Indian emissions inventories. Apart from its implications for transport air pollution and emissions inventories, the foregoing discussion demonstrates the interactions between fuel adulteration and other vehicle user choices, monitoring and enforcement, and fuel pricing.

3.3.7 Motor Vehicle Activity

The foregoing sections explored the various vehicle and fuel technology, transport system, climatic and vehicle user behavioural factors that contribute to air pollutant emissions from M2W vehicles in the Indian context, on a vehicle-kilometre basis. It would now be useful to examine the factors that contribute to motor vehicular activity, since transport emissions are a function of emissions per vehicle-kilometre and vehicle-kilometres driven.[28] And after all, vehicle and fuel technology have, if anything, been improving over the last decade, as discussed. Transport emissions are becoming a public policy issue in that context, because of technological factors, but also because motor vehicular activity, particularly on M2W vehicles, and congestion, are growing rapidly. Specifically in terms of the high level of M2W vehicle activity in India, it would be useful to understand vehicle user motivations, within the context of wider institutional factors.

Subsidies exist in terms of coal prices and electricity tariffs as well. Apart from being a barrier to long-term financial viability, energy subsidies have significant environmental effects. An example in Indian transport is inappropriate dieselization. About 20% of Mumbai's vehicles are diesel powered, though only 9% are trucks or buses. Progress is being made in eliminating energy subsidies, including in India. The ratio of Indian domestic to international prices in 1991 were 3.8, 0.8 and 0.62 for gasoline, diesel and kerosene. In late 1997, the ratios for gasoline and diesel stood at around 2 and 1 (ASRTU/CIRT 1997; Brandon and Ramankutty 1993; CSE 1996; TERI 1997a).

[28] Motor vehicular activity is particularly important in terms of re-suspended road dust, a significant source of transport PM. While other transport emissions can be controlled fairly effectively by technologies that target per-vehicle emissions, re-suspended emissions cannot, since they are largely dependent on total vehicular activity.

Rising incomes are certainly an important factor contributing to rapid motorization in Indian (and other LIC) cities (Faiz et al 1992). As incomes increase, the poor majority purchase bicycles, and those who own bicycles graduate to M2W vehicles.[29] Second, as motor vehicle production has grown rapidly over the last decade or so (AIAM 1994a and 1995; ASRTU/CIRT 1997), supply constraints have greatly eased. Further, with economic liberalization, many automobile purchase financing institutions have started business lately, and credit has become easy to obtain (Bhardwaj 1994). Also, manufacturers are offering old vehicle buy-back schemes in order to generate new vehicle sales (Kinetic Honda 1997).

While the above factors certainly play an important role, increased motor vehicle ownership and use are also responses to circumstances in which users find themselves. A key factor in this regard is the growing consumerism, driven by social pressures and aggressive marketing, in urban India. Second, the rapid pace of urbanization and motorization have contributed to sprawl, which in a vicious circle further increases motor vehicle ownership and activity. The urban area of Delhi has grown more than 15 times since 1911, and five times since just 1981 (DDA 1996; Misra et al 1998). Correspondingly, average trip lengths have increased 79, 122 and 62% since 1969, and 37, 40, and 24% since only 1981, for M2W vehicles, cars and buses respectively (RITES/ORG 1994).[30] The effect of urban sprawl is exacerbated by rental housing becoming increasingly unaffordable in the heart of Delhi, which is where the bulk of employment is. Many M2W vehicle users interviewed by the author reported being forced to live far from their workplaces on account of this fact.

Buses are often the only affordable motorized modes for the majority, but demand far exceeds availability. Delhi has the country's largest bus fleet, numbering around 28,000.[31] Even this fleet has not been able to keep up with ridership, which increased from 22.4% of

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[29] Nearly every M2W vehicle user interviewed by the author said s(he) would buy a car when they could afford it (see Chapter VI).

[30] Sprawl likely has a greater impact on motor vehicle activity in the suburbs and outer periphery than in the inner core. In the outlying areas of Greater Mumbai, M2W vehicle activity has reportedly increased 200% in just a decade (CSE 1996).

[31] The state-owned Delhi Transport Corporation (DTC) operates around 3000 of Delhi's buses (ASRTU/CIRT 1997; Chima 1997). A large number of private bus operators run the city's balance 25,000-odd buses.

all trips in 1957 to 39.6% in 1969 and 42.3% in 1994 (RITES/ORG 1994). Buses are generally becoming more crowded, inconvenient and time-consuming. The situation is further aggravated by the shortened bus life due to heavy use, poor fleet maintenance, and poor roads (Sathaye, Tyler and Goldman 1994).[32]

Because of sprawl, unaffordable housing close to workplaces, and increasingly unreliable and inconvenient public transit, people are forced to purchase and use personal motorized modes if they can afford them. As congestion increases due to motorization, walking and cycling become increasingly tedious and hazardous, and owners of personal motorized modes begin to use them, even over short distances.[33] Children are driven to and from school, to protect them from other motor vehicles. Given these effects, it is not surprising that the mode shares of personal motorized modes have increased as rapidly as they have (RITES/ORG 1994; Sathaye, Tyler and Goldman 1994). Nor is it surprising that large numbers of the not-so-poor, for whom cars are out of reach, purchase and use M2W vehicles in Delhi and other Indian cities.

M2W vehicles offer door-to-door capability, require very little parking space, can be (and typically are) parked securely inside the home, and carry passengers as well as things. Though these vehicles contribute to congestion, they can cope with it as no other motorized mode can, because of their size and maneuverability. Their average speed in Delhi is 17.8 km/h, as against 19.7 km/h for cars, and 12.1 km/h for buses. The superiority of M2W vehicles in this regard is demonstrated in Figure 3.1, which compares door-to-door journey times for various modes by distance, computed based on data in RITES/ORG (1994). M2W vehicles are only marginally slower than cars, right up to distances of 25 kilometres.[34] In short, M2W vehicles offer excellent and affordable

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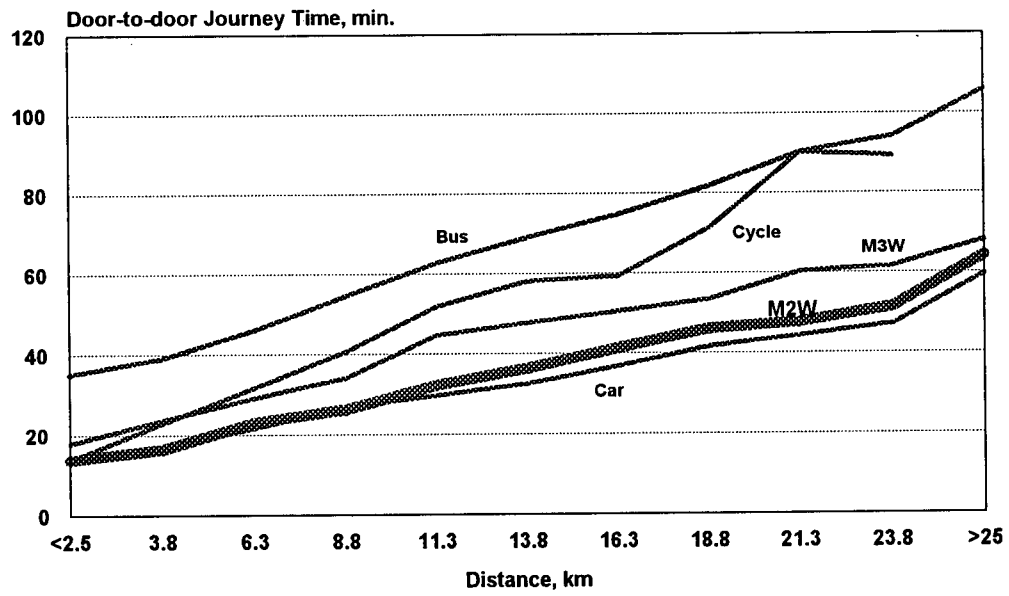
[32] The problems of inadequate and poorly maintained transit are shared by other LIC countries. Public spending on urban transport in these countries, massive as it has been, has met no more than 15% of needs. With the myriad urgent demands on scant resources, there is little room for expansion. In Bangkok, bus trips increased 85% in the 1980s, but the fleet increased only 7%. In Mumbai, almost 80% of trips are by transit -- 44% by bus, 36% by suburban rail -- but the World Bank has warned that unless services are improved, personal vehicle use will increase (Brown and Jacobson 1987; CSE 1996; Pendakur 1987; Sathaye, Tyler and Goldman 1994).

[33] Compromised access also affects public transit usage, since users need to walk to and from bus-stops. Additionally, it becomes increasingly difficult for low-income people who cannot afford motorized modes to walk or cycle to essential services.

[34] Interestingly, bicycles in Delhi appear to be faster than buses right up to 25 km (RITES/ORG 1994). Obviously, there is considerable potential for efficient bicycle travel, if only the facilities existed for them.

mobility, and easy access to employment and other essential services, in a context in which there are few other attractive options. And thanks to technology, M2W vehicles are becoming increasingly easy to use. The Kinetic Honda scooter, for example, is push-button, rather than kick-started (Kinetic Honda 1997), and has reportedly dramatically expanded mobility for women, who are entering the work-force in large numbers. Ironically though, advances such as these will only serve to increase motor vehicle ownership and activity.

Figure 3.1 Door-to-door Journey Times by Different Modes in Delhi



M2W/M3W = Motorized two-/three-wheeled vehicles. Calculations based on data in RITES/ORG 1994. Walk and wait times included.
mgb99

Before closing this section, it is worth noting the importance of vehicle trips in terms of transport emissions and energy consumption. While sprawl increases trips and trip lengths, compromised access due to motorization tends to increase motorized trips over short distances. Short distance trips are the most polluting on a per-kilometre basis, because trip-end (cold start and hot-soak evaporative) emissions form a significant proportion of total trip emissions, and are the same regardless of trip length. Indeed, the shorter the trip, the greater the trip-end emissions as a percentage of total trip emissions. While a 32 km trip on an average 1987 model car with a catalytic converter would

produce 34 grams HC, a mere 8 km trip would produce 25 grams (Faiz et al 1992; Kessler and Schroeer 1993). Of course, in the Indian case, cold starts would not play a major role, but hot-soak evaporative emissions would. Further, because the vast majority of Indian vehicles are not fitted with catalytic converters, running emissions would form a much larger percentage of total emissions. Nevertheless, *vehicle trips,* particularly over short distances, are critically important. Nearly one-third of motorized trips (and 60% of all trips), are executed over distances less than five km in Delhi, and the average speed for trips over this distance is lower than over greater distances (RITES/ORG 1994).

3.3.8 The Role of Government Policy

Travel behaviour in terms of personal motorized mode ownership and use of course depend on urbanization, incomes, and user preferences and choices. But also critical is government policy with regard to planning and infrastructure provision for private motorized modes versus public transit and non-motorized modes, full cost pricing of travel, and land use and housing. For example, planning for personal motorized modes in the form of road building to relieve congestion and maintain high speeds, and provision of parking, serves to increase their use, and render other modes less viable. As personal motorized mode use increases, the system is increasingly designed to suit these modes, and those who can afford them. Conversely, the fact that the other modes are becoming increasingly unviable serves as a justification for not providing for them, which in turn makes them even less viable than previously, and those who rely on these modes more vulnerable. A vicious circle is created in which personal motorized modes become self-perpetuating. Further, once a city becomes dependent on automobiles, automobile reliance and inefficient land use patterns tend to become self-reinforcing (Brown and Jacobson 1987; Hillman 1990; Richmond 1990; Whitelegg 1993). Brown and Jacobson (1987) put it well: "Urban planners, by assuming ever greater automobile use, build cities that make it inevitable".

Variations in car dependence and transit use, and travel behaviour generally, even among countries with similar per capita incomes and urbanization, arise largely from public policy differences. The low automobile dependence of affluent Singapore, Tokyo

and Hong Kong and Manhattan show that wealth need not inevitably lead to heavy dependence on private motorized modes. Policies which favour more compact development, promote investments in transit, and keep automobile infrastructure spending to a minimum, dampen automobile ownership and use, while at the same time strengthening transit use, even as wealth increases (Kenworthy et al 1994; Pucher 1988).

Unfortunately, urban transport decision making in the LICs is biased in favour of motorized vehicles and other extremely costly modes of transportation that serve only a small section of society. Little or no restrictions are placed on cars (of course, it would be highly problematic to put in parking restrictions, for example, without also providing attractive options). While scarce resources are made available for expensive infrastructure to accommodate motorization, apparently nothing can be found for low-cost improvements to benefit the poor majority. Non-motorized modes are not only ignored, but actively discriminated against (Replogle 1991; Whitelegg 1993). This is despite the fact that these modes account for a significant proportion of travel activity in the LICs. In Delhi, for example, walking and cycling (and travel by cycle rickshaws) account for nearly 39% of all trips, even among residential households (RITES/ORG 1994). It is likely that these modes account for an even higher share of trips in the city as a whole, since every second person in Delhi reportedly lives in a slum or a squatter settlement (Singh 1997b). Meanwhile, policies in countries like India (and China) are providing market and investment opportunities for international automobile manufacturers. In India, 11 heavy truck and 16 car companies are forecast for the near future, involving collaborations with Daewoo, Fiat, Ford, GM, Honda, Hyundai, Mercedes-Benz, Opel, Peugeot, Renault, Suzuki, and Volvo, among others (AIAM 1997a; Champagne 1998).[35]

In this connection, a rail-based Mass Rapid Transit System (MRTS), an idea studied repeatedly since the 1950s, is at last taking shape in Delhi. When completed in the "horizon year" of 2021, the system is expected to be 198.5 km. long, comprising 111 km.

[35] Significant excise and import duty reductions related to motor vehicles and parts have been introduced recently (Ramachandran 1994; Mohan Ram 1994). In China, the growth of private vehicles since the 1980s has been dramatic. Foreign manufacturers are already producing a million vehicles annually. By 2000, half of this production is expected to be cars. It should be noted, however, that while this trend will fuel rapid motorization, it will also (for what it is worth) improve per-vehicle fuel economy and emissions.

at grade and 35.5 km. underground, and a 35.5 km. elevated portion. Construction on the initial 8.3 km. surface corridor has commenced, and the first phase of 52 kilometres (comprising 11 km. underground and the balance elevated and at grade) is expected to be completed by 2005. The first phase is expected to cost Cdn $1.6 billion, 56% of which will be loaned by Japan (Delhi Metro Rail Corporation 2001; Gambhir and Narayan 1992; Iijima 1999; Mohan et al 1997; Singh 1997a).

There are divergent views on the ability of MRTS to reduce personal motor vehicle activity and congestion, and its financial viability in the LIC context. Kenworthy et al (1994), Kenworthy and Laube (1999a), Kenworthy and Laube (1999b), and Poboon et al (1994) argue strongly in favour of urban rail. They point out that a high level of service including time competitiveness is required to persuade personal motor vehicle users to switch to transit, particularly as incomes grow. Buses play an important public transit role, but cannot provide the frequency or capacity to cope with heavy passenger loads. This is particularly so in dense cities such as those in the Asian LICs. Such cities constrain bus service due to limited road capacity and severe traffic congestion. Note in this regard the unfavourable door-to-door journey times for buses compared to cars and M2W vehicles, and even bicycles, in Figure 3.1. On the other hand, segregated rail systems, because they are not constrained by traffic, have the potential to transport large numbers of people quickly -- up to five times the passengers per hour as buses in mixed traffic (Mohan et al 1997). This potential is particularly enhanced when rail is well integrated with land use around stations and with feeder buses, and delivers passengers into pedestrian-friendly environments. Further, urban rail provides more reliable, comfortable, safe and high profile service than do buses. As a result, rail has the potential to attract people from personal motor vehicles in addition to only captive users (Kenworthy et al 1994; Kenworthy and Laube 1999a; Kenworthy and Laube 1999b; Poboon et al 1994).

Cities with a higher level of rail service within their transit systems generally have lower automobile dependence and higher transit utilization, due to the superior speed of rail systems and the other advantages alluded to above. Further, many more rail systems around the world have provided effective sites for integrating high density mixed-use development with public transit and the formation of poly-centric urban form than have

bus systems. This in turn is due to the ability of rail systems to transport large numbers of people to high density nodes without compromising the pedestrian environment at these nodes. Finally, rail is the most energy efficient motorized urban transport mode, consuming 2.5-5 times less energy per passenger-kilometre than buses (Kenworthy et al 1994; Kenworthy and Laube 1999a; Kenworthy and Laube 1999b).

While highly dense cities can constrain buses, they have the potential to support high capacity rail systems on account of the presence of strong corridors of development, as exemplified by Hong Kong, Singapore and Tokyo. Despite their wealth, these cities have low automobile dependence and high transit usage, in large part due to investment in rail, and the degree to which land use is integrated with transit, particularly rail (Kenworthy et al 1994; Kenworthy and Laube 1999a; Kenworthy and Laube 1999b; Poboon et al 1994).

Mohan et al (1997) have assessed urban rail with specific reference to the LIC context, based on a survey of the performance of rail systems constructed over the past 25 years in Bogota, Cairo, Calcutta, Hong Kong, Istanbul, Manila, Mexico City, Medellin, Porto Allegre, Pusan, Rio de Janeiro, Santiago, Sao Paulo, Seoul, Singapore and Tunis. This survey revealed that rail systems in only three cities, Hong Kong, Seoul and Singapore were built on time. Most of the others experienced construction delays. Calcutta, the only Indian city to have an urban rail system, stands out in this regard. The city's 16.5 km. system, originally scheduled to be completed in six years, took 23 years to complete. Construction delays have occurred in cities such as Calcutta because of lack of awareness of what lies beneath the surface. Delays have also been caused by disputes of various kinds, service diversions, material and funding shortages, and traffic disruptions (Iijima 1999; Mohan et al 1997; Rekhi 1996).

Urban rail systems typically entail huge capital costs, ranging from US$ 8 million to US$ 165 million per kilometre, many times more than bus based systems (Mohan et al 1997). Further, only the systems in Hong Kong, Singapore and Porto Allegre were constructed within the projected budget. Only four systems in the Mohan et al (1997) survey, including Hong Kong, show patronage levels up to or close to expectations. Once again, Calcutta's system appears to be the one with the highest cost overrun and the lowest patronage relative to what was projected. Revenue-to-operating cost ratios are

greater than unity only for Hong Kong, Manila, Santiago and Seoul (this figure was not available to Mohan et al (1997) for Singapore). Thus, while rail systems require heavy levels of investment, many require continued subsidies (Brown and Jacobson 1987; Sathaye, Tyler and Goldman 1994).

It is difficult to estimate the impact of urban rail systems on congestion. However, there appears to be only short-lived or no impact in the majority of cities for which information exists. Congestion relief is short lived because private traffic rapidly grows to utilize released road capacity. Experience from even well run high-capacity rail systems as Singapore's and Hong Kong's shows that while they may cause bus users to transfer to them, they attract no more than a small share of private motor vehicle users (which is key in terms of reducing congestion and emissions). Further, while passengers are mostly captured from buses, reduction in bus traffic is not proportional, and in any case represents only a small portion of overall traffic. Finally, the extent of energy savings due to (underground) urban rail systems is unclear, because of energy requirements for air-conditioning and escalators in stations (Mohan et al 1997; Sathaye, Tyler and Goldman 1994).

Based on their survey, Mohan et al (1997) conclude that a large population with a high per capita income is required to provide the revenue base to sustain urban rail systems. A high per capita income would ensure high rail shares of work as well as non-work trips. A report quoted by Mohan et al (1997) suggests that a minimum per capita income of US$ 1000 is necessary to justify urban rail. In this regard, it is worth noting that in their survey, Calcutta, whose rail system is the worst performer in terms of various parameters also has the lowest per capita income. The three cities with the best performance in the survey, Hong Kong, Singapore and Seoul, have the highest per capita incomes.

The financial viability of urban rail systems depends critically on keeping utilization and fares as high as possible, and staffing and wage levels as low as possible. But experience from several LIC cities suggests that high fares cannot be charged without losing patronage. In order to attract patronage, the integrated bus and rail fare should ideally not be much higher than the existing bus fare; if it is, the poor will continue to use buses. And any attempt to remove bus competition will likely cause major disruptions in

peoples' lives, and the displacement of many small operators, as would be the case in Delhi (Mohan et al 1997). All of this means that fares in LIC cities have to be subsidized. But this would effectively drain resources from other important social sectors (and rural areas), to benefit the urban middle class. This has in fact been Calcutta's experience. Between 1972 and 1978, expenditures related to its subway consumed 48% of the city's investment for all purposes. And despite massive cost overruns and time delays, and continuing subsidies, the poor majority cannot afford to ride it (Brown and Jacobson 1987).

In order to be truly effective, urban rail needs to be supported by multiple intensely mixed-use centres close to stations. This is possible to achieve in dense LIC cities, and in turn, urban rail enables such densification, as discussed. Additionally, strong economic controls to curb personal motor vehicle ownership and use, by means of high taxes, parking costs and traffic restraint, would be required. In this regard, low provision of road infrastructure (to maintain transit speeds competitive with private motor vehicle speeds), and good provision for non-motorized modes, would also be desirable. The success of the urban rail systems in Hong Kong, Singapore and Tokyo is in fact largely due to these features. Half of Hong Kong's population lives within walking distance of, and 69% of rail passengers in the city walk to and from, a Mass Transit Railway station. In Singapore, which is less dense than Hong Kong, the corresponding figures are 30% and 65%, in large part because new development is being integrated with rail and routes have been planned to service existing development (Kenworthy et al 1994; Poboon et al 1994).[36, 37] Many LIC cities, however, do not have such large numbers of people in proximity to rail stations. This would necessitate many passengers using buses to access urban rail (Mohan et al 1997), which in turn would call for efficient feeder bus services.

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[36] While such figures are the result of conscious planning, it is also the case that the intense pressure on scarce land, and the potential for overwhelming congestion if private vehicles remain uncontrolled, has necessitated physical planning based on highly compact nodes of mixed-use development in Hong Kong (Kenworthy et al 1994).

[37] The close integration of rail and land use in Hong Kong has in turn attracted major capital contributions from private developers, and enabled on-going non-fare revenue flows from property leases around stations. Also, the transit operator is actively involved in controlling development which will determine how effective the system will be at meeting access needs (Kenworthy et al 1994).

Several of the issues raised above are worthy of consideration in relation to the urban rail system under construction in Delhi. Whereas Singapore's gross regional product per capita is around US$ 12,939 (Kenworthy and Laube 1999a), the per capita income in Delhi (incidentally India's wealthiest region) is only US$ 740 at current prices (NCTD 2001). In terms of the financial viability of Delhi's MRTS, it should be noted that while the Japanese loan carries a low interest rate of 2.3%, interest payments could effectively escalate due to rupee depreciation and other factors (Iijima 1999; Rekhi 1996). While Hong Kong and Singapore have the demonstrated ability to control land use, plan and implement intense mixed-use development integrated with rail transit, and apply strong economic and traffic restraint measures to curb personal motor vehicle ownership and use, it is unclear how successful Delhi will be in accomplishing these ends, which as discussed are so necessary for the success of urban rail systems. Finally, while Singapore (for example) is a small, wealthy city state, Delhi is predominantly poor, growing in all directions, cannot control in-migration, which is occurring at a rapid rate, and attracts motor vehicle activity from the surrounding regions (NCTD 2001; RITES/ORG 1994; Singh 1997b; WHO/UNEP 1992).

Last but not least in the complex of factors that contribute to motorization and transport emissions and energy consumption is urbanization itself. It is important to understand the forces that drive the phenomenon, and the role of government. The locational advantages, concentration of economic and political power, and economies of scale of large cities enable them to generate economic activity and jobs disproportionate to their share of national populations. Because economic and political power are concentrated in urban centres, little public investment occurs in rural areas, limiting productivity and non-farm employment. Land allocation regimes often compel the poor to cultivate marginal land, with no tenure. The resulting environmental degradation and poverty drive migration to the cities. While urbanization accelerates, the dwindling resources of the hinterland are bled further to cope with its impacts. Environmental degradation, poverty, population growth and urbanization thus spiral on inexorably (Brandon and Ramankutty 1993; Brown and Young 1990; Harrison 1988; The Economist 1995; WHO 1992).

Because of its geographic location, Delhi has been an important trading and commercial centre for centuries. Several national highways and railway lines converge there. Its pre-eminent position was reinforced by the concentration of government, administrative, and commercial services and employment opportunities in this century. The most recent spurt in Delhi's urbanization was caused by massive investments related to the Asian Games in 1984. Delhi now adds around 600,000 people to a population of 13 millions every year (DDA 1996; Dhingra 1997; Encyclopaedia Britannica 1998; Singh 1997b).[38]

3.4 CONCLUSIONS

The foregoing discussion highlights the fact that transport air pollution is not just a matter of vehicle, fuel and oil technology. A multitude of other technological, transport system, climatic and user behavioural factors exacerbate per-vehicle kilometre emissions due to vehicle and fuel technology. These factors include congestion, road quality, fuel system evaporative controls, vehicle maintenance, and fuel and oil adulteration.

While the above factors influence per vehicle-kilometre emissions, motor vehicle activity, in terms of vehicle kilometres as well as vehicle trips, also plays a key role in transport air pollution and energy consumption. After all, vehicle and fuel technology have if anything improved over the last decade. Transport air pollution has become an increasingly important public policy issue in Delhi and other Indian cities largely due to rapidly growing motor vehicle activity, and resulting congestion. The discussion in the chapter also highlights the importance of considering system-wide emissions due to motor vehicle activity, including re-suspended dust, an important source of transport PM emissions, and evaporative emissions from the vehicle as well as the fuel distribution system.

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[38] Industry and employment have been growing rapidly in Delhi. Its industrial units increased from 8000 in 1951 to 125,000 in 1991. In 1961-71 alone, small industries grew 444%. But Delhi is by no means unique. Bangkok, Dhaka, Manila, Mexico City and Shanghai also account for economic activity and jobs disproportionate to their share of population. Mumbai, with 1% of India's population, generates 10% of its industrial jobs, and more than a quarter of its foreign trade (Brandon and Ramankutty 1993; Misra et al 1998).

Technological, transport system and vehicle user behavioural factors that influence transport air pollution and energy consumption have underlying institutional causes. Travel behaviour in terms of personal motorized mode ownership and use, and vehicle operation and maintenance behaviours such as fuel and oil adulteration, depend on incomes, and user preferences and choices, but are also responses to circumstances in which vehicle users find themselves, which in turn are influenced strongly by institutional factors. These factors include the quality of public transit service, provision for non-motorized modes, and fuel and spare parts prices.

In short, as Figures 3.2 and 3.3 show, a whole complex of inter-locking technological, climatic, vehicle user behavioural, institutional, and ultimately political factors, influence motor vehicle activity, and transport air pollution and energy consumption. A good example of how these various factors interact is the role of fuel pricing and monitoring and enforcement in fuel adulteration, and in turn in fuel quality. The complex of factors in Figures 3.2 and 3.3 shows the magnitude of the public policy challenge. If we are to effectively deal with transport air pollution and energy over the long term, all of these factors need to be addressed in a comprehensive and integrated manner. In this connection, note the critical role of government policy with regard to vehicle emission and fuel quality standards, monitoring and enforcement of in-use vehicle emissions and fuel and oil quality, vehicle, fuel and spares duties and taxes, full cost pricing of travel, planning and infrastructure provision for private versus public and non-motorized modes, land use and housing, and regional development.

Of course, some of these factors are more easy to address than others, particularly given resource constraints. Urban form and land use are strong determinants of personal motorized vehicle ownership and use (Kenworthy et al 1994; Kenworthy and Laube 1999a), but are rather difficult to control, particularly to influence travel demand and patterns, and especially over the short term. This is true even in the West where the potential for such control exists by virtue of effective local governments, because of strong cultural and political barriers (Downs 1992). In the case of Delhi, as discussed in Chapter IV, there are serious constraints in the ability to control land use, especially at the urban fringe (Chandra 1997; Misra et al 1998; Singh 1997b).

But in any case, Delhi, including its rural areas, already has population densities ranging from 65 persons/ha to 665 persons/ha, with an average value (estimated by the author) of 90-100 persons/ha. Even in recently developed areas at the urban fringe, population densities are 200 persons/ha (DDA 1996; Mohan et al 1997; Tiwari and Kale 1997). These figures for Delhi are higher than those for North American and European cities, and even for Asian countries, with the exception of Bangkok, Hong Kong, Jakarta, Manila and Seoul (Poboon et al 1994; Raad and Kenworthy 1998; Kenworthy and Laube 1999a; Kenworthy and Laube 1999b). It is important to note that while the densities quoted above for Delhi were computed based on the total land area including rural areas, those for the other cities were based on the urbanized area and excluded all undeveloped land, regional open space, forests, agricultural land and water bodies (Kenworthy and Laube 1999a). Further, land use in Delhi is quite mixed in both the inner and outer areas, in part due to a conscious effort to develop district centres with mixed-use zoning, but also due to pressure on scarce land and high land prices, and the inability of authorities to control the proliferation of commercial operations to serve peoples' needs. So much so that household trip rates for different purposes in the outer areas are similar to those in the inner areas (Mohan et al 1997; Tiwari and Kale 1997). More importantly, non-motorized modes and public transit account for 39 and 42% of all trips, and 22 and 53% of work trips respectively, even among residential households. Further, public transit accounts for 71% of total passenger-kilometres in motor vehicles (RITES/ORG 1994). These figures compare favourably with those quoted for the least automobile dependent Asian (and global) cities in Kenworthy and Laube (1999a), with the possible exception of Hong Kong.[39]

Moreover, sprawl in Delhi is quite different from, and has been caused by different reasons than, the sprawl in North America (for example). Urban sprawl in the latter case, involving small populations spread over large areas, has in part been made possible by high incomes, abundant land, substantial and subsidized transport infrastructure, and low energy prices, as Hanson (1992) argues. In a situation like Delhi's, on the other hand,

[39] Such high non-motorized mode and public transit shares in Indian cities are enabled by high densities and mixed land use, but are also due to the fact that the majority have low incomes and cannot afford personal motorized modes.

sprawl has occurred due to rapidly growing population pressures, which in turn have been caused largely by the in-migration of the rural poor from the hinterland, as discussed. Further, none of the features that made sprawl in North America possible have obtained in the case of Delhi, except for the fact that several national highways pass through the region. In Delhi, the lower and middle income groups have been priced out of the land market in the inner areas and have been forced to move to areas in the periphery despite the lack of adequate transit and other services there. Indeed, land demand has been concentrated outside the urban boundaries over the past three decades (Misra et al 1998).[40] Under these circumstances, it is hardly surprising that large numbers who can afford M2W vehicles purchase and use them, as discussed. Finally, if land use control implies influencing where people live with respect to where they work, it should be noted that many of the millions who live in Delhi's slums and squatter settlements often move where work (in the informal sector) is available. Given all of the foregoing, land use control in Delhi is neither as feasible nor as imperative as in the West.[41]

As for urban rail in Delhi: it is difficult to say when it will be fully operational, and how effective it will eventually be in reducing personal motor vehicle activity and emissions. But it is reasonable to expect that the population and personal motor vehicle activity will continue to grow in Delhi and the surrounding regions in the foreseeable future, for all of the reasons discussed earlier in this Chapter. M2W vehicles will very likely continue to be the personal motor vehicle of choice for the middle classes for a long time to come in Delhi and the rest of the country, because of the lack of other affordable and attractive options. Further, urban rail, and for that matter public transit generally, will contribute nothing to reducing air pollution from the goods sector, which is predominantly diesel based and accounts for the bulk of PM, SO_2 and NO_2 emissions in Delhi, as discussed in Chapter II. Finally, it is unlikely that urban rail will significantly displace buses, which are

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[40] Additionally, resettlement of the poor in the urban fringes during the mid-1970s drastically increased trip lengths for them (Mohan et al 1997).

[41] However, much higher densities than currently obtain would be desirable, especially in some of the inner areas in South Delhi. As Hong Kong's experience shows, inner city areas can accommodate densities of 300-400 persons/ha without compromising healthy environments (Mohan et al 1997). It would also be desirable to plan for high densities and mixed land use to enable high public transit and non-motorized mode use, particularly in the newly developing areas, and in areas along the proposed MRTS route in Delhi.

also diesel operated. Indeed, feeder buses will be needed to transport passengers to rail stations.

In view of the foregoing, vehicle, fuel and transport infrastructure technologies will be important issues to address, particularly since these technologies in India lag behind global standards. In this regard, note that emissions and other transport impacts in Delhi are already exceedingly high despite far lower absolute motor vehicle activity levels compared to OECD cities, and despite significant public transit and non-motorized mode shares. At the same time however, technological solutions will not be sufficient since they can be neutralized by increases in motor vehicle activity and congestion. Further, given multiple urgent demands on scarce resources, and factors such as high population pressures, there is little scope to expand transport infrastructure to accommodate growing motor vehicle activity.[42] A wide range of technological, economic, regulatory as well as transport demand reduction policies will therefore be needed to address the transport air pollution problem effectively over the long term. This dissertation recognizes and reflects this need, by addressing the questions of how to think systematically about policies generally, and of what issues and perspectives to consider in order to make policies more attractive and effective over the long term. And although the dissertation focuses on technological and regulatory policies targeted at M2W vehicles, it has relevance for these and other policies targeted at other modes as well.

Lastly, consideration of system-wide sources of pollutant emissions due to motor vehicle activity, and of contributory factors as discussed, including in particular in-use vehicle operation and maintenance, and fuel and oil quality realities, will make emissions measurement and modeling efforts more effective, in turn allowing for more effective policy evaluation and monitoring.[43] A framework for modeling long-term emissions and

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[42] In this connection, it is worth critiquing the view that because there is great scope for improving transport efficiency in the LICs, their motor vehicle usage could increase two to three times without affecting their contribution to greenhouse gases (Faiz et al 1992). This may well be true, but it does not consider other transport emissions and impacts, and how LIC cities, with their meagre resources, might cope with them.

[43] In this regard, the importance of a driving cycle that reflects local driving conditions cannot be stressed enough. In the Indian context, this is borne out by studies conducted by Gandhi et al (1983), and by Tiwari and Kale (1997). Although dated, the former study, based on tests on the driving patterns of a car in Delhi, showed that acceleration and deceleration accounted for as much as 78% of the total driving time, significantly higher than in the ECE cycle (on which the Indian driving cycle is based). The latter

other policy impacts that takes into consideration these in-use realities, among other things, is proposed in Chapter V.

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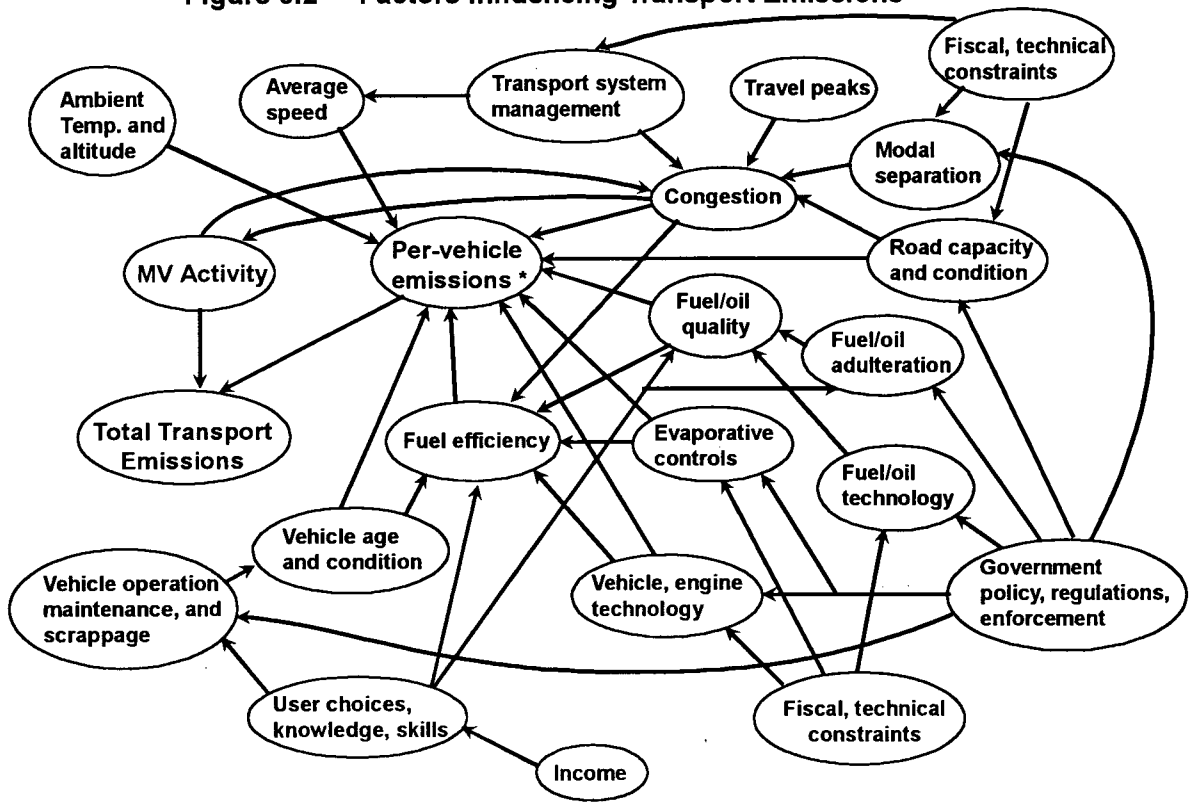
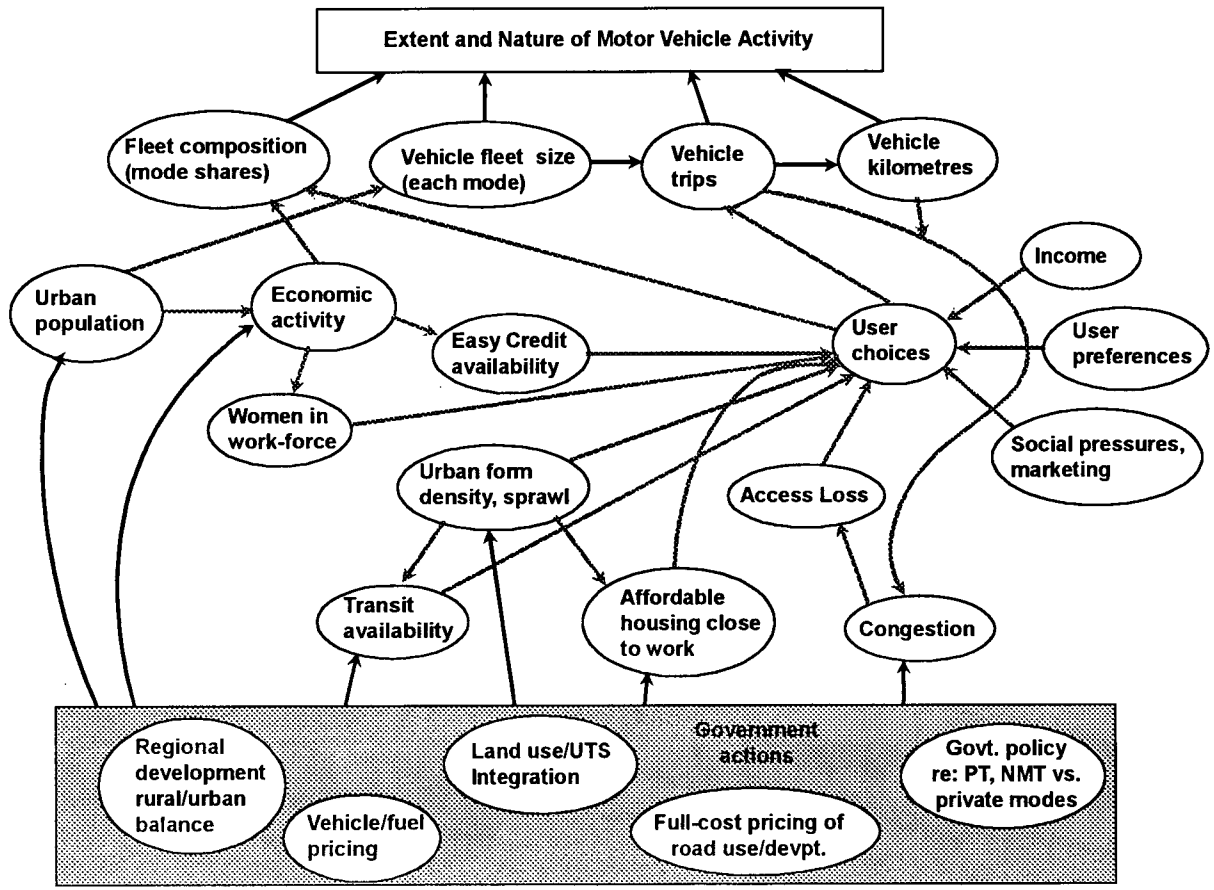
study confirmed the predominance of accelerations and decelerations, and also showed that driving patterns varied significantly from mode to mode. Finally, it is worth noting that maximum acceleration levels 3-5 times higher than in the US FTP and ECE cycles have been recorded on M2W vehicles in Bangkok (Faiz et al 1996).

Figure 3.2 Factors Influencing Transport Emissions



* -- Exhaust, crankcase, evaporative (vehicular and fuel distribution system), re-suspended PM

Figure 3.3 Factors Influencing the Extent and Nature of Motor Vehicle Activity



CHAPTER IV
TRANSPORT AIR POLLUTION IN INDIA: A DISCUSSION OF THE INSTITUTIONAL SETTING

4.1 INTRODUCTION

4.1.1 The Urban Challenge in Asian LICs, and the Role of Institutional Factors

The global urban challenge is greatest in the LICs, particularly in Asia. Urbanization is most pronounced in Asia, with the bulk of urban growth occurring in the region's low income countries. In 2025, South Asia's urban population will likely be 1.4 billion (out of a *total global* population of 8 billion). Rapid urbanization in the LICs is characterized by a proliferation of megacities. In 2015, India alone will likely have four of the world's 27 (and Asia's 15) megacities, in addition to 40 cities with over one million population.[1] Rapid urbanization is causing massive environmental and social impacts in LIC cities, including those related to air pollution and transport. And it is the poor who bear the brunt of these impacts, since they are typically the most exposed to, affected by, and least capable of coping with them. Nearly half the world's poor will likely be urban, and concentrated mainly in South Asia. The poor already account for 45-60% of Calcutta's and Chennai's populations (Brandon and Ramankutty 1993; Hardoy, Mitlin and Satterthwaite 1992; Midgley 1994; Romieu, Weitzenfeld and Finkelman 1991; Romieu et al 1992; The Economist 1995).

The serious urban situation in the LICs is rendered more daunting by the fact that, even as basic urban infrastructure and services are already woefully inadequate, and the resources necessary to provide them dwindle, demands multiply rapidly. While London's population took 100 years to grow from one to seven million, Delhi's increased from 0.7 to 13 million in a mere 50 years. Moreover, LIC cities lack the resources and power of their industrialized country counterparts, which are able to keep their local environments clean and export their wastes, thus directing their impacts mostly at the global level (Brown and Jacobson 1987; Midgley 1994; The Economist 1995; WCED 1987; White and Whitney 1992). This fact is borne out, interestingly, by the OECD accounting for the bulk of motor vehicle activity, and

[1] India's megacities in 2015 will be Mumbai (with a projected population of 27 million), Calcutta, Delhi and Hyderabad, with Bangalore and Chennai not far behind (Brandon and Ramankutty 1993; Midgley 1994; The Economist 1995).

transport energy consumption and greenhouse gas emissions, with potentially global effects, but a much smaller proportion of emissions with adverse local or regional effects, whereas the situation is reversed for the LICs, as discussed in Chapter II (Faiz et al 1992; Grübler 1994; Walsh 1994).

Institutional and political factors also play a crucially important role in urban environmental problems. Urban environmental issues are complex and multi-dimensional, and highly effective institutional mechanisms are required to address them. Yet, LIC governments largely lack the institutional capacity to formulate, implement and enforce urban environmental policies. It is not so much in terms of environmental legislation or even political commitment, but implementation, and monitoring and enforcement at the local level, that LIC institutional weaknesses are greatest (Brandon and Ramankutty 1993; Douglass and Lee 1996; Hardoy, Mitlin and Satterthwaite 1992).

One important reason for weak institutional capacity at the local level is the fact that in most Asian countries, governance is dominated by the central government, and municipal governments have little power. Perhaps most importantly, local governments lack the authority to raise revenues, even as their mandates are expanding. Urban environmental agencies in particular have low status, and inadequate political authority and human resources to change the behaviours of firms and individuals. Thus, environmental regulations are not taken seriously. Weak institutional capacity is exacerbated by jurisdictional complexity. Actions by agencies at the municipal as well as provincial and national levels have an important bearing on urban environmental outcomes. However, these agencies often have unclear, overlapping, and uncoordinated responsibilities. Further, while urban environmental problems are cross-sectoral, most planning and investment is sectoral (Brandon and Ramankutty 1993; Douglass and Lee 1996; Hardoy, Mitlin and Satterthwaite 1992).

Environmental policy and planning are also hampered by the inability to collect reliable information and conduct quality policy analyses. National capabilities that do exist in these areas are often not tapped, because of poor interaction between the policy-analytic and decision-making communities. The inability (or unwillingness) to involve the public at large results in less support for long term operations. At the same time, ad hoc responses to specific local pressures, rather than coherent, sustained programmes, become the norm (Brandon and

Ramankutty 1993; Douglass and Lee 1996; Hardoy, Mitlin and Satterthwaite 1992; Kandlikar 1998).

4.1.2 Chapter Objectives and Outline

As Chapter III showed, transport-generated air pollution is a complex problem, involving a range of inter-dependent technological, vehicle user behavioural and institutional factors. By its very nature, this problem requires a range of public policy interventions co-ordinated by an equally wide range of agencies. It would be useful to critically examine the institutional setting in relation to this problem in the Indian context, in terms of the effectiveness with which various concerned agencies and actors in that context formulate and implement prevention and control policies. This chapter attempts this task.[2]

The chapter addresses the following research questions: Who are the actors and what are their roles, responsibilities and interactions in terms of policy-making and implementation with respect to prevention and control of transport air pollutant emissions? What are the institutional barriers and constraints? And finally, what are the implications of all of the above for transport air pollution prevention and control in the Indian context? The discussion addresses actors' roles, responsibilities, interactions, and barriers and constraints in relation to the various aspects of the transport air pollution problem discussed in Chapter III. The actors include key government agencies at various levels, vehicle and fuel manufacturers, academic and research institutions, environmental NGOs, the courts and public interest litigators, and the media.

The discussion is intended to help in identifying institutional barriers and constraints that are critical to long term policy effectiveness, and in developing institutional mechanisms and arrangements to overcome these barriers and constraints. At the same time, policies can be designed to be insensitive to the lack of these mechanisms, and therefore to have a better chance of long-term effectiveness, given contextual constraints. Finally, while the discussion focuses on prevention and control of M2W vehicle emissions prevention in Delhi, it has

[2] A similar institutional analysis focusing on the Indian context is the work by Kandlikar and Sagar (1999), which examined climate change research and analysis in India, the factors that contribute to India's capabilities and constraints in this regard, and implications for international co-operation on climate change.

relevance for transport air pollution generally, and indeed other urban environmental issues, in the Indian context.

4.2 METHODOLOGY

The discussion in this Chapter is based on a critical analysis of a wide range of published as well as unpublished written material, including pertinent environmental legislation, reports and position papers prepared by local and national government agencies, environmental NGOs, and vehicle and fuel manufacturers and industry associations, transcripts of proceedings in Supreme Court public interest cases, excerpts from reports of the Saikia Committee, which was charged by the Court to develop emission control action plans, and media reports and commentaries.

Information culled from the above sources was supplemented with that obtained in the course of in-depth interviews with various individuals interested in and/or knowledgeable about the range of issues involved, and representatives of institutions whose actions have an important bearing on transport air pollutant emissions in the Indian context. These individuals included decision makers in relevant government agencies at the national and local levels, vehicle and fuel industry representatives, and academics and researchers. A list of interviewees is provided in Appendix V. In addition to sharing their insights, the interviewees made available to the author the bulk of the documents referred to in the previous paragraph. The interviews were therefore invaluable in gaining a comprehensive understanding of policy-making and implementation processes, and institutional capabilities and constraints, in relation to transport air pollution in the Indian context.

Interviewees' informed consent was obtained prior to interviews being conducted. The interview protocol, and the Informed Consent Form (Appendix VI), were approved by the Behavioural Research Ethics Board of the UBC Office of Research Services and Administration. One of the conditions of this approval was that the identities of interview participants would be kept confidential. It is for this reason that, while their information and insights were of immense value to the author, interviewees are not explicitly acknowledged in the following discussion.

4.3 ACTORS, RESPONSIBILITIES AND ROLES

The Ministry of Environment and Forests (MoEF) is the lead Government of India agency for all national environmental and forestry programmes. Its mandate includes environmental policy formulation, developing and enforcing environmental legislation, and executing, co-ordinating and monitoring pollution prevention and control programmes. These tasks are implemented through its various divisions and agencies, one of which is the Central Pollution Control Board (CPCB). The CPCB's functions regarding air pollution include advising the Government of India, setting national air quality standards, air quality monitoring, and recommending motor vehicle emission and fuel quality standards, based on the work of committees representing, among others, R&D institutions and other ministries. The CPCB is also mandated to conduct and sponsor research, co-ordinate and assist state pollution control boards, and disseminate information on air pollution and its prevention and control. The enabling legislation include the Air (Prevention and Control of Pollution) Act (1981), and the omnibus Environment Protection Act (1986), enacted following the 1984 Bhopal disaster (CPCB 1996; CSE 1996; GoI 1981; GoI 1986; MoEF 1991; MoEF 1997a; TERI 1997a).

While local state pollution control boards implement pollution control action in the Indian states (the equivalent of the Canadian provinces), the CPCB is mandated to play the role of a state board in Delhi and other union territories. Interestingly, it is also only for the union territories that CPCB is additionally mandated to conduct studies on air pollution effects. Finally, Delhi and other union territories have been declared "air pollution control areas" (GoI 1982; GoI 1983), thus privileging these over other regions in the country, many of which have air pollution levels that are at least as high as in Delhi, as discussed in Chapter II (Brandon and Hommann 1995; CPCB 1992; CPCB 1996).

MoEF recommends vehicle emission standards, but it is the Ministry of Surface Transport (MoST) that notifies and enforces them. Other responsibilities of MoST that are pertinent in the context of the present discussion include developing standards, rules, and procedures with regard to type approval and in-use vehicle emissions testing, and vehicle licensing, registration, road-worthiness, and service life, through the Central Motor Vehicle Rules (MoST 1996; Universal Law Publishing 1995). It is worth noting that, while MoST is responsible for enforcing vehicle emission standards, the agency's primary mandate is the

well-being of the transport industry, which is a major economic player and employer nationally. MoST's role in transport air pollution prevention and control is inherently conflicted, since the agency has the task of regulating the industry whose interests it also has the mandate to promote.

The Ministry of Petroleum and Natural Gas (MoPNG), along with the oil refineries, which are predominantly state-owned (this is changing), are responsible for exploration, production, refining, distribution, marketing, and export and import of crude oil and petroleum products. As such, MoPNG and the oil refineries determine the quality of Indian transport fuels and lubricating oils, which critically influence transport emissions. Fuel and oil quality standards are nominally developed by the Bureau of Indian Standards, an independent statutory body, through committees which include the oil refineries and vehicle manufacturers, but it is actually MoPNG that drafts and implements them. Other energy-related government agencies which influence policies and actions affecting transport emissions include the Energy Policy Unit of the Planning Commission, whose mandate is to plan for energy self-sufficiency, the Oil Co-ordination Committee (OCC), which coordinates and monitors oil imports, exports, and refining, and perhaps most importantly administers fuel pricing (through the "administered pricing mechanism", or APM),[3] and the Petroleum Conservation Research Association (Author's interviews 1997; BIS 1995a; BIS 1995b; BIS 1996; CSE 1996; TERI 1997a).

MoEF, MoST and MoPNG are the three national government agencies whose policies and actions most critically influence transport air pollution and energy consumption. But other agencies at the national level also play a role. The Ministry of Industry (MoI), whose mandate is industrial policy and promotion, was powerful until the early 1990s, but their role has declined considerably because of economic liberalization and rising environmental concerns. The Ministry of Finance plays a crucial role in setting excise and import duties and tariffs, and vehicle, fuel and spares sales taxes. Both the Union Ministry of Health, and its Delhi government counterpart, surprisingly play a marginal role in air pollution control (Author's interviews 1997; CSE 1996; CSE 1997).

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[3] The cross-subsidization of kerosene and diesel, among other fuels, under the APM, was discussed in Chapter III.

Several academic and research institutions in the public, private and quasi-public sectors are involved in R&D and policy analysis related to urban transport, vehicle and fuel technology, and transport emissions and control. Representatives of these institutions serve on committees to set vehicle emissions and fuel and oil quality standards, and/or investigate the problem of transport air pollution and energy consumption generally (BIS 1995a; BIS 1995b; BIS 1996; CSE 1996; IIP 1994; MoEF 1991; Mohan et al 1997; Mohan and Tiwari 1997; RITES/ORG 1994; TERI 1997a).[4]

In addition to the above agencies at the national level, there are several local agencies in Delhi with jurisdiction over issues that have a significant bearing on the city's transport air pollution. As indicated earlier, the CPCB is mandated to play the role of a state pollution control board in Delhi and other union territories (GoI 1982; GoI 1983). At the same time, the Delhi Pollution Control Committee (DPCC), an agency of the Government of the National Capital Territory of Delhi (NCTD) has responsibility for pollution control in the city (Prem Kumar 1997). But CPCB reportedly conducts its work in Delhi in collaboration with the DPCC (Author's interviews 1997). Nevertheless, this situation has the potential to be a recipe for jurisdictional confusion.

The Transport Department of the Government of NCTD is responsible primarily for vehicle licensing, registration, and inspection and road taxation in Delhi. As will be discussed later, vehicle licensing and registration are functions with important implications for in-use transport emissions control, for which the agency is also responsible. In this connection, the Transport Department of the Government of NCTD certifies and licenses fuel dispensing and service stations to test in-use vehicle emissions and repair non-complying vehicles. The regulation of vehicle service life, and therefore vehicle scrappage, is MoST's responsibility, as already indicated, but it is the Transport Department of the Government of NCTD that enforces this regulation. Further, in the case of Delhi exclusively, MoST has delegated the

[4] These institutions include the Automotive Research Association of India (ARAI), Central Institute of Road Transport, Central Road Research Institute (CRRI), Indian Institute of Petroleum (IIP), the Indian Institutes of Technology, Indian Oil Corporation R&D Centre, National Environmental Engineering Research Institute, Operations Research Group, Rail India Technical and Economic Services Ltd., and Tata Energy Research Institute (BIS 1995a; BIS 1995b; BIS 1996; CSE 1996; IIP 1994; MoEF 1991; Mohan et al 1997; Mohan and Tiwari 1997; RITES/ORG 1994; TERI 1997a).

authority for fixing vehicle life spans to the Government of NCTD (MoEF 1997; NCTD 1997a; NCTD 1997c).

Traffic control and the enforcement of traffic regulations, which have important implications for smooth traffic flow and therefore for transport emissions, are the responsibility of Delhi's Police Department. The police are also charged with booking vehicle users with polluting vehicles or with invalid PUC ('Pollution under Control') in-use emissions test certificates, a largely futile exercise fraught with legal difficulties, as discussed later. Interestingly, fuel adulteration control falls under the purview of the Ministry of Food and Civil Supplies, though the police are also responsible for this function (Author's interviews 1997; MoEF 1997b; NCTD 1997a; NCTD 1997c; NCTD 1997d).

The Delhi Transport Corporation (DTC), which operates no more than 3000 of Delhi's buses (ASRTU/CIRT 1997; Chima 1997), and the large number of private bus operators who run the city's balance 25,000-odd buses, critically affect transport emissions, because the quality of the service they provide influences private (including M2W) vehicle use, as discussed in some detail in Chapter VI. Additionally of course, DTC and the private bus operators determine transit vehicle maintenance, a key factor in vehicle emissions, as discussed in Chapter III.

Three agencies, New Delhi Municipal Corporation (NDMC), Municipal Corporation of Delhi (MCD), and Delhi Cantonment Board, are responsible for transportation planning, road construction and maintenance, and transport system management in Delhi. Land development and use is the responsibility of the Delhi Development Authority (DDA) (Author's interviews 1997; DDA 1996). In light of Chapter III, the actions of these agencies have profoundly important long-term implications for access and mobility, private motor vehicle ownership and use, congestion, and transport emissions and energy consumption, in Delhi and the surrounding region. So do agencies responsible for development and transport policies in the states surrounding Delhi. In this connection, note that nearly 200,000 people in the neighbouring industrial centre of Faridabad in the state of Haryana State commute to and from Delhi daily (Misra et al 1998; Verma 1997).

So far, we have discussed the roles and responsibilities of government agencies and other institutions at the national, local and regional levels in relation to transport air pollution. We

now turn our attention to the crucially important role of private sector actors. Perhaps the most important of these in terms of their influence on transport emissions are the vehicle manufacturers, fuel refiners and marketers, and vehicle users, who daily make critical travel and vehicle purchasing, operation and maintenance choices. The interests of the vehicle manufacturers in relation to transport air pollution control, among other transport-related matters, are jointly represented by the Association of Indian Automobile Manufacturers (AIAM). As indicated earlier, private fuel dispensing stations test in-use vehicle emissions, and repair non-complying vehicles. These stations therefore obviously play a critical role in controlling in-use vehicle emissions, and in ensuring the quality of in-use transport fuels and lubricants (Author's interviews 1997; AIAM 1994a; AIAM 1995; AIAM 1996a; AIAM 1996b; NCTD 1997a; NCTD 1997b).

The NGOs and the media can and do play a key role in transport air pollution prevention and control, as indeed in the case of other environmental issues. They do so by building public awareness of the air pollution problem, and of control measures that are either in place or are being contemplated, and by critiquing or building political support for government policy and decisions. Several such efforts by NGOs and the media (for example, CSE 1996; CSE 1997; Delhi Midday 1997; Ganguli 1997; Indian Express 1997; Nag 1997) are referred to and critiqued in the following discussions.

As governments at both the national and local levels are increasingly perceived to be unwilling to address, or incapable of effectively addressing, transport air pollution and other environmental problems, the role of public interest litigation has grown rapidly. An activist Supreme Court has responded,[5] with sweeping decisions that have in many cases gone well beyond merely laying down the law. In response to public interest litigation to save the Taj Mahal from air pollution, the Supreme Court has, among other things, directed that new registrations of coal based industries in the surrounding area be stopped, that a whole range of industries either convert to natural gas or relocate outside the region, that government agencies lay a gas pipeline to the industries, and that non-complying industries be shut down. Similarly, the Supreme Court has ordered the relocation of polluting industries in Delhi. In

[5] The Supreme Court of India and the High Courts have long had a tradition of accepting petitions on even postcards, brought by people who claim to be aggrieved or affected by state action or inaction, and also by citizens acting *pro bono publico* (Author's interviews 1997; Bal Krishna 1997).

response to public interest litigation on transport emissions, the Supreme Court has directed, among other things, that catalytic converters be fitted on new motorized four-wheeled vehicles in Delhi and the other major cities, thus actually specifying vehicular technologies. Additionally, the Court has commissioned studies of technological options, and directed governments to stop new M3W vehicle registrations in Delhi, and that M3W vehicles and buses in that city be operated on alternative fuels. Finally, the Court has closely monitored implementation of its directives (Agarwal 2000; CSE 1996 and 1997; CSE/DTE 1997a; Hindustan Times 1997; Prem Kumar 1997; Sharma 1997; Mehta 1993; Saikia Committee 1997a and 1997b; Supreme Court 1996a-g; Supreme Court 1997a and b). In short, the increasingly active role of public interest litigants, and of the judiciary, is becoming an important factor in the prevention and control of transport air pollution, and other environmental issues. Their role is discussed at some length later.

To conclude this section: the institutional setting for policy-making and implementation with regard to transport air pollution in the Indian context is characterized by a multitude of agencies and actors with diverse interests, and fragmented, overlapping and/or conflicting, roles and responsibilities, in terms of the various aspects that have important implications for the problem. This situation, depicted in Figure 4.1, is a good illustration of the point made by Brandon and Ramankutty (1993) about the jurisdictional complexity that characterizes environmental management generally.[6] This jurisdictional complexity exacerbates the difficulty of dealing with transport air pollution, characterized as it is by a large number and variety of motor vehicles and literally millions of vehicle users. Additionally, many actors face political, technological, financial, and administrative constraints and barriers, which we now discuss.

4.4 INSTITUTIONAL CONSTRAINTS

MoEF potentially has enormous powers under the Environment Protection Act (1986), to the extent that it can order units, including automobile manufacturers, to close down, if it deems fit. In practice, however, the agency is largely restricted in its ability to even co-ordinate implementation of policies on issues like air pollution. Despite its title, and the mandate

[6] Figure 4.1 shows the key actors and issues in terms of transport air pollution prevention and control. Actors with roles related to several issues are shaded, to minimize clutter. All the abbreviations used in the Figure are expanded in the Chapter text.

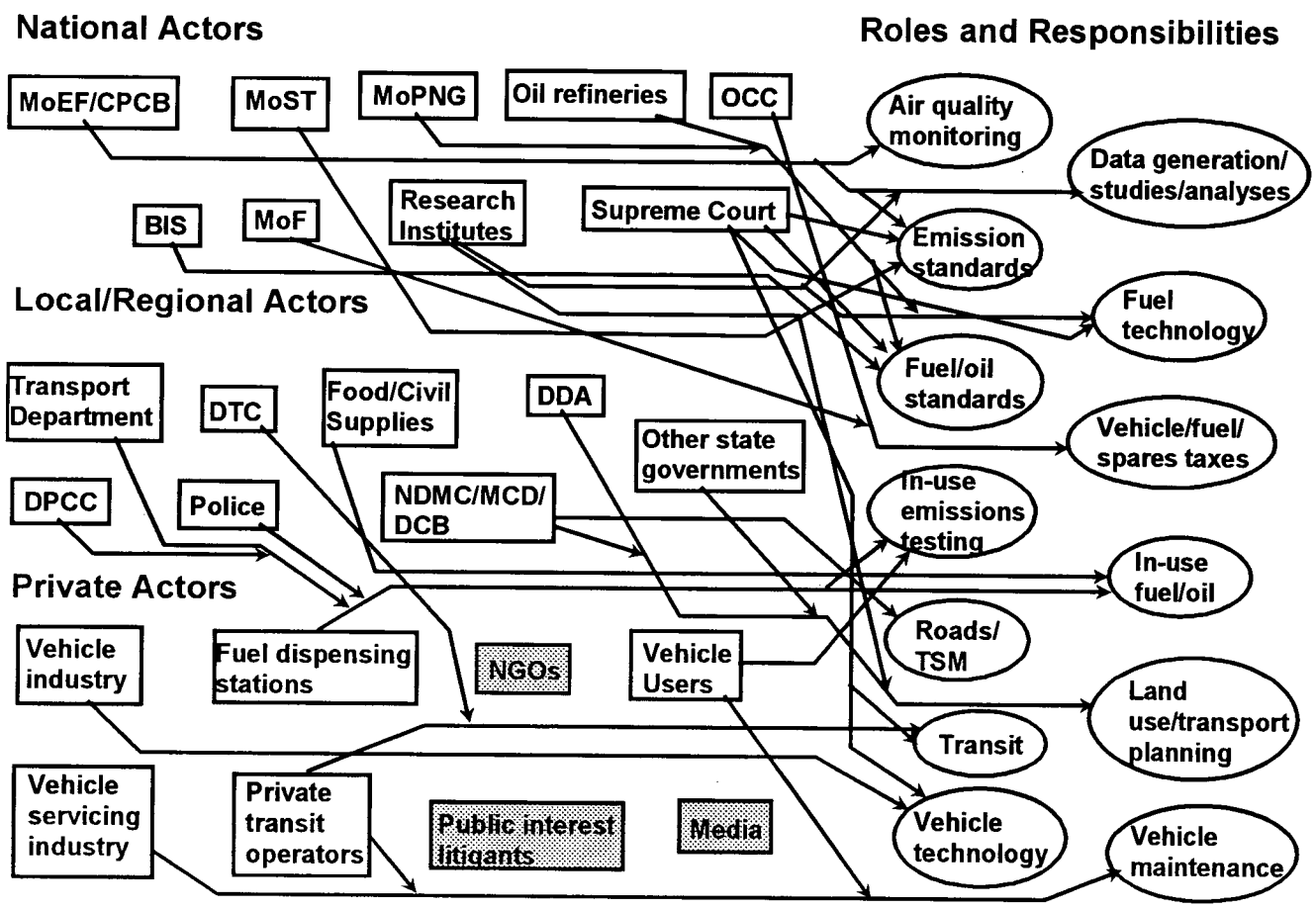
conferred upon it by the Environment Protection Act, the CPCB can in practice only advise government, conduct and commission studies, and exhort action. According to the CPCB chair, Mr. Biswas, the only way in which the agency can effect change is by providing information to the Supreme Court, NGOs and the media (CSE 1996).

Unfortunately, the CPCB's resources and capabilities in terms of data generation and analyses appear to be restricted. As discussed in Chapter II, air quality monitoring, even in Delhi, is far from adequate. Neither CPCB (nor the NEERI) monitored CO, O_3 or PM_{10} on a regular basis, at least until 1997. Even those pollutants that were monitored were not monitored continuously, or even regularly, contrary to requirements that the CPCB itself stipulates in the Indian NAAQS. More fundamentally, as also discussed in Chapter II, the Indian NAAQS are either unnecessarily or unrealistically stringent in some cases, and too lenient in some others, as compared to WHO limits. No reliable exposure studies nor emissions inventories exist, to enable prioritization of emissions sources for control action. This is true not only for Delhi, but also other cities like Mumbai. In this regard, recall the critique of Indian transport emissions inventories offered in Chapters II and III.[7] Further, no systematic indigenous epidemiological studies to link air pollution with health effects, using actual Indian mortality and morbidity data, have been conducted (Brandon and Hammonn 1995; CPCB 1995 and 1996; CSE 1996 and 1997; Shah and Nagpal 1997; WHO/UNEP 1992).

Anil Agarwal, who heads the Centre for Science and Environment (CSE), a leading Indian environmental NGO, charges MoEF and the CPCB with not developing the necessary institutional mechanisms to study air pollution (or other environmental issues) comprehensively, and in an inter-disciplinary framework, because doing so "would threaten the generalist bureaucracy and the minister" (CSE 1996). The motivation ascribed to MoEF and CPCB is open to debate, but Agarwal is not far off the mark as to the net result.

[7] However, WHO ranked Delhi's emissions inventory as "good" in 1992. Also, WHO ranked Delhi's monitoring of SO_2, SPM, and NO_2 as adequate, of CO and O_3 "non-existent", and lead "rudimentary" (CSE 1996; WHO/UNEP 1992).

Figure 4.1 Actors, Roles and Responsibilities



The CPCB's own view of the matter is that the agency has considerable difficulties, owing to restricted resources, in conducting even the air quality and other environmental monitoring that they do, let alone policy analyses. Further, according to Mr. Biswas, CPCB's chairperson, there is an unnecessary obsession with monitoring and "academic exercises", when the focus should be on preventive and control action. Lastly, good air quality monitoring, emissions inventories and policy analyses are useful, but futile without effective policy implementation, for which the mechanisms are lacking (Author's interviews 1997; CSE 1996; Prabhu 1997).

One can sympathize with the CPCB view that given the growing seriousness of the air pollution problem, there is little sense in waiting for studies, which are resource-intensive in any case, before initiating action. And it certainly is true that policy implementation mechanisms leave much to be desired, as will be discussed shortly. However, precisely because resources are scarce, it is important to prioritize action, based on whatever data exists, even as plans are drawn up for more effective data gathering and policy implementation. This is in fact the approach that underlies the policy-analytic framework proposed in Chapter V.

Anil Agarwal and others believe that the involvement of the Ministry of Health in air pollution prevention and control is essential, in terms of, for example, epidemiological studies. However, the Ministry's involvement in this area is minimal. The air pollution related epidemiological studies that are conducted are reportedly poorly designed and executed. But even if the capabilities existed to do quality studies, health records, which are also the domain of local and national Ministries of Health, are unreliable for scientific analysis (Author's interviews 1997; Agrawal 1997; Cropper et al 1997; CSE 1997; Mohan, Tiwari and Kanungo 1996). Even if none of these obstacles existed, such work would be very expensive, time consuming and require skilled manpower. Finally, given the range of influencing factors in the context, it would be difficult to isolate the contribution of air pollution to health outcomes. This is particularly so in the case of transport emissions, because of the multitude of organic and inorganic pollutants and atmospheric reaction products, and the uncertain nature of their

toxicology and synergistic effects, and of chronic effects of long term low dosage exposure (Bates 1994; Chang et al 1991; Faiz et al 1992; Hardoy and Satterthwaite 1991).[8]

According to the national Ministry of Health, there are no funds available for studies on air pollution health effects. Besides, the Ministry is far more concerned about infectious and parasitic diseases, which account for nearly 20% of Indian deaths (Mohan, Tiwari and Kanungo 1997), and AIDS. The position of the Ministry of Health in relation to air pollution may be justified. Air pollution, though important, does far less damage to health than poor quality water (Brandon and Hommann 1995). Further, indoor air pollution (rural as well as urban) does far more damage than outdoor urban air pollution (Smith 1988 and 1994).[9]

According to Brandon and Ramankutty (1993), urban air pollution tends to be the most well-documented environmental impact in Asian LICs. Perhaps urban air pollution gets the most attention, because it is a great leveler. The well-off can insulate themselves from other environmental impacts, but not air pollution. One decision maker that the author interviewed called air pollution a "bourgeois pre-occupation".[10] Even in terms of transport, air pollution may be its most widely felt impact. But road accidents cause a significant number of mortalities and morbidities in Delhi and other Indian cities, with considerable productivity loss and expenses that are often not recovered. The health and economic damages due to road accidents, which predominantly affect young men in their prime (Mohan and Tiwari 1997) very likely exceed the damages due to transport air pollution, which incidentally cannot be attributed with certainty to the sector, for all of the reasons just discussed, and also because

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[8] Note in this regard the discrepancy between the annual air pollution deaths estimated for Delhi by Brandon and Hommann (1995) and by Cropper et al (1997), referred to in Chapter II. Delhi's Health Minister is reported to have challenged his colleague, the Transport Minister's stress on air pollution and its health effects based on Brandon and Hommann's study.

[9] Rather than taking MoH to task for not paying attention to this or that specific environmental health risk, its critics may do better to urge it to use its limited resources to do good research on prioritization of health risks generally, and then to focus on the most serious (and easily preventable) ones.

[10] The argument that urban air pollution is a bourgeois pre-occupation is given credence by comments on the subject in the press, such as: "environmental hazards for long considered the problem of the poor, have now entered the world of the urban rich and the middle class" (Prabhu 1997). Similarly, the then Minister of MoEF is quoted as saying: "(Air) pollution in Delhi will be controlled as all high-ups like me, Members of Parliament and journalists live in Delhi. So it will be our first concern." (India Today 1996). This also explains why air pollution in Delhi is more important than air pollution in other cities. Interestingly, the magazine in which this quotation appeared did not criticize it, but rather offered it as evidence that something would actually be done about Delhi's air pollution.

transport is but one of several air pollution sources.[11] And yet, the transport problem that gets the most sustained media and policy attention is air pollution. Indeed, the transport problem increasingly tends to be framed almost exclusively in terms of air pollution. Because of this, and also because resources are scarce, other important transport impacts such as road safety, and loss of access are likely to be given short shrift.

As indicated in Chapter III, Indian vehicle technology is decades behind that in the West. The long-standing protection of local industry by means of high tariffs has been an important factor (Biswas in CSE 1996). Given this, and the lack of incentives/disincentives related to fuel economy and emissions, user choice has had little role in determining vehicle technology. R&D lead-times in the industry typically run into years, and require massive investments in financial and technical resources, which, even if forthcoming, cannot be mustered quickly enough to effect urgently required improvements. Technology import, which is occurring in the case of cars (and to an extent, in trucks), encounters barriers in the case of the M2W vehicle industry. This is because of the limited role that these vehicles play in the technologically advanced countries, and also because of the (recreational) uses they are typically put to there (Author's interviews 1997; CSE 1996). As discussed in Chapter III, M2W emission standards in many of these countries are considerably inferior to current Indian standards (Faiz et al 1996; MoST 1996). But more importantly, M2W vehicle manufacturers such as Bajaj control significant market share (AIAM 1994a and 1995), and would not like to see this dominance diluted through foreign collaborations (Author's interviews 1997; CSE 1996).[12]

All aspects of the Indian petroleum industry, from oil exploration and production, to refining and marketing, are dominated by state-owned public sector undertakings, under the administrative control of MoPNG. India is one of the few countries globally in which government has a monopoly over these activities, and also determines fuel pricing. While the BIS committees for fuel and lubrication oil standards include automobile industry

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[11] 1885 people were killed, and 8099 injured in road accidents in Delhi in 1993 (ASRTU/CIRT 1997). Compare these figures to the 3430 premature mortalities due to PM from all air pollution sources estimated by Cropper et al (1997) for Delhi. Further, many accidents go unreported, as the author discovered during his interviews with M2W vehicle users (Chapter VI).

[12] Bajaj Auto and TVS account for 39 and 14.6% of all Indian M2W vehicle production respectively (AIAM 1995).

representatives and other actors, they are headed by a representative of MoPNG. Effectively, therefore, the manufacturers have until recently determined the standards they will follow. Further, BIS standards, mandatory for other industries, are voluntary in the case of the petroleum industry (Author's interviews 1997; CSE 1996; Ganguli 1997; Nag 1997; Paul 1997; TERI 1997a).

At the same time, as discussed in Chapter II, petroleum products demand has been growing dramatically, and continues to grow, especially in terms of middle distillates, largely due to rapidly increasing diesel-based road transport. Domestic refining capacity has been unable to meet demand. To boost production, Indian refineries take wide cuts of high demand products like diesel and gasoline, and crack heavy distillates (to maximize middle distillates). This practice, coupled with outdated technology, and the use of cheap, high-sulphur imported crude, to make up for the shortfall in domestic crude, has contributed to poor quality fuel in India (CSE 1996; GoI/ESCAP 1991; TERI 1997a).

However, because of increasing urban air pollution, and also because of increasingly stringent vehicle emission standards in response to this problem, it has become imperative to improve transport fuel quality, as discussed in Chapters II and III. With MoEF taking the lead, under the Environment Protection Act, tighter fuel standards have been developed (BIS 1995a; BIS 1995b; Appendix IV). Their task of meeting rapidly growing demand, hard as it already was, has been made even harder for Indian refineries with the tightening of fuel quality standards. It has been a major challenge for the refineries to produce adequate quantities of unleaded gasoline, while also meeting the more stringent requirements for other fuel parameters (Author's interviews 1997; CSE 1996; Hari 1994; Lal 1994a; Lal 1996b; Lal 1996d; Mehta 1993; Supreme Court 1996c).

Reforming is the simplest option for boosting production, and is either available, or is being installed at various Indian refineries. Reforming converts naphtha into high octane aromatics, to compensate for lead removal, but increases levels of benzene and other aromatics. Also, yields fall as octane number increases, and reformate alone is too involatile. Reformates thus have to be complemented with lighter components, by means of catalytic cracking, to maintain volatility, control benzene and aromatics, and boost gasoline yield. However, cat-cracked components have relatively low octane quality, and increase gumming,

which affects fuel injectors, and HC emissions (Author's interviews 1997; CSE 1996; Faiz et al 1996; Hari 1994; Raje and Malhotra 1997).

It is estimated that Indian refineries will need to invest around US$ 1,600 millions over the next few years, in hydro-desulphurization, hydro-cracking, MTBE blending, alkylation and isomerization units, to improve gasoline and diesel quality to meet year 2000 specifications. This task is all the more difficult, because it has been postponed so long. The administered pricing mechanism (APM), by means of which diesel and other fuels were heavily cross-subsidized, is believed to have contributed to this delay. Because of the APM, there has been a lack of resources for boosting oil exploration and production, and for improved refining technology. Further, investors are understandably unwilling to commit large funds under an administered price regime. In fact, private refineries allowed under the gradual re-structuring (and APM dismantling) currently underway, propose to use 40-year old refining equipment that had been lying idle abroad (Author's interviews 1997; CSE 1996; Ganguli 1997; Nag 1997; Paul 1997; TERI 1997a).[13]

As for the local government agencies: the Transport Department of the NCTD, which is responsible for the important function of in-use transport emissions control, is seriously short of staff to properly certify and monitor the fuel dispensing stations that actually conduct the vehicle testing and repair, in terms of operator qualifications, equipment calibration and test procedures. In 1997, the Department reportedly had only one mobile inspector for every 50-100,000 vehicles on the road. It cannot even ensure that personal vehicles return after 15 years for re-registration, as required by the law. Similarly, the Ministry of Food and Civil

[13] The APM itself is going to be difficult to dismantle. Since so much of transport in India (particularly freight) is dependent on diesel, deregulating diesel prices might cause inflation to rise, with consequent regressive effects and political outcry (Duleep 1994; TERI 1997a). Also, vehicle manufacturers who had invested in producing diesel cars, to take advantage of administered diesel prices, would now be at a disadvantage. Further, if diesel were deregulated and kerosene were not (and there is justification for kerosene subsidies as discussed in Chapter III), diesel adulteration would only increase. If both diesel and kerosene were deregulated, regressive effects would further intensify. Kerosene subsidies hardly benefit the rural poor, since they rely principally on traditional fuels. The urban poor are likely to be harder hit energy-wise than the rural poor, due to fuel price increases. As kerosene became more expensive, there would likely be increased use of traditional fuels among the urban poor, with consequent increased exposures to indoor air pollution and increased deforestation. On the other hand, if the APM were not dismantled, massive oil pool deficits would continue, and opportunities would be lost in social spending. Lastly, there would be no incentives for the motor vehicle industry to improve fuel efficiencies. The foregoing demonstrates the importance of considering system-wide impacts of transport policies.

Supplies and the Police Department have neither the equipment nor the personnel to effectively deal with fuel adulteration. While the police are mandated to book vehicles with invalid in-use emissions test certificates, they do not have the resources to even deal effectively with traffic violations. The police, and enforcement officials generally, are highly susceptible to corruption. This is not surprising, given their paltry salaries. The vast majority of police personnel in Delhi reportedly live with their families in slums (Author's interviews 1997; NCTD 1997a).[14]

As discussed, and as will be demonstrated in Chapter VI, the quality of public transit service critically influences private (including M2W) vehicle use and emissions. But even the Delhi Transport Corporation (DTC), the state-owned public bus transit operator in Delhi, has experienced ever increasing gaps between revenues and expenditures. DTC, along with Calcutta's bus transit operator, has the lowest revenue and the highest costs per vehicle-kilometre in the country. The Corporation is continually dependent on government loans, which can realistically never be repaid, for maintaining operations to meet ever growing demand. Its buses are poorly maintained, and frequently non-operational.[15] DTC runs no more than 15% of Delhi's buses. The vast majority of buses in Delhi are owned and operated by a large number of private parties. These private operators have to operate under conditions of high capital costs, regulated fares, and extremely slender margins, and therefore have little ability or incentive (given lax inspection) to properly maintain their vehicles for passenger comfort and convenience or emissions, let alone invest in improved vehicle technology (ASRTU/CIRT 1997; Chima 1997; Duleep 1994; Gambhir and Narayan 1992).

The agency responsible for land use, DDA, lacks the resources to control unplanned development in fringe areas. The National Capital Region (NCR), formed in 1985 to achieve planned development in these areas on land to be given by neighbouring states, and with central government funding, has been ineffective. The funds have not been forthcoming, and

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[14] There is a general inability to control polluting activities. While only 3700 diesel generating sets have been licensed, about 150,000 power generators are estimated to be operating in Delhi, as power supply falls short of demand. Notices to close/relocate polluting industries, pursuant to court orders, have not been effective (CSE 1996).

[15] This is a fate apparently shared by many LIC city bus fleets. Supply shortage causes buses to be heavily over-loaded, leading to maintenance problems, which in turn exacerbate the supply situation (Sathaye, Tyler and Goldman 1994).

the states, increasingly assertive, have in fact encouraged massive private development on these lands to take advantage of their proximity to Delhi, thus aggravating the transport situation there. DDA's own financial position, and therefore its ability to control land use, has been further weakened because it has not collected betterment charges from private developers (Chandra 1997; Misra et al 1998; NCTD 1997a and d; Singh 1997b).

Thus, in addition to the jurisdictional complexity discussed in the previous section, the institutional setting related to transport emissions prevention and control in the Indian context is characterized by serious barriers and constraints.

4.5 POLICY-MAKING AND IMPLEMENTATION: ACTORS' INTERACTIONS

This section discusses actors' agendas and interactions related to policy-making and implementation for prevention and control of transport air pollution in the Indian context. The discussion focuses on vehicle emissions and fuel and oil quality standards, monitoring of in-use emissions, and vehicle scrappage. The implications of the policy-making and implementation process for policy effectiveness are explored, especially in light of the institutional barriers and constraints discussed earlier.

Each of the principal actors brings to this issue positions that reflect its agendas, interests and concerns. Each stresses the importance of action on those aspects of the multi-dimensional transport air pollution problem for which they are not responsible. This situation is not surprising because, for each of them, taking action involves spending considerable amounts of money and effort, which they are ill-equipped to do, given the constraints they face. Government and the state-owned fuel industry stress the need to tighten new vehicle emission standards, improve vehicle technologies, and scrap aging vehicles. Meanwhile, the vehicle industry stresses the need to improve fuel quality and traffic management, enforce vehicle scrappage, and implement effective I&M programmes. Interestingly in this connection, while the "experts" reportedly claim that transport emissions can be reduced 70-90% by engine modifications alone, a representative of AIAM, the vehicle industry association, believes fuel quality improvements, traffic management and I&M will together produce a 70% reduction (India Today 1996; Shah 1996).

The Indian motor vehicle industry has felt little pressure until recently to improve vehicle technology, because it was largely insulated from international competition. But with the advent of economic liberalization in the early 1990s (and deteriorating urban air quality), the industry has been compelled to do so (Biswas in CSE 1996). As Anil Agarwal observes, the motor vehicle industry "can and will respond .... if we are prepared to turn the heat on them", or if they have no choice (CSE 1996). Interestingly, while liberalization is leading to increased motor vehicle activity, it is also helping improve vehicle performance, including emissions, at least on a vehicle-kilometre basis.[16] Another strong motivation for the Indian vehicle industry to reduce emissions (and improve fuel economy and vehicle performance) is the potentially large export market, which demands competitively priced vehicles with these parameters conforming to international standards (Author's interviews 1997; CSE 1996). Interestingly though, while this motivation would be strong in the case of Indian cars and trucks, which lag behind international standards, it would not be so for M2W vehicles, for which emission standards are already some of the most stringent globally, as discussed in Chapter III.[17]

4.5.1 Vehicle Emission Standards and Fuel Quality Improvements

The process of developing Indian vehicle emissions standards, and correspondingly tightening fuel and oil quality standards, started as early as the late 1980s (IIP 1994; MoEF 1991). And as discussed, progressively stringent standards have been stipulated and implemented since 1991 (Appendices III and IV). However, the vehicle manufacturers and other observers have serious doubts that these standards have a rational basis (Author's interviews 1997). As discussed in Chapters II and III, there is no reliable accounting of the contribution of various transport modes and system components, or indeed of other sectors, to air pollutant emissions and related health effects.[18] Further, there have been no studies of the likely impacts of the

[16] A similar example from another sector is the Indian leather industry rapidly changing to cleaner dyes once the German market indicated it would not buy leather goods with azodyes (CSE 1996).

[17] At the same time, Indian M2W vehicle manufacturers are well positioned to exploit the export market, at least in terms of emission standards.

[18] Also, it is likely that transport is less important than other sources in terms of exposures to critical pollutants, which is the key factor in terms of health effects. As for the epidemiological studies that have been conducted (such as Cropper et al 1997), while it is likely that respiratory diseases and deaths are under-reported, it is also the case that indoor, not outdoor, air pollution may be the most important cause. However, in the Indian context, outdoor air pollution has a greater influence on indoor levels than in the West.

standards (and of technologies to achieve them) over the long term, in terms of air pollutant emissions and related health effects, and other policy impacts.

Even the Mathur Committee Report (MoEF 1991), which forms the basis of vehicle emission standards over the last decade, acknowledged that since no reliable emissions inventories exist, the Committee's recommendations were based on standards in force in other countries, and on technological availability or achievability. While ECE standards were recommended for cars, standards for M2W vehicles were based on their large numbers, and were suitably tightened for subsequent years, so as to maintain the same pollution loading from these vehicles as in the early 1990s (Author's interviews 1997; MoEF 1991).[19] Impacts such as costs to vehicle users and industry profitability were raised (Singhal 1996) but not considered in any great detail.

The perceived, if not actual, lack of a rational basis for vehicle emission standards causes vehicle manufacturers (and other actors) to feel that they are being blamed for somebody else's problem (Author's interviews 1997). This not only reduces their commitment to environmental action, but also allows them to push their own agendas, as discussed. Most importantly, from a public policy standpoint, it is not clear that the most stringent standards are applied to the most important pollutants, or (transport and other) sources.[20] Motor vehicle industry representatives interviewed by the author pointed out that they are agreeable to progressively tightened emission standards, provided these are adequately justified. The M2W industry feels particularly put upon, because they believe decision makers are responding merely to the high visibility of these vehicles, by virtue of their large numbers, and the equally visible nature of their exhaust. They also argue, with justification, that in terms of HC emissions, sources such as the fuel system evaporative losses and solvent use are ignored (Author's interviews 1997; Nandi 1996b).

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[19] This approach has some justification. Notwithstanding the need to reflect local realities (as discussed in Chapter III), there is little practical sense in developing new standards (and accompanying test procedures) for cars, especially in small markets like India (Faiz et al 1992). In the case of M2W vehicles, India is the dominant market, and these vehicles are an important contributor to transport emissions.

[20] The lack of reliable knowledge of which sector is responsible for how much of which pollutant, has other interesting consequences. In response to Supreme Court rulings closing industrial units in Delhi, workers' groups (quoting CPCB data) claimed transport was the main culprit, and demanded curbs on private vehicles (Times of India 1997a).

Insofar as actually implementing vehicle emission standards, recall that while MoEF recommends them, based on the work of consultative committees, MoST notifies and enforces them. Similarly, while MoEF has recently taken the lead in tightening fuel and oil quality standards, it is MoPNG and the fuel manufacturers that actually implement them. At least until recently, the working relationship between these principal actors, and the vehicle manufacturers, has been conflict-ridden (Author's interviews 1997).

Both the vehicle and fuel manufacturers have attempted to have standards diluted. In the case of vehicle manufacturers, this has applied to the emission standards themselves, as well as other stipulations. For example, when the 1996 emission standards (themselves a diluted version of the Mathur Committee recommendations), were notified in 1993, the vehicle manufacturers successfully protested the cold start and emissions durability requirements on cars, on the grounds that they could not meet these requirements with carbureted engines. The cold start requirement, which they had wanted deferred until 2000, was effected in 1998. The emissions durability requirement is expected to come into force in 2000, in the form of a "deterioration factor" to be applied to the type approval test standards, but there is no clear stipulation as to the service life over which this deterioration may take place. Evaporative and crankcase emission requirements for cars were also sought to be deferred, but these came into effect in 1996. The M2W vehicle emissions durability requirement (recommended by MoEF) was apparently deleted by MoST, at AIAM's request (Author's interviews 1997; Central Motor Vehicles (Amendment) Rules 1995; AIAM 1996a; AIAM 1996b; CSE 1996; MoST 1996).

As for the emission standards proposed for 2000, the motor vehicle industry, through the AIAM (AIAM 1996a and b) suggested that the European driving cycle be followed (with maximum speed in the extra urban driving cycle limited to 90 km/h), rather than the Indian cycle with cold start (this is rather curious, given that the ECE is more stringent than the Indian cycle, and involves cold start). They also called for more stringent fuel quality standards than those that are expected to be implemented (0.05% sulphur, and 0.005 g/L lead), and for these stipulations to be notified along with the emission standards. Their justification for these demands was that these would be necessary to enable use of fuel-injected engines, which would be required to meet the 2000 emission standards and emissions

durability requirements for cars. The M2W vehicle emissions durability issue had not been resolved until late 1997 (Author's interviews 1997; AIAM 1996a and b; CSE 1996 and 1997).

The vehicle industry originally agreed to meet the 1996 car emission standards through engine design changes, but then claimed they could do so only with catalytic converters, which of course would require unleaded gasoline. The industry insisted that unleaded gasoline be made available country-wide, thus passing the buck to MoPNG and the refineries. Meanwhile, the Supreme Court ruled in 1994 that all new cars in the major cities would have to be fitted with catalytic converters from April 1995. The refineries accepted the challenge and provided unleaded fuel in the major cities in 1995, and in a phased manner country-wide thereafter (Appendix IV) (Author's interviews; CSE 1996).

Things took a slightly different course in the case of M2W vehicles. It appears that the M2W vehicle manufacturers originally considered catalytic converters to meet the 1996 norms, but decided eventually on the engine design route. In 1996, the Supreme Court-appointed Saikia Committee recommended that converters be required to be fitted on all new as well as in-use M2W and M3W vehicles in the major cities, from 1997 (Saikia Committee 1997a). AIAM, the vehicle industry association, argued strenuously against catalytic converters, citing converter durability concerns on M2W vehicles, and other implementation issues (Nandi 1996a). MoEF supported the Saikia Committee recommendation in principle, but suggested implementation in 1998, when unleaded gasoline would be available in all state capitals. But MoST and MoI were of the view that government should mandate only performance standards, not technologies, and urged a go-slow approach in forcing vehicle manufacturers to fit catalytic converters on M2W vehicles. MoEF eventually backtracked, and restricted unleaded gasoline in the major cities to new cars with catalytic converters, because of concerns over fuel supply problems and high benzene levels in unleaded gasoline (Author's interviews 1997; CSE 1997; Lal 1996b; Lal 1996d; Mehta 1993; Nandi 1996 a and b; Saikia Committee 1997a; Supreme Court 1996b). The foregoing demonstrates the conflicting, and rapidly shifting, positions of various government departments and other actors in the matter.

4.5.2 In-use Vehicle Emissions Monitoring and Control

As indicated, private fuel dispensing stations, licensed by the Transport Department of the NCTD, inspect in-use vehicle emissions in Delhi. Vehicles are required to be tested as frequently as every three months. Testing is by means of a no-load road-side pollution check, on the basis of which "Pollution Under Control" (PUC) stickers are issued. In Chapter III, we discussed the technical shortcomings of no-load testing, particularly in the case of vehicles with catalytic converters. Quite apart from this, the system is riddled with loopholes and plagued by corruption. It is reportedly common for people to purchase stickers in bulk, often at a discount, and without so much as taking the vehicles to the inspection centre. Because the fuel dispensing stations also have the authority to repair non-complying vehicles, they have an incentive to needlessly claim that vehicles require adjustments to pass, for which they charge an additional fee, without a receipt. Because of the adjustments, there are frequent driveability problems, which users typically rectify by re-adjusting their carburetors immediately afterward, and before the next test (Author's interviews 1997).

The inability of the Transport Department to either monitor the performance of the fuel dispensing stations, or to check vehicles for valid and up-to-date PUCs, because of severe staffing shortages, has already been alluded to. The situation is only made worse by the fact that it is extremely difficult to ensure that users will in fact present their vehicles for inspection, since vehicles are currently required to be registered only when purchased, and there is no linkage between registration and inspection.[21] Finally in this regard, a large number of vehicles registered outside Delhi ply in the city daily. These vehicles are not required to undergo in-use emissions testing in the states in which they are registered (Dhingra 1997).

Various other steps to control in-use emissions have been of little avail. The Delhi government launched surprise road-checks in 1997, and began to fine vehicle owners with polluting vehicles, even those with a valid PUC sticker. Vehicle users were reportedly

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[21] All new vehicle registrations have been computerized since around 1994, and records of traffic and other violations have begun to be recorded in the database. But PUC test results cannot be recorded, because of the decentralized system, and also all in-use vehicles are yet to be included. By law, personal vehicles are required to be re-registered (only) after 15 years, but this rarely happens, and it is impossible to enforce, because of lack of records and adequate enforcement resources. Another barrier in the Indian context is the fact that automobile insurance is not mandatory. The MV Act is proposed to be amended to require registration and inspection periodically after purchase depending on the vehicle category (Author's interviews 1997).

subjected to a great deal of harassment by inspectors and the police. The fines were ruled illegal by the Delhi High Court. The petitioner argued that, because test equipment were situated at multiple locations, and were seldom properly calibrated, site-to-site measurement variations were common. It turned out, in fact, that the machines had not even been certified by the Weights and Measures Department. Under these circumstances, the petitioner argued, in-use emissions testing was meaningless, and fines should be imposed on those issuing the certificates, not on vehicle users (CSE/DTE 1997b; Delhi Midday 1997; Indian Express 1997; NCTD 1997b; Times of India 1997b; Times of India 1997e). In 1997, the Delhi government decreed that users with vehicles without valid stickers would not be allowed to purchase any fuel (Times of India 1997c). This measure had to be abandoned shortly after introduction, because literally thousands lined up at fuel dispensing stations, causing serious traffic jams. In any case, the measure would not have succeeded, because the stations could not possibly refuse to sell fuel for very long.

All in all, the in-use emissions monitoring and enforcement regime currently in place in Delhi (and other Indian cities), combining as it does a decentralized test-repair system[22] and no-load testing, is burdensome, both for users and the administrators, as well as ineffective in achieving its intended purpose. Interestingly in this regard, when there were only a few test centres, users were at the mercy of the operators, and there were many false failures. Now, there are many false passes because there are many test stations all over the city, and vehicle users can take their "business" elsewhere if their vehicles are not passed. All that the current in-use emission testing appears to do is create the illusion that something is being done about the air pollution problem. Anil Agarwal (CSE 1996) believes the system to be no more than an attempt to shield the government (and industry) from any blame, and to shift the onus on to vehicle users. This impression is only reinforced by the fact that buses and trucks, which are significant polluters, and government vehicles, are hardly if ever checked. A recent study in Calcutta revealed that many polluting vehicles sported PUC stickers, and that state-owned

[22] Decentralized test-repair systems invite fraud, both against users and the system, and improper inspections. California's is a classic example. To deter fraud, the state has had to resort to excessively complex and expensive automation, and extensive audits. Despite these measures, improper inspection (and repairs) run as high as 50% (Bhattacharyya 2000; Faiz et al 1996).

buses were among the biggest defaulters (Author's interviews 1997; CSE 1996; Priti Kumar 1997; Times of India 1997d).[23]

4.5.3 Vehicle Scrappage

Old vehicles, including two-stroke M2W vehicles, are proposed to be scrapped in a phased manner in Delhi (Appendix VII). Mandated vehicle scrappage would undoubtedly be popular with the motor vehicle industry. It remains to be seen, however, if the rules announced will actually be implemented, and how effective implementation will be. The rules (Appendix VII; MoEF 1997b; NCTD 1997c: NCTD 1997d; Roy Paul 1997) are confusing, convoluted, and unrealistic, particularly with respect to M3W vehicles.[24] There is likely to be strong vehicle user resistance to mandated scrappage, given the absence of viable options to personal motorized vehicles, as discussed in Chapter VI. M2W vehicles are typically used for as long as 20 years, and users expect to get a reasonable re-sale value when they do dispose of them in the second-hand markets that thrive in Delhi and elsewhere (Author's interviews 1997). An effective scrappage programme requires the ability to track down and penalize non-compliant vehicle users, but institutional mechanisms for these are lacking, as we have seen in the case of in-use emissions monitoring and control. Lastly, given the likely resistance from vehicle users, implementing scrappage will call for a considerable amount of political commitment. Late in 1997, the NCTD governments reportedly backed off on its decision to phase out old vehicles, particularly those in the commercial sector, because of the upcoming elections (CSE/DTE 1997c).

4.5.4 Public Interest Litigation and the Supreme Court

The increasingly important role of public interest litigation and of the Supreme Court has already been alluded to. In this section, we critically examine these roles. The public interest

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[23] World-wide experience has shown that effective monitoring and control of in-use emissions would require loaded tests, which give substantially better correlation with real-life emissions, and centralized inspections done in high volume facilities operated by government or by competitively selected operators regulated by government, with decentralized repair (Bhattacharyya 2000; Faiz et al 1992 and 1996; Radian 1994). A computerized system to link registrations with inspections, periodic re-registrations, and the administrative ability to penalize non-compliant users, would also be needed.

[24] Even with regard to M2W vehicles, it is not clear if the rules will apply to two-strokes fitted with catalytic converters after 2007.

petition calling for regulation of pollution in Delhi was filed in 1985 (CSE 1997; Mehta 1993; Supreme Court 1996a-g). The Court has sat several times to hear submissions and deliver judgments on this petition, particularly since the early 1990s. Senior officials representing various government agencies and vehicle and fuel manufacturers, and other interested parties, have been called frequently to make submissions to the Court on various matters related to the petition. Indeed, just one official in MoEF appeared before the Court five times in as many months in 1996, by the author's counting (Author's interviews 1997; Lal 1996a-d).

An examination of the proceedings related to transport air pollution (Chandini 1996; Lal 1996a-d; Mehta 1993; Nandi 1996a and b; Saikia Committee 1997a and b; Supreme Court 1996a-g; Supreme Court 1997a and b) reveals that the Supreme court moved from largely enforcing the law, in terms of ordering the notification of emission standards, in the early 1990s, to becoming involved in and passing judgments on purely technical issues, as opposed to legal and procedural matters. Not only that, the Court has, as already indicated, become increasingly involved in the implementation of its judgments, co-ordinating action by various agencies, refereeing inter-agency conflicts, and monitoring progress, sometimes as frequently as every week.

Because of the technical complexity of the subject matter, the Court directed that a committee be appointed to advise them (Saikia Committee 1997a and b). This committee, headed by a retired Supreme Court judge, was charged with assessing vehicle pollution control technologies available worldwide, and identifying low-cost alternatives to minimize motor vehicular pollution over the long term. Given its sweeping mandate, and the Court's activism with regard to transport air pollution, this Committee's powers to influence policy were potentially great. Further, given the technically complex, and multi-dimensional nature of the problem, one would have expected this Committee to be comprised of persons with a wide range of expertise, and capable of giving competent and independent advice. However, the committee comprised, besides the retired Supreme Court judge, the lawyer who brought the petition in the first place, a representative of AIAM, the motor vehicle industry association, and the then Chair of the CPCB.

The Saikia Committee and the Court proceedings addressed many issues related to transport air pollution. However, the following discussion will restrict itself to their roles as they related to catalytic converters on M2W (and M3W) vehicles, and alternate fuels.

That the Saikia Committee recommended fitment of catalytic converters on all new as well as in-use M2W and M3W vehicles in the major cities, and the conflicting and shifting positions of various agencies and actors in this matter, have already been alluded to. The Committee's report (Saikia Committee 1997a) appears to show that their recommendations were made on the basis of a visit to one Canadian company. The report does refer to concerns over implementation issues such as catalyst durability and vehicle user safety (due to high operating temperatures), particularly on in-use vehicles, only to reject them out of hand, on the basis of assurances from the Canadian company that these concerns were baseless. Other critically important implementation issues, such as the lack of widespread availability of unleaded gasoline, catalyst contamination by lubricating oil, which then contained phosphorus, vehicle performance loss, the lack of effective in-use vehicle emissions monitoring, and long-term replacement costs, were not considered. Indeed, with regard to industry concerns over liability, the Committee took the position that catalytic converters ought to be considered merely as a vehicle part, whose fitment industry could not in good conscience object to on in-use vehicles, since, in the Committee's view, industry did not appear to take responsibility for pollution. Left undefended was the position that government could mandate the use of catalytic converters, without anyone being responsible for any mishaps users might suffer due to their use (Saikia Committee 1997a).

Not surprisingly, the AIAM representative did not sign the report. Another interesting aspect of the Committee's recommendation is that it may have been prompted by the impression on their (and CPCB's) part that unleaded gasoline required the use of catalytic converters, rather than the other way around, and due to concern over elevated benzene levels in unleaded gasoline (Lal 1996b; Nandi 1996a and b; Saikia Committee 1997b).

At the same time that the Saikia Committee was proposing implementation of catalytic converters on all M2W and M3W vehicles in the major cities, they were also recommending conversion of all M3W vehicles in Delhi to run on propane (Saikia Committee 1997b). As in the case of catalytic converters, this recommendation was made based on a visit to a Canadian

company, who assured the Committee that they could easily convert Delhi's 80,000 M3W vehicles in three years, and also on the basis of the fact that propane was used as a transport fuel in many countries. The Committee went so far as to recommended a specific technology for propane conversion marketed by the Canadian company (Saikia Committee 1997a and 1997b). Serious concerns were raised by various government agencies (MoPNG 1996; Kanade 1996), relating to technology reliability and performance, lack of resources for importation, storage, transport and distribution, especially given emerging demands related to unleaded gasoline and CNG (see below), lack of resources for and regulation of vehicle conversion and dispensing sites, and public safety and liability. In particular, it was pointed out that there were severe constraints in meeting even current requirements of liquefied petroleum gas (LPG) for domestic cooking, a priority in terms of avoiding indoor air pollution and deforestation, and that LPG had to be imported at volatile prices. Further, since it was highly subsidized, there were concerns about LPG being diverted from domestic cooking to transport uses, with safety implications.

Interestingly, the Saikia Committee did acknowledge severe propane availability constraints, and also a law that specifically prohibits the use of propane as a transport fuel. Notwithstanding this, they recommended the fuel, seemingly with little regard to the implementation issues discussed above, and also matters such as flexibility of operation, and poor vehicle maintenance. Based on the Committee's recommendation, the Supreme Court ordered a pilot project to convert 50 M3W and 50 M2W vehicles to propane, and ordered various national and local government agencies to extend their co-operation to the Canadian company. Further, the Court ordered the government to study the possibility of importing propane for the purpose of converting all M3W and even M2W vehicles country-wide (Saikia Committee 1997a and 1997b; Supreme Court 1996c and d).[25]

The Saikia Committee recommended the use of compressed natural gas (CNG) as well (Saikia Committee 1997b). Several concerns were raised, including the lack of resources for ensuring widespread fuel availability, of workshops capable of carrying out conversions, and

[25] The Supreme Court ordered in December 1996 that the pilot tests be completed in a mere four months. However, the company had not conducted the tests even as late as November 1997. The Court extended the deadline for the tests until March 1998. The company claimed bureaucratic delays and lack of propane availability for their inability to complete the tests (CSE/DTE 1997a).

of appropriate ignition systems, and vehicle performance loss and reduced payload. An interesting constraint that was indicated was the inability to transport large quantities of CNG owing to truck weight restrictions because of road capacity limitations, an issue discussed in Chapter III (Author's interviews 1997; Lal 1995a; Kanade 1996). But the Supreme Court ordered that all government vehicles in Delhi be converted to CNG or be fitted with catalytic converters, on a "war footing", within a mere six months, or else be scrapped. The Court was actually also considering ordering the use of CNG in all old cars in Delhi (Lal 1996c; Saikia Committee 1997b; Supreme Court 1996a and g; Supreme Court 1997a). But even the limited project to convert government vehicles quickly became a fiasco, because of the high capital costs of conversion kits, and the lack of a widespread distribution network. Three of eight CNG stations had apparently been non-functional for two years (CPCB 1997). Additionally, there was a lack of commitment on the part of the drivers, because they could no longer siphon off money on fuel purchases, as they used to be able to do with gasoline. Only around 1,000 vehicles in Delhi were converted, and most of these were converted back to gasoline (Author's interviews 1997).

Despite the foregoing, the Supreme Court ordered in July 1998 that all eight-year old buses in Delhi, both publicly and privately owned, be converted to CNG by April 2000. Not only that, the Court ordered DTC to augment its fleet to 10,000 by April 2001, and to ensure that all the new buses also operate on CNG. Apart from the issues discussed above, the indigenous bus manufacturers have expressed their inability to meet such a requirement at such short notice. And DTC have apparently just asked for an extension of the Court's deadline by five years (Agarwal 2000).

To conclude this section: technological policy development is of necessity a painstaking, time-consuming process involving large numbers of people in a wide range of disciplines, and is best conducted outside the glare of publicity. As it is, government agencies in the Indian context are severely constrained in terms of human and other resources. Given this, the time and effort decision makers appear to be spending on the public interest litigation process can hardly make for carefully designed and executed policy.

There is an useful role for public interest litigation and for judicial activism in the Indian context, given its many unaddressed injustices, and executive lethargy and inability. However,

judging from the results that it has actually achieved, it is difficult to conclude that the public interest litigation process has been particularly effective. The process certainly has helped raise awareness, and forced governments to take action, but it has been characterized by decisions that have not always been well-informed, that have not taken into account long-term consequences, and that have often been simply unimplementable. Further, many decisions have been made that would have been best left to the market. Quite apart from their implications for long-term policy effectiveness, such decisions call into question the credibility of the Court, an important issue in itself. Lastly, the process has potential for abuse. The CSE was apparently approached by private companies to launch petitions before the Court to promote their technologies (CSE 1997).

A critical appraisal of the utility of the public interest litigation process, and how it can be made more effective, needs to be undertaken urgently. In particular, the issue of how the process can better address and reconcile complex technical and social issues, needs to be addressed. As Prem Kumar, the then Chief Metropolitan Magistrate of Delhi himself observed, a major challenge for the Court is to access reliable, competent, independent, dispassionate technical advice (Prem Kumar 1997). This challenge is perhaps best illustrated by government agencies themselves quoting data in submissions to the Supreme Court that diesels are responsible for 100% of PM emissions due to motor vehicles (Dhingra 1996). The challenge in terms of addressing social issues is demonstrated by the fact that workers unions', in addition to claiming that motor vehicles were responsible for the bulk of air pollution in Delhi, as already discussed, called for a review of the Court's order to close or relocate polluting industries in Delhi, on the grounds that it would result in 700,000 workers becoming unemployed and displaced (Times of India 1997a).

4.5.5 NGOs and the Media

Representative (and responsive) government structures, particularly at the local level, are necessary for effective urban environmental management, but even these are unlikely to implement environmental policies without strong democratic pressure, as the European and North American experience have shown. Unfortunately, both representative local governments and strong public pressure are lacking in India and other LICs. As Mr. Biswas of

the CPCB observes: "We talk about the environment but when it comes to paying for it, we're not willing to pay even a single extra paisa" (CSE 1996). While the constituency opposing air pollution control is economically and politically powerful, that in favour of it is dispersed, poorly informed, and insufficiently motivated. Further, as discussed in Chapters II and III, current air pollution, particularly from transport, is complex in its origins and effects (Bates 1994; Brandon and Ramankutty 1993; Douglass and Lee 1996; Faiz et al 1992; Hardoy and Satterthwaite 1991; Hardoy, Mitlin and Satterthwaite 1992; Mehta 1997). Given all of this, informed public awareness is imperative. Government obviously has an important role in this matter, in terms of the causes and effects of air pollution, and of possible control actions and potential trade-offs, but so do NGOs and the media. A particularly important role that these institutions can play is that of serving as "watch dogs", by conducting and broadcasting the results of investigations and studies that serve as a counterfoil to those conducted by government agencies, and critique government policies.

Many Indian NGOs, such as CSE, have played and continue to play a vital role in building public awareness of and public support for environmental action, and critiquing government policy. CSE's report "Slow Murder--The Deadly Story of Vehicular Pollution in India" (CSE 1996) is but one among many such efforts, both by the CSE as well as other NGOs. But the NGOs have been less successful in terms of independent and critical analysis. Anil Agarwal, the founder and head of CSE (who has been quoted several times in this Chapter) himself admits that "the Indian NGO sector remains relatively weak on pollution-related issues (because of) their reluctance and inability to deal with technical issues" (CSE 1996). Further, the NGOs often tend to sensationalize issues, take unrealistic positions, and, while there is much to criticize government and industry for, be a little too harshly critical.

This is true of even Agarwal and the CSE. For example, Agarwal accuses Rahul Bajaj, the chief executive of Bajaj Auto, India's largest M2W and M3W vehicle maker, as the country's "environmental criminal number one", because these vehicles are the "leading polluter on Indian roads", responsible for "much of the urban pollution in India".[26] He has also called for the Indian Council of Medical Research to be renamed the Indian Council for State-sponsored

[26] At the same time, Agarwal concedes that he found Rahul Bajaj's eagerness for dialogue refreshing, and that he understands the latter's frustration, considering that a wide range of issues need to dealt with, not all of which the vehicle industry can be held responsible for.

Promotion of Slow Murder, because of its "neglect of environmental health", and has labeled the Ministry of Petroleum and Natural Gas, and the refineries, "environmental criminals of the first order" (CSE 1996; CSE 1997). Such characterizations are not only unduly harsh, given the very real constraints that these agencies face, but are also unproductive. M2W and M3W vehicles are undoubtedly major contributors to transport air pollution, especially on a passenger-kilometre basis. But they are by no means the primary contributor to transport air pollutant emissions, let alone urban air pollution, as discussed in Chapter II. Even if M2W and M3W vehicles were the primary contributor to urban air pollution, their manufacturers cannot justifiably be called criminals. After all, they have been fulfilling the mobility needs of millions of people for decades, and it is only since the 1980s that urban air pollution has become an issue.

Some of the analysis in CSE documents (CSE 1996; CSE 1997; CSE/DTE 1997d; Priti Kumar et al 1997) shows a lack of clear thinking. Just a few examples follow. Not only are Brandon and Hommann's 1991-92 estimates of health effects due to air pollution in Delhi and other cities, which were based on US dose-response data, reported uncritically,[27] these estimates and extrapolations for subsequent years are presented as actual facts, rather than as merely estimates or projections (CSE 1996; CSE 1997; Priti Kumar et al 1997). In this connection, it is worth noting that even the hospital admissions that Brandon and Hommann estimated for 1992, based on US dose-response data, might not have actually occurred in Delhi. Delhi's poor air quality is explained on the grounds that motor vehicles account for 64% of its air pollution, and that motor vehicle emissions in the city exceed those in Bangalore, Calcutta and Mumbai put together (CSE 1996). Apart from the desirability of evaluating sectoral contributions on a pollutant-by-pollutant basis, and ideally in terms of exposure to critical pollutants, these "facts" by themselves do not support the stated conclusion. Similarly, Priti Kumar et al (1997) attribute the "lion's share" of Pune's increased SPM to two-stroke engines, since these vehicles make up more than 67% of the city's motor vehicles, and because of the lack of polluting industries and thermal power plants in Pune. In the same article, Priti Kumar et al (1997) justify their subjective assessment that air quality is

[27] See Chapter II for a discussion of the problems associated with making such estimates, and the discrepancies between those by Brandon and Hommann (1995), which were based on US dose-response data, and those by Cropper et al (1997), which related daily PM levels to daily mortalities in Delhi

much worse than that indicated by CPCB air quality data, on the grounds that this data does not reflect vehicular emissions. Air quality data may be inaccurate, but cannot exclude any source. The benefits of using catalytic converters with Indian unleaded fuel is questioned, on the grounds that benzene emissions will increase (CSE 1996). This is not why catalytic converters are problematic (benzene is a reactive hydrocarbon, and is treated in the converter). The problem is the use of unleaded fuel with high benzene levels without converters.

Lastly, contradictory figures are stated in various CSE documents for the transport sector's contribution to air pollutant emissions. Whereas M2W and M3W vehicles are labeled the most polluting motor vehicles in Delhi (CSE 1996), Priti Kumar et al (1997) uncritically report a CPCB study that purports to show that diesel vehicles in the city account for 100% of particulate emissions from motor vehicles, which is definitely not the case (see Chapters II and III).

Media reporting on environmental pollution, which is becoming increasingly frequent, tends to focus, as does public policy attention, largely on outdoor urban air pollution, and the role of transport in it.[28] Unfortunately, the reporting is often sensationalistic, confusing, misleading, and even erroneous. Facts and opinions as to air pollution effects, the role of transport, and the potential of various control measures, are often reported uncritically. Examples abound, but following are only a few, all from the same article in a leading national news magazine: "close to 30% of vehicular emissions can be reduced if low quality fuel is improved"; "the level of sulphur and carbon in fuel is more than what it should be. Excess sulphur in diesel causes smokier exhausts; the sulphur is unburnt"; "Indian automobile fuel is of poor quality and contains sulphur which does not burn but only adds to pollution -- despite the best of combustion engines"; (experts say that) "engine modifications alone can reduce 70-90% of auto emissions. Only the last 10% clean-up needs a catalytic converter" and "good fuel reduces emissions by 10%, another 10% will come from traffic (moving at higher speeds), and good maintenance will reduce emissions by a whopping 50%. These should cut down three-fourths of emissions" (India Today 1996). Rawat (1997) quotes an environmentalist as

[28] The media discusses road accidents only as *incidents*, especially when catastrophes occur -- as in the case of a school bus plunging into the Jamuna in late 1997 -- but rarely as a major public health issue.

accusing the government of promoting catalytic converters to increase demand for unleaded fuel (this at a time when the refineries were hard put to meet even the supply requirements in the major cities). The same article shows M2W vehicles as being responsible for 77.7% of vehicular pollution, and trucks and buses for only 5.4%. Prasad (1999) goes one step further -- "two wheelers are the single biggest cause of urban pollution".

The many contradictory and confusing figures in media and NGO documents for the share of transport and individual transport modes in urban air pollution, which are in part a reflection of the lack of a reliable and comprehensive emissions inventory, does not bode well for increased public understanding, for purposive government action, or for cooperation from industry. And given the excessive focus on M2W vehicles, the concern expressed by the manufacturers of these vehicles, discussed earlier, is hardly surprising.

Brandon and Hommann's estimates of excess air pollution deaths in Delhi are reported widely (after all, even government agencies and NGOs quote them uncritically), and often as if these deaths were all due to motor vehicles. Even the international media is not immune. Delhi's transport minister is quoted as saying that "there (are) 2.7 million vehicles in New Delhi and the stifling pollution (is) killing some 7500 people every year" (Agence France Presse International News, 1997). The same day's Toronto Star also reported that "about 7500 people died premature deaths" resulting from air pollution, and that "mounting pollution in the Indian capital .... caused deformed and premature babies to be born to its residents, officials and analysts said this week." One wonders how it is possible to definitively trace such births to air pollution. While such reporting highlights an important issue, it does little for informed public awareness, reasoned public choices and responses, or effective policy action.

4.6 CONCLUSIONS

The transport air pollution problem is complex and multi-dimensional, and requires concerted action by a range of agencies. However, the institutional setting for policy making and implementation with regard to this issue in the Indian context is characterized by a multitude of actors and jurisdictions with fragmented, overlapping, and conflicting roles and responsibilities, and interests and agendas. The institutional setting is also characterized by restricted financial, technological, and administrative resources for the manufacture of clean

vehicles and fuels, adequate transport and public transit infrastructure, reliable information generation and policy analysis, and effective policy implementation, co-ordination, monitoring, and enforcement. Actors' interactions have been characterized, at least until recently, not only by the lack of co-ordination, but by conflict. MoEF, which is nominally responsible for co-ordinating policy, is in practice largely restricted in its ability to do so. Another important barrier to rapid and effective action is the fact that many of the key actors, being government agencies, are difficult to effectively regulate. A good example are the state-owned oil refineries and MoPNG effectively setting the fuel standards they will follow. Lastly, the absence of reliable information on the contribution of various modes and transport system components to air pollution, and therefore the lack of a rational basis for vehicle emission standards, contributes to reduced commitment on the part of vehicle manufacturers and other actors, and "passing the buck" and conflict.

Overall, it appears that the major actors postponed action for long. While the Mathur Committee recommendations were made in the early 1990s, the vehicle manufacturers only began to respond seriously in 1995. There was no clear programme to implement fuel quality improvements until about the same time, though lead phase-out in gasoline had been contemplated since 1988. Then, in the face of rapidly deteriorating air quality in Delhi and the other major cities, and rulings by an activist Supreme Court, hasty decisions requiring urgent action by various actors appear to have been made, with little attention to implementability, and with long-term consequences not having been thought through. Some decisions have not taken into account the lack of institutional support mechanisms that are essential to their success. While conveying the illusion of action, many of these decisions have been expensive and burdensome, yet have had not entirely positive outcomes. Mandating catalytic converters on new four-wheeled vehicles in the major cities from 1995, without appropriate engine fuel systems and widely available unleaded gasoline, fitting converters on M2W and M3W vehicles at short notice, which was considered but not implemented, conversion of government vehicles to CNG, vehicle scrappage rules, and the in-use emissions monitoring and control regime currently in place, are only some examples. While the lack of policy-analytic and other resources have contributed to this situation, it is likely that the confrontational and not always

well-informed public litigation process has played a role as well. Finally, the lack of reliable information has contributed to lack of public understanding, and misdirected public pressure.

Given all of above, the institutional setting appears to be unequal to the challenge of addressing transport air pollution, let alone transport impacts generally.

CHAPTER V

A POLICY ANALYTIC FRAMEWORK FOR PREVENTION AND CONTROL OF AIR POLLUTANT EMISSIONS FROM MOTORIZED TWO-WHEELED VEHICLES IN THE INDIAN CONTEXT

5.1 INTRODUCTION

Chapter II discussed the seriousness of the urban air pollution problem in Delhi and other Indian and LIC cities, the increasingly important contribution of transport to the problem, and the prominent role of M2W vehicles in transport air pollution. An argument was made for urgent policy action to prevent and control transport air pollution, while recognizing growing access and mobility needs, in the Indian and LIC contexts. Chapters III and IV showed that, while transport air pollution is multi-dimensional and complex, the institutional setting in the Indian context is characterized by fragmented and conflicting actors' roles, responsibilities and interactions, and restricted technological, financial and administrative resources. Chapter IV also argued that many current and proposed policies have not been sufficiently thought through in terms of their long-term effectiveness and other consequences, so that they could turn out to be expensive and burdensome, and yet do little to address transport air pollution.

In view of these concerns about policy effectiveness, there is a critical need for an analytical framework. This framework should reflect the complexity of, bring to bear an integrative perspective on, and enable systematic thinking with regard to, M2W vehicle (and more generally, transport) air pollution, while taking into account contextual needs and constraints. This need is particularly great, given the importance of long-term policy cost-effectiveness in view of multiple urgent demands on scarce institutional resources in the Indian context, the lack of effective co-ordination among key actors, and the tenuous linkages between the policy-analytic community and decision makers.

The objective of this chapter is to propose such a policy-analytic framework. The chapter first discusses the criteria for good policy analysis, both generally and with specific reference to transport air pollution in the Indian context. Then, it presents an analytical scheme based on these criteria, that prescribes a systematic methodology, with scope for re-examination and refinement, for:

- identification of pollutants, and vehicular and other related transportation system sources to be targeted, based on their contribution to critical health, welfare and environmental impacts;
- analysis of the technological, vehicle user behavioural and institutional contributory factors, and institutional barriers and constraints; and
- evaluation of policy alternatives based on long-term cost-effectiveness and other multiple objectives representing the interests and concerns of multiple stakeholders and affected groups, while explicitly considering contextual constraints, in-use realities, and other implementation issues.

Note that the second element in the above list was the subject of discussions in Chapters III and IV, but has been included here for the sake of completeness. Also, while the above policy-analytic framework applies to M2W vehicles, it may be adapted to accommodate other modes and transport system components. The chapter concludes by exploring the implications of the framework for policy-making and implementation, and outlining the policy-relevant research tasks conducted by the author on M2W vehicle emissions in Delhi. These tasks are the subject of subsequent dissertation chapters.

5.2 METHODOLOGY

This chapter integrates perspectives from the environmental policy analysis, urban transport and engineering literatures, and builds on analytic frameworks proposed with respect to transport air pollution in the current literature (Faiz et al 1992; Carbajo 1993; Shah, Nagpal and Brandon 1997). At the same time, the chapter attempts to address their shortcomings, by demonstrating the inappropriateness of the conventional welfare economics based cost-benefit approach for policy evaluation in the Indian context, and by considering urban transport and long-term implementation issues, and multiple objectives for multiple actors and affected groups, in estimating and valuing emissions and other policy impacts. Reference is also made to the scheme used by Bose (1993) to estimate air pollution from various personal motorized transport modes in Delhi.

The proposed framework is also informed by the in-depth interviews the author conducted with decision makers, vehicle and fuel industry representatives, academics and researchers, and M2W vehicle users. The interviews focused on a wide range of issues including technical and institutional factors contributing to emissions, actors' roles and interactions, considerations underlying current and proposed policies, likely impacts of policies on users and industry, institutional barriers and constraints, and M2W vehicle user choices and motivations relating to vehicle purchase, operation, maintenance and disposal, and their perspectives on various policy alternatives.

Interview protocols were approved by the Behavioural Research Ethics Board of the UBC Office of Research Services and Administration, and discussed with researchers at the Indian Institute of Technology, Delhi (IIT Delhi), the local institution with which the author was affiliated for the purposes of the IDRC award which partly funded the study. The Informed Consent Forms for the interviews are exhibited in Appendices VI and VIII.

5.3 CRITERIA FOR GOOD POLICY ANALYSIS

Environmental policy issues are inevitably characterized by complexity, uncertainty, conflicts between multiple stakeholders, and trade-offs. Several authors, including Keeney (1982; 1988a; 1992) and Morgan and Henrion (1990), have discussed what constitutes, and how to conduct, good policy analysis, including with respect to environmental issues. The following is a brief synthesis of their prescriptions.

The purpose of policy analysis is not to make a decision or arrive at the "right" solution. Rather, it is to inform decision making, so that good decisions can be made (Keeney 1982; Morgan and Henrion 1990). At the same time, policy analysis should provide a basis on which decisions that result from such analysis can be defended and communicated in public. Policy analysis must therefore be based on systematic thinking, and on sound principles that reasonable people can agree on. In this regard, according to Keeney (1988a), good policy analysis should be informed by what he calls *value-focused thinking*. Because the purpose of policy analysis is to help achieve objectives that reflect important values, it is important to clarify values early in the planning or policy analysis context. Value-focused thinking as applied to public policy problems would call for consideration of a broad range of societal

values, since such problems typically have a similarly broad range of implications for large sections of society and for future generations, and are typically characterized by multiple stakeholders with multiple, conflicting objectives (Keeney 1982; Keeney 1988a and b; Keeney and McDaniels 1999).

Policy analysis should also illuminate the complexity of the policy issue under consideration. An integrated rather than a reductionist approach should be followed, and multiple perspectives generated, for a full and deep understanding of issues and their inter-relationships (Ganapathy 1990; Fischer 1985; Keeney 1982; Morgan and Henrion 1990).

As a *process*, policy analysis should be self-reflective and iterative. Assumptions and value judgments which inevitably underlie every stage of the policy-analytic process, and thus ultimately determine policy choice, should be exposed, and their implications explored. Problem definition, policy objectives, evaluation criteria, choice of policy alternatives and so on, should be open to re-examination and refinement, in the light of experience, thereby enabling continual mutual learning and adaptive policy-making and implementation. The policy-analytic process should enable stakeholders and affected groups to become aware of complexities and trade-offs, and to help identify key issues over which they can carry on an informed debate leading to a mutually beneficial consensus (Anderson 1985; Argyris and Schön 1978; Forester 1979; Keeney 1982 and 1988; Wachs 1982 and 1985).

Last but not least, policy analysis and implementation should be sensitive to the needs, capabilities and constraints in the relevant context.

5.3.1 Important Contextual Characteristics

As discussed in Chapter IV, and in the introduction to this chapter, government agencies, vehicle and fuel manufacturing industries, and vehicle users in the Indian context are faced with restricted technological, financial and administrative resources for effective transport air pollution prevention and control.[1]

To foster long-term policy effectiveness, policy-making and implementation, and the analytic framework to support these activities, should reflect these constraints and realities.

[1] Another important contextual characteristic is the low awareness among vehicle users and vehicle servicing personnel, particularly in relation to advanced technologies. At the same time, the context is characterized by an abundance of inexpensive labour, which is a potential strength in cash-strapped countries such as India.

Ideally, policy analysis should evaluate policies as they would be implemented under real-life conditions, rather than in a friction-free world. Therefore, it would be desirable to explicitly consider in policy analysis issues that are typically relegated to the policy implementation phase. This approach will enable problems to be anticipated, and mechanisms to be put in place in a timely fashion to address them. Just as importantly, policies can be selected that minimize demands on, and are insensitive to these mechanisms not working optimally. Thus, in addition to the risk of failure being minimized, the chances of long-term success will be enhanced, given the realities of the Indian context. Lastly, in view of the lack of reliable information in the context, it would be desirable for policy analysis to explicitly consider uncertainties and variabilities, by employing expert judgments based on the best available information.

As noted in the previous chapters, although M2W vehicles are a significant contributor to transport emissions, they offer affordable mobility for millions of people with few other viable options. Therefore, the public policy challenge is, how to address M2W vehicle emissions while minimizing adverse policy impacts for vehicle users. In this regard, it is worth considering the distribution of M2W vehicle ownership and usage by user income in Delhi.

M2W Vehicle Ownership and Usage by Income Unsurprisingly, M2W vehicle ownership rates increase with income (Figure 5.1), and the higher income groups account for the bulk of M2W vehicle usage (Figure 5.2). However, the majority of M2W vehicle owning households earned less than INR (Indian Rupees) 5000 monthly (Figure 5.2). This was not a very large sum for a 4-5 person household in Delhi, even in 1991. Besides, most of these households were unlikely to have any other personal motorized vehicles.

Though users in households earning under INR 5000 relied on M2W vehicles for a smaller proportion of their trips than did higher income users (Figure 5.5), they accounted for the majority of M2W vehicle trips by all households (Figure 5.2). While only 17% of all work trips were performed on M2W vehicles (Figure 5.4), the bulk of all M2W vehicle trips were either work or business related (Figure 5.3). Further, while a much smaller percentage of work trips were conducted on M2W vehicles by the two lowest income groups than by higher income groups (Figure 5.5), 56% of all work trips on these vehicles were by users in households earning INR 5000 monthly or less. Finally, among those who used M2W vehicles

regularly, 30% spent below INR 250, and 68% spent INR 250-1000 monthly on transport. By contrast, 81% of regular car users spent less than INR 250, and only 14% spent INR 250-1000 monthly. It is likely that such a large percentage of car users spent so little, compared to M2W vehicle users, because of company travel expense reimbursements (RITES/ORG 1994).

The foregoing points show that, although higher income groups account for a considerable proportion of M2W vehicle ownership and usage, there is need to be concerned about policy impacts for low-income M2W vehicle users. Policies should attempt to avoid adverse impacts on the ability and cost of ownership and use. If policies do result in restricted ownership and usage, the benefits offered by M2W vehicles should as far as possible be preserved by other means. Restricting M2W vehicle ownership and use without providing viable options, such as accessible, frequent, convenient and affordable public transit service, would be to put M2W vehicle users to considerable hardship.

It should be noted that the RITES/ORG (1994) travel survey referred to is perhaps the most extensive conducted for Delhi, but it focused only on the residential population.[2] The homeless, institutional and floating populations were not covered. As many as 50% of the residential households surveyed resided in "bungalow/plot" type houses. Every single household surveyed had at least one employed person. Even so, more than a quarter of the households had an income lower than INR 2000 monthly, and three quarters had an income lower than INR 5000 monthly. Nearly 20% did not own even one personal motorized vehicle. Finally, residential households form a minority proportion of the total urban population, even in a relatively affluent city like Delhi, where every second person reportedly lives in a slum (Singh 1997b), as discussed in Chapter III. In view of this fact, it is likely that walking and cycling, and to a lesser extent public transit, account for a significantly higher share of trips in Delhi than the RITES/ORG (1994) survey would indicate.

Quite apart from policy impacts for M2W vehicle users, therefore, potential access and mobility losses and other impacts for the vast majority in the Indian context without recourse to motorized modes should be an important consideration in developing policies. Emission control policies can have distributional consequences, even as they improve conditions that

[2] The RITES/ORG (Rail India Technical and Economic Services/Operations Research Group) study was based on a survey of 18,721, or 1.1% of households in the Delhi Urban Area (DUA). The total number of individuals involved was 99,868 (RITES/ORG 1994).

affect the poor the most (Brandon and Ramankutty 1993; OECD 1994). More generally, there are several groups, including vehicle users,[3] vehicle and fuel manufacturers, and the urban poor, that are differentially affected by motorization, as well as by the policies to deal with its impacts. Further, these groups have varying degrees of power to influence the decision making process. Policy analysis and implementation should reflect these realities. Therefore, in addition to the other considerations discussed, policies should be evaluated in terms of multiple objectives representing the interests and concerns of multiple stakeholders and affected groups.

5.4 APPLYING SYSTEMATIC AND VALUE-FOCUSED THINKING TO M2W VEHICLE AIR POLLUTION IN THE INDIAN CONTEXT

Applying systematic and value-focused thinking to the problem of M2W vehicle air pollution in the Indian context would lead to the following line of reasoning. The policy objective is not M2W vehicle emissions prevention and control *per se*, but rather the minimization of adverse impacts due to these emissions. Thus, a systematic analysis and prioritization of the adverse impacts, the pollutants responsible for the impacts, and the M2W vehicular and related transport system sources of these pollutants, is necessary. A brief treatment of each element in this analytic scheme follows.

5.4.1 Prioritizing Air Pollution Impacts and Air Pollutants

Some air pollution impacts may be aesthetic in nature, or more of a nuisance than anything else. Pollutants may cause acute or chronic morbidities of various kinds, and/or mortalities. The health impacts of some pollutants may manifest themselves only over the long term. A pertinent example, in the context of removal of lead in gasoline is that, apart from its other effects, lead induces neurological damage and lowered learning ability in children, and these effects persist irreversibly into adulthood. On the other hand, the effects of benzene, the levels of which can be enhanced by refinery processes to compensate for lead removal, and asbestos from brake and clutch wear, are typically manifested over the longer term.

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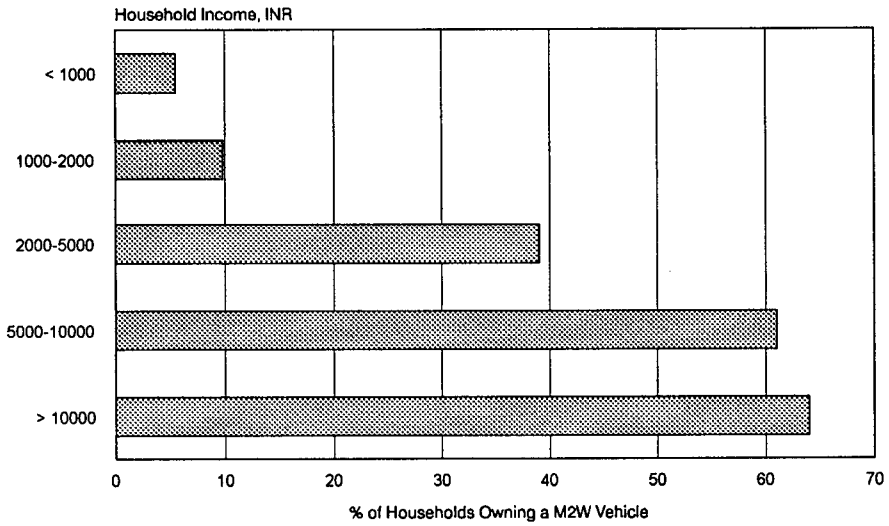
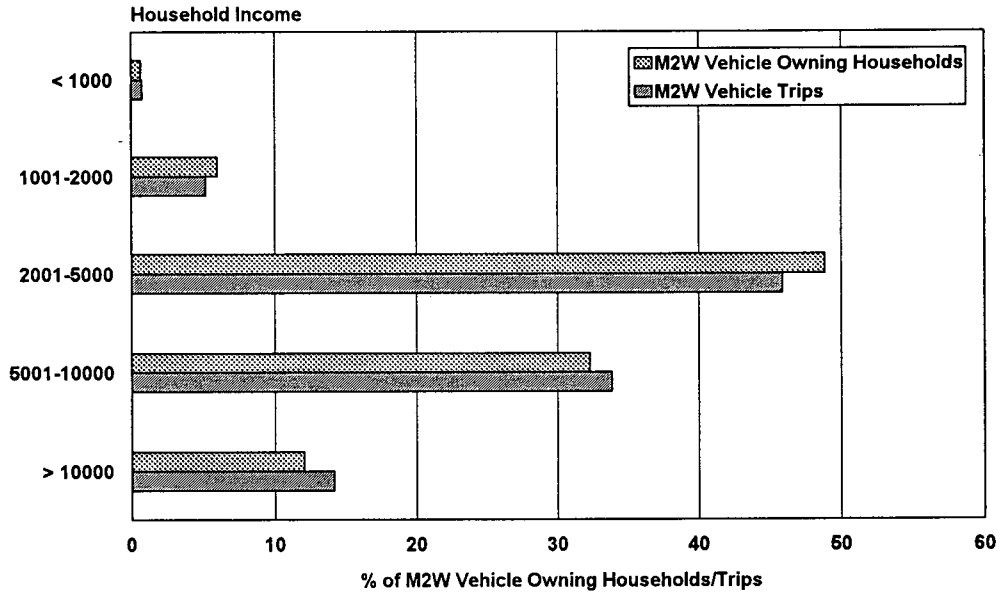
[3] In this context, note that policies targeted at transport emissions in Delhi and other major Indian cities which have serious air pollution, will have cost impacts for users in areas of the country where these policies might be unnecessary.

Figure 5.1 Percentage of Residential Households in Delhi Owning At Least One M2W Vehicle by Income Group



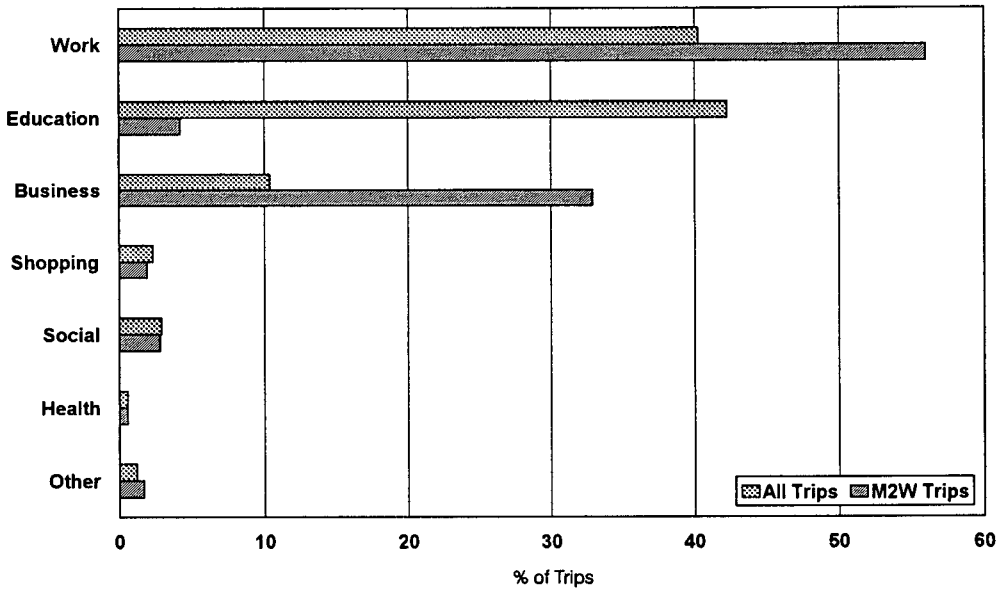
M2W Vehicle = Motorized Two-wheeled Vehicle; INR = Indian Rupees. Source: RITES/ORG (1994). mgb00

Figure 5.2 Distribution of M2W Vehicle Owning Households and M2W Vehicle Trips by Household Income in Residential Households in Delhi



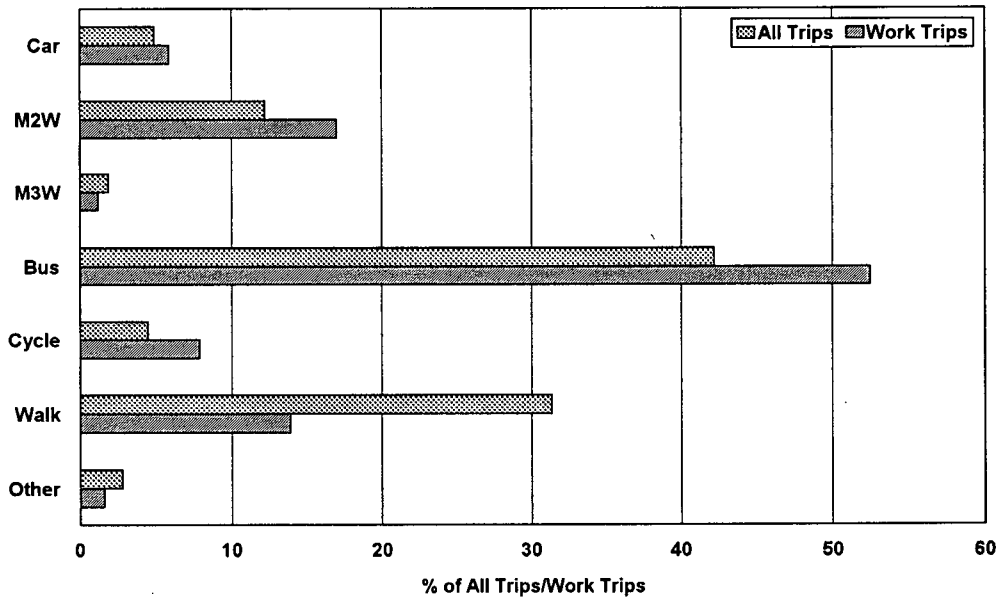
Note: Data refers to households owning at least one M2W (motorized two-wheeled) vehicle. Source: RITES/ORG (1994).
mgb1999

Figure 5.3 Distribution of All Trips and M2W Vehicle Trips by Residential Households in Delhi, by Purpose



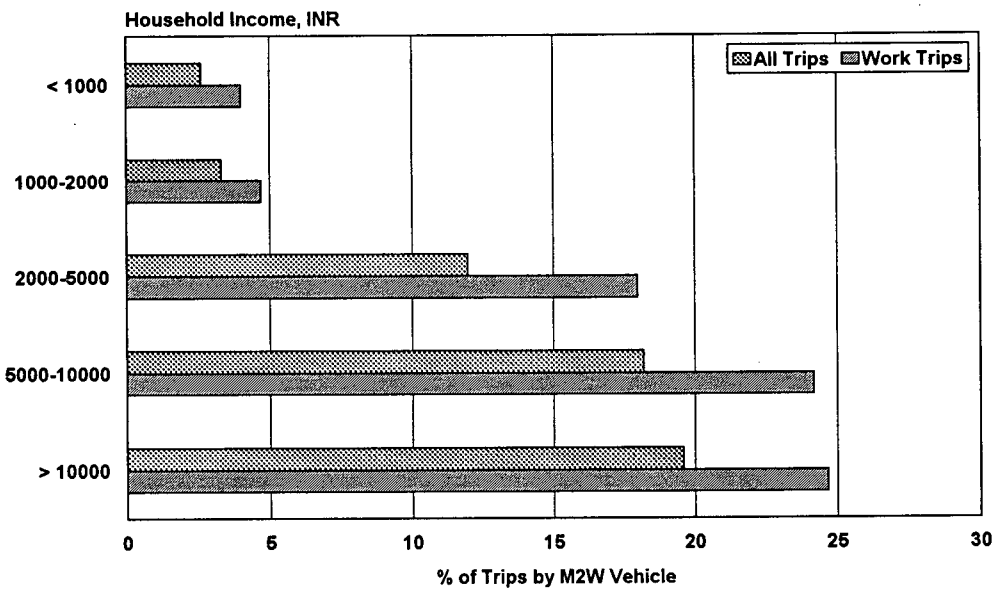
M2W = Motorized Two-wheeled Vehicle. Source: RITES/ORG (1994). mgb00

Figure 5.4 Distribution of Trips for all Purposes and Work Trips by Mode in Residential Households in Delhi



Note: M2W/M3W = Motorized two-/three-wheeled vehicles. Bus includes charter bus. Source: RITES/ORG 1994. mgb1999

Figure 5.5 Percentage of All Trips and Work Trips Performed by M2W Vehicle by Residential Households in Delhi, by Income Group



M2W = Motorized Two-wheeled Vehicle; INR = Indian Rupees. Source: RITES/ORG (1994). mgb00

Air pollutants can thus be ranked based on mortalities and/or morbidities, among the old and the young,[4] over the short and long terms, and in terms of hospital admissions, productive days lost, and so on. Synergistic effects between pollutants may also be considered (Bates 1994; Brandon and Hommann 1995; Cropper et al 1997; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman 1991; Romieu et al 1992; Wijetilleke and Karunaratne 1995).

Whether ambient concentrations exceed WHO or other guidelines may be used as a basis for prioritizing pollutants, but this criterion must be used with caution. First, the guidelines themselves involve assumptions and value judgments that may not be valid in all socio-economic contexts, since poverty and nutrition levels, and the size and nature of sensitive populations vary from context to context. Further, there may be important pollutants that may not be covered by WHO guidelines. In this connection, it is pertinent to mention transport-generated air toxics such as benzene, aldehydes, and 1,3-butadiene (Brandon and Hommann 1995; Faiz et al 1992; Romieu et al 1992; Walsh 1991a).

[4] Greater importance may be placed on health effects for the young, as opposed to the old, by using "life-years lost" as a measure rather than "lives lost", as discussed in Cropper et al (1997).

Since air pollutants have regional and global environmental impacts in addition to local health and welfare impacts, and since some of these impacts manifest themselves over the long term, trade-offs have to be made among various impacts, and between impacts to present and future generations. Finally, indirect health effects, in terms of, for example, poor nutrition, which may occur as a result of crop damage due to pollutants such as ozone,[5] and due to climate change because of CO_2 and CH_4 emissions, would ideally also need to be considered.[6]

Finally, the spatial boundary over which emissions impacts will be considered, is an important issue. The spatial system boundary is important because vehicular emissions within the boundary can have impacts outside it. Indeed, the worst affected people may not be in the area in which the pollutants are produced. Thus, a value judgment is involved in terms of whether or not to include in the analysis emissions impacts outside political jurisdictions.

The prioritization of pollutants to reflect trade-offs between their various adverse impacts is discussed as part of a later section on valuation of policy impacts, but has been alluded to here, mainly to show that assumptions, value judgments, complexities, and uncertainties are inevitably involved even in the first step of the policy-analytic process, with significant implications for policy choice. Because pollutants contribute to different emissions impacts to varying extents, which pollutants will be targeted, and to what extent, will depend on trade-offs between the impacts.

5.4.2 Prioritizing M2W Vehicular and Transport System Sources

As discussed in Chapters II to IV, a reliable and comprehensive accounting of the contribution of M2W vehicles and other transport modes and system components to emissions of critical pollutants does not exist, either for Delhi or the other Indian cities (CSE 1996; CSE 1997;

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[5] In this connection, it is useful to recall from Chapter II that damage to crops such as wheat, soybean, rice and groundnut due to tropospheric ozone could be substantial in India (Roy Chowdhury 1997).

[6] A full accounting of impacts is obviously ideal. However, in practice, impacts are selected based on available information. Attention therefore often tends to be focused on the already well lit aspects of a problem, and on alternatives for which it is easiest to predict impacts. But it is likely that those impacts for which there is the least information available (or obtainable) may in fact be the most important. For example, a study of the health benefits from improved air quality in California (Hall 1989, quoted in Faiz et al 1992) focused on "adverse health effects *that could be quantified and for which exposure and economic data were extensive enough to support the calculation of estimated benefits of reducing those effects*" (emphases added). This is of course understandable, but had other effects been included in the analysis, the benefits of mitigative policies would have been calculated to be much greater, and more stringent controls would likely have been justified.

Shah and Nagpal 1997). It is unclear what methodology was used to generate the most recent emissions inventory for Delhi (CPCB in CSE 1996; CPCB 1997). The transport component of this inventory more than likely focused only on vehicular exhaust emissions. Further, it is likely that the emission factors were not representative of real-life conditions. The need for a comprehensive and realistic emissions inventory cannot be stressed enough, since it would provide a rational basis for prioritizing pollutants and transport sources for control action.

Detailed emissions inventories as exist in many jurisdictions in the OECD (for example, Calvert et al 1993) would obviously be very useful, but such inventories would require expensive and time-consuming empirical studies. The challenge in the Indian context, given its constraints, is how to make intelligent choices, based on the information that is available or can be discerned, and on informed estimates. There would be great value in generating an emissions inventory based on avaliable information. Such an inventory would attempt to minimize *specification* errors, by accounting for all factors that critically influence emissions in the Indian context, while accounting for *measurement* errors, by employing ranges for various variables.[7]

Such an inventory targeted at the transport sector must focus on emissions of critical pollutants and pollutant components most closely correlated with the impacts of concern, due to vehicular *activity*, rather than merely vehicular exhaust, as discussed in Chapter III. Thus, for example, volatile organic compounds (VOCs) rather than only total HCs from all vehicular sources (exhaust, crankcase and evaporation) as well as the fuel distribution system, and PM_{10} rather than only TSP, from all vehicular sources (exhaust, and brake, clutch and tyre wear) as well as re-suspended dust due to vehicular activity, must be estimated. In this connection, note that on uncontrolled vehicles typical of the Indian context, only 55% of vehicular VOCs are from the exhaust (Faiz et al 1992). And as noted in Chapter III, crankcase HC emissions can be as high as 20% of exhaust HC emissions on four-stroke M2W vehicles (Hare et al 1974). PM_{10}/PM and $PM_{2.5}$/PM ratios on a gram/vehicle-kilometre basis can vary considerably from mode to mode (Bhattacharyya 2000; GVRD 1995).[8] Finally, re-suspended dust likely forms a

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[7] The distinction between specification and measurement errors is borrowed from Wachs (1985).

[8] Interestingly in this regard, while the PM_{10}/PM and $PM_{2.5}$/PM ratios for North American gasoline and diesel vehicles range from 0.998-1 and 0.87-0.89 respectively, they are 0.96 and 0.50 for M2W vehicles (GVRD

significant proportion of Delhi's PM, since SO_2 and NO_x levels remain below WHO guidelines. The PM_{10} component of re-suspended PM is considerably smaller than for vehicular exhaust and other combustive PM sources. However, although much of the road dust in Delhi is natural, a significant portion is likely combustive in origin (Bhattacharyya 2000; Cropper et al 1997; GVRD 1995; Shah, Nagpal and Brandon 1997).

The inventory must as far as possible take into account all contributory factors, in-use conditions, and data uncertainties and variabilities that critically influence emissions in the Indian context. These factors include vehicular activity growth rates, real-life driving cycles including cold starts, real-life fuel/oil conditions, vehicle age distributions, emissions variations as a function of vehicle age and maintenance levels, and trip length distributions, for various modes. An emissions inventory generated along the lines indicated would serve as a basis for designing and prioritizing policy actions in a disaggregated manner, in terms of various vehicular sources for various modes, various components of the fuel distribution system, short and long distance trips, vehicle age and maintenance, and fuel and oil quality. More generally, since urban transport is not the only air pollution source, particularly in the case of PM, VOCs and SO_2, an emissions inventory along similar lines for various sectors including transport would be useful. It should not be the case that, after expensive measures have been undertaken to control transport emissions, there is no substantial reduction of air pollution impacts.[9] Finally, as noted in Chapter IV, exposure to, rather than merely emissions of, critical pollutants, is key in terms of evaluating the relative role of transport and other sectors to air pollution impacts.[10]

1995). These figures appear to show that M2W vehicle PM comprises larger diameter particles than PM from other gasoline vehicles and diesels.

[9] As discussed in Chapter IV, it is precisely the lack of such an emissions inventory that various actors exploit, in order to further their own agendas, and transfer the responsibility for action to others.

[10] Smith (1988) proposes total exposure as an useful criterion for prioritizing action on pollutants and sources. In the case of health impacts, total exposure would be the product of the local concentration of health critical pollutants, exposure duration, and the number of people exposed. Strictly speaking, prioritization of various transport sources, discussed in the preceding paragraphs, should be done based on exposures, which can vary with transport source, rather than only emissions.

5.4.3 Policy Options

After having prioritized pollutants and vehicle and related transport system sources for prevention and control action, as discussed, the next step in the policy-analytic process is to select appropriate policy alternatives that target these pollutants and sources.

Table 5.1 (based on Carbajo 1993) summarizes the various technological, infrastructural, economic, regulatory and transport demand reduction instruments for prevention and control of transport air pollution generally. These policies are directed at a wide range of technological, user behavioural and institutional contributory factors related to motor vehicles as well as the transport and urban activity system. The policies reflect the equally broad range of issues that influence motor vehicle ownership, use and emissions, discussed in Chapter III. The instruments in the left-hand column act on the *grams/vehicle-kilometre* component of the transport emissions problem, and may be thought of as curative in nature. Those on the right, on the other hand, address the *vehicle-kilometre*, *vehicle-trip* and *vehicle occupancy* components, and may be thought of as being *preventive*. As discussed in Chapter II, M2W vehicles are important in the Indian context, because they are high emission factor, vehicle-trip and vehicle-kilometre, and low-occupancy vehicles.

In order to evaluate policy alternatives meaningfully, it is desirable that alternatives are specified as clearly as possible. Further, given that carefully co-ordinated technological, economic, and regulatory policy packages need to be applied for effectiveness, keeping in mind the range of inter-dependent contributory factors discussed in Chapter III, it is desirable to evaluate carefully specified *policy packages*, rather than individual policies (though in practice, it may be difficult to do so). Additional assumptions may need to be specified as well, because the same policy package can have different impacts under different assumptions.

Thus, in evaluating mandated emission standards via technological improvements, it would be desirable to consider, apart from emission factor changes, any fiscal incentives and disincentives that may be applied, since these will play an important role in policy attractiveness, and therefore effectiveness. In-use emissions monitoring and enforcement programmes that may be applied also need to be considered, given the importance of such programmes to long-term emissions reductions. These programmes need to be specified in terms of the pollutants targeted, test and repair methods, and standards. Finally, the modalities

of any vehicle scrappage policies that may be applied to complement mandated emission standards should also be considered, since scrappage will affect the entry of new, improved vehicles into the fleet.

In the case of fuel quality improvements, the extent to which different fuel parameters (lead and sulphur content, fuel vapour pressure, etc.) will be improved would need to be specified. In the case of gasoline taxation, modal shifts, travel activity and emission factors for various modes, and thus overall emissions and other policy impacts, will depend critically on whether proceeds from taxation go into general revenue, or are used to augment highway infrastructure, or to improve public transit. Thus, how revenues will be used would need to be specified in addition to the level of gasoline taxation.

In summary, policy packages comprising an appropriate mix of policies need to be selected and specified carefully, in terms of their parameters and other assumptions, for a meaningful analysis of policy alternatives.

5.5 ANALYTICAL FRAMEWORK FOR EVALUATING POLICIES TARGETED AT M2W VEHICLE AIR POLLUTANT EMISSIONS IN THE INDIAN CONTEXT

Pearce and Markandya (in Faiz et al 1992) propose that the following be determined, in order to evaluate policy alternatives with respect to transport air pollution:

- economic activity of the polluter (in vehicle-trips, vehicle-kilometres);
- pollutant emissions (in CO, HC, NO_x, SO_x, etc.);
- ambient pollutant concentrations;
- population exposure;
- physical damage (in terms of the health and welfare impacts of air pollution);
- monetary value of damage; and finally,
- comparison of the monetary value of the damage with the costs of policy implementation, in a cost-benefit analysis framework.

The policy-analytic framework proposed by Shah, Nagpal and Brandon (1997) applies to air pollution from all sectors. It follows roughly the same scheme as above, but lays out the steps in detail.

Grams/vehicle-kilometre	Transport demand (Vehicle-kilometres, vehicle-trips), modal choice, vehicle occupancy
Fuel • Relative fuel prices/taxes (e.g. leaded vs. unleaded gasoline; gasoline vs. diesel; gasoline vs. alternative fuels) • Fuel quality improvements and standards (gasoline, diesel etc.) in terms of volatility, lead or sulphur content, octane or cetane ratings etc. • Vapour recovery systems	• Fuel prices/taxes
Vehicle • Fuel economy and emissions improvements and standards (new, in-use, retro-fits) • Inspection and maintenance programmes (private and high-use vehicles) • Vehicle retrofits • Vehicle replacement and scrappage programmes	• Vehicle prices/taxes
Transport Activity • Traffic system management • Highway infrastructure investment • Road maintenance	• Road, congestion pricing • Vehicle use bans • Public transport policy (fares, service levels, modal integration) • Parking policies • NMT Policy • Land use policies and integration with transport planning

Based on Carbajo (1993)

Table 5.1 Policy Instruments for Prevention and Control of Transport Air Pollution

Figure 5.6 represents Shah, Nagpal and Brandon's framework, as applied specifically to transport air pollution. This framework proposes that policies be evaluated either on the basis of cost-benefit, or cost-effectiveness, that is, on the basis of costs per unit mass of pollutant emissions avoided due to various policy alternatives.

In the remainder of this Chapter, a policy-analytic framework is proposed for evaluating policy alternatives targeted at M2W vehicle emissions in the Indian context. Specifically, a

detailed discussion follows of the various steps involved in the evaluation of policy alternatives. These steps relate, for each policy alternative, to the determination and valuation of emissions and other policy impacts. Figure 5.7 is a schematic depiction of the proposed policy-analytic framework. Various principles are proposed for making the above determinations more effectively, and to discriminate between various policy alternatives. Also discussed are the information requirements for each step. The policy-analytic framework reflects the criteria for good policy analysis discussed in the previous section, and provides for the evaluation of policy alternatives for long-term cost-effectiveness, by explicitly considering contextual constraints, implementation issues, and the interests and concerns of multiple stakeholders and affected groups.

5.5.1 Determination of Motor Vehicle Activity and Emissions

The first step in evaluating policy alternatives is to determine the M2W vehicle activity and air pollutant emissions due to each policy alternative, over the analysis period. Urban transport planners forecast future travel demand using a sequence of standardized computer models (Wachs 1982).[11] But these models require vast amounts of different kinds of data and computational resources which may not be available in the Indian context, particularly at the local level. Bose (1993) uses a regression equation,[12] and current mode shares, to estimate travel demand by various passenger transport modes in Delhi. In view of the contextual constraints related to data generation and computation, it may be more preferable to rely on informed expert judgments, based on a range of contributing social, economic, and demographic factors, to estimate the rate of M2W vehicle growth for various policy alternatives, over the analysis period. Further, the uncertainty that is inevitably involved in estimating vehicle growth can be explicitly accounted for by considering a range of M2W

[11] These models are: a) the urban activity (land use) model, which determines the spatial distribution of population and economic activities; b) the trip generation and attraction model, which estimates the number of trips originating and terminating in each urban zone by purpose and time of day; c) the trip distribution model, which determines the trip interchanges for each origin-destination zone pair; d) the mode choice model, which apportions the trip interchanges between various origins and destinations among various transport modes; and e) the traffic assignment model, which forecasts the routes that will be followed by the trips using each mode, and travel volumes on various transport system links (Wachs 1982).

[12] The origin of the regression equation is not indicated (Bose 1993).

vehicle growth rates. Thus, the sensitivity of various policy alternatives to such uncertainty may be determined.

M2W vehicle growth rates over the analysis period would need to be estimated in terms of different M2W vehicle types (two- and four-strokes, for example), in order to account for the different emissions characteristics of the vehicle types. The rate at which M2W vehicles are scrapped needs to be accounted for as well, for each policy alternative, for the reason already discussed, and also because vehicle emissions are strongly influenced by vehicle age.[13] A range of values, rather than a single value, may be considered for scrappage rate as well. Combining determinations of the above variables with information from travel surveys on M2W vehicle trips and trip lengths would yield estimates of age-distributed M2W vehicle trips and kilometres over time, for each M2W vehicle type, for each policy alternative. It would be desirable to model M2W vehicle travel activity in terms of vehicle trips in addition to vehicle kilometres, because vehicle trips are crucial in terms of evaporative trip-end emissions, as discussed in Chapter III. Emissions prevention and control policies can potentially affect both factors.[14]

For each policy alternative, it is important to estimate emissions of CO, HC, VOC, NO_x, SO_2, Pb, PM, and PM_{10} from all M2W vehicle and transport system sources, including re-suspended dust, fuel distribution and vehicle re-fueling, due to M2W vehicle activity. CO_2, CH_4 and N_2O emissions may also be estimated, because of their implications for climate change. CO_2 is a proxy for energy conservation, which, as discussed in Chapter II, is an important consideration in itself in the Indian context.

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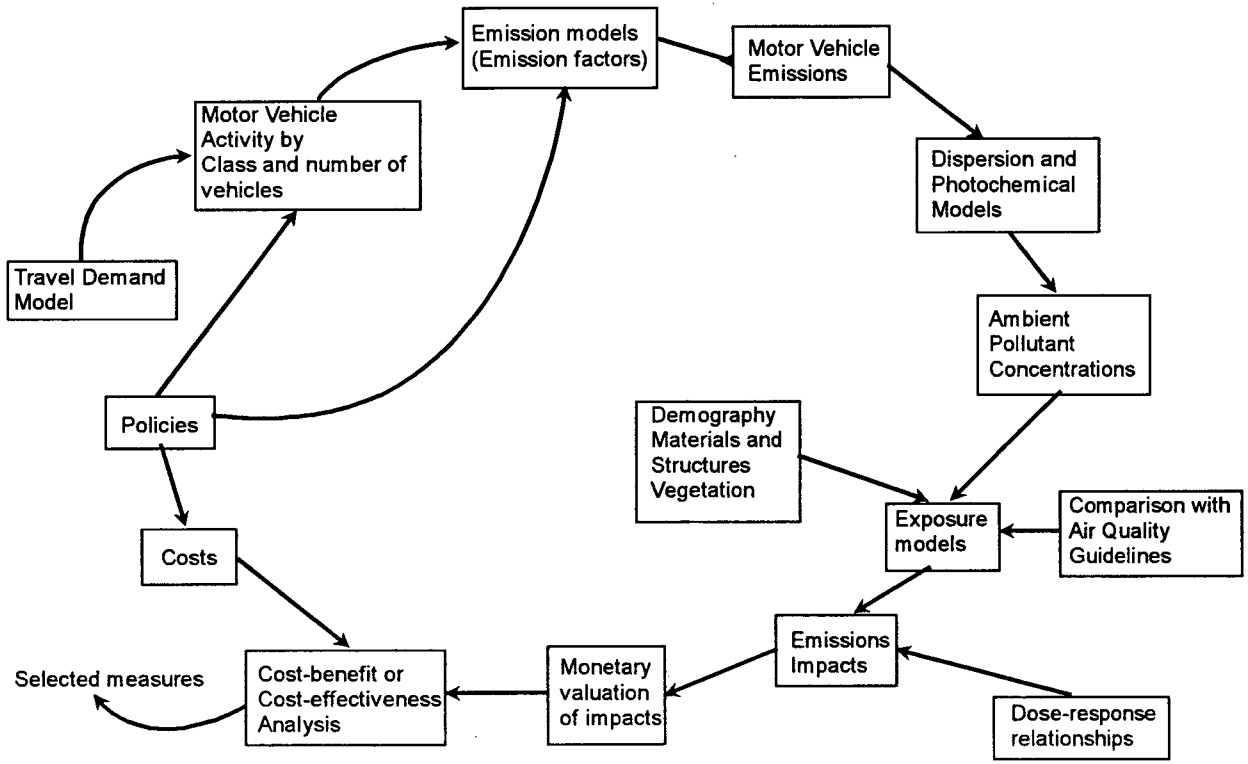
[13] Another important reason for accounting for scrappage is that policies such as emission standards typically raise the relative price of new vehicles and can delay scrappage of old and highly polluting vehicles and/or induce substitution toward older vehicles (Gruenspecht 1982). This effect can be taken into account.

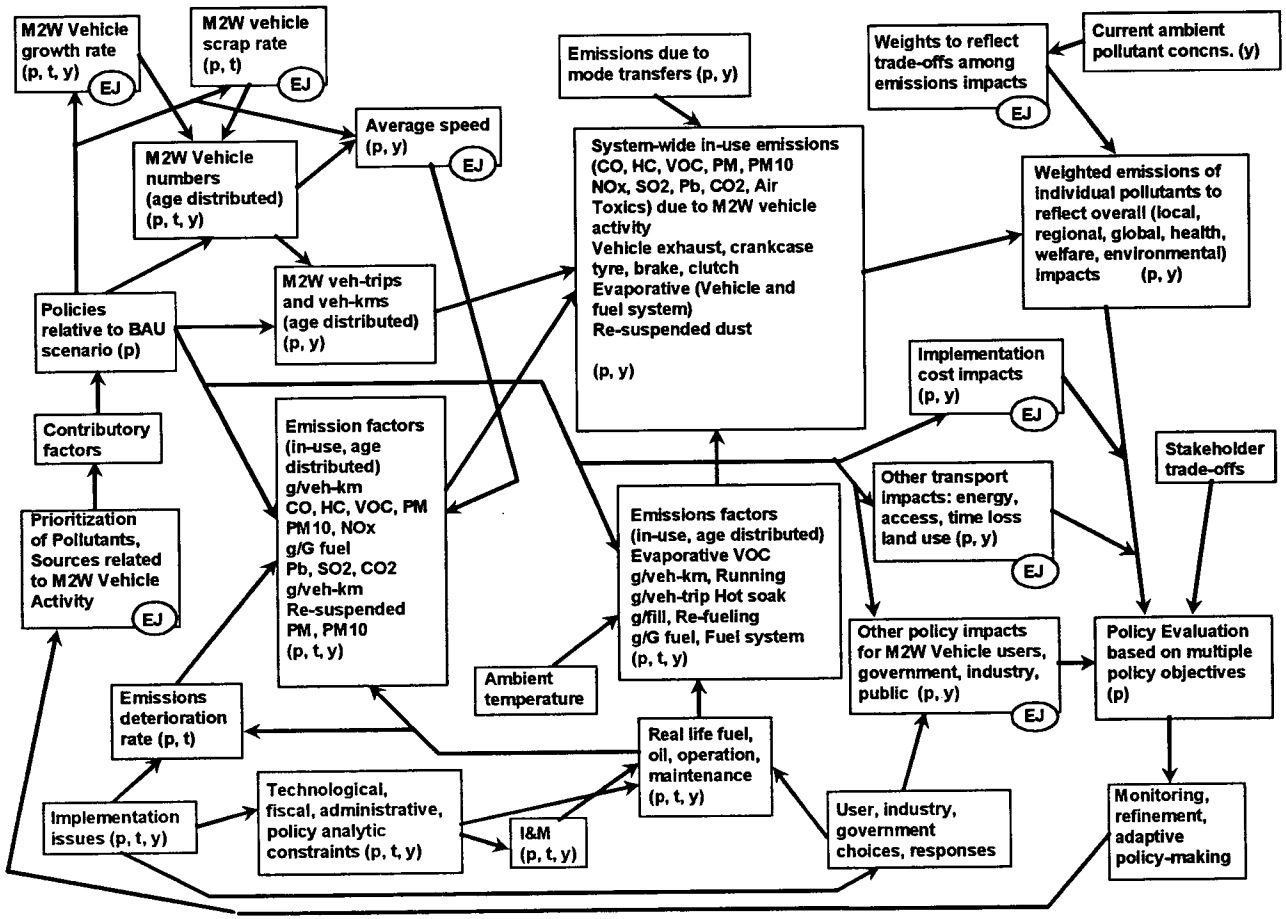
[14] Indeed, it is important to consider policies that target both vehicle trips and kilometres, in addition to emission factors.

Figure 5.6 Policy-Analytic Framework for Evaluating Policies Targeted at Motor Vehicle Emissions



Based on Carbajo (1993), Faiz et al (1992), Shah, Nagpal and Brandon (1997), and Wachs (1985).

Figure 5.7 Analytical Framework for Evaluation of Policies Targeted at M2W Vehicle Air Pollutant Emissions



BAU – Business-as-usual; p – BAU and policy alternative scenarios; t – M2W vehicle types; y–Analysis period; EJ – Expert judgment

Thus, emissions of all critical air pollutants due to M2W vehicle activity system wide will be accounted for, for various policy alternatives. This is important because different policies would likely target different pollutants and sources. Incidentally in this regard, Shah and Nagpal (1997) account for only exhaust emissions and re-suspended PM, whereas Bose (1993) targets only exhaust emissions.

As in the case of the emissions inventory discussed in a previous section, all important in-use conditions and variabilities that critically influence emissions must be accounted for in estimating system-wide emissions for various policy alternatives over the analysis period. After all, the overall policy objective is to minimize in-use emissions over the life of the vehicle fleet under actual driving conditions, rather than only new vehicle emissions. Emission factors that are measured or estimated for the in-use conditions pertaining to the policy alternatives being considered must therefore be used, rather than data on vehicle populations in other contexts (Faiz et al 1992), or even new vehicles in the Indian context. Emission factors should reflect human dimensional realities such as user choices as to vehicle operation and maintenance.

In addition to estimating emission factors under in-use conditions, it would be desirable to account for variations in emission factors for various target pollutants from various sources for different M2W vehicle types with vehicle age, speed, vehicle maintenance, etc. for different policy alternatives. Considering emissions over time would take into account both improved emission standards as old vehicles are scrapped, and deterioration of new vehicle emissions with age, and declining road speeds.[15] A range of values, rather than a single value, may be considered for emission factors, accounting for uncertainties with respect to the quality of vehicle maintenance, spares and servicing, and monitoring and enforcement.[16] Finally, in the case of policies that might result in transferring M2W vehicle trips to other modes, it would be desirable to know the distribution of M2W vehicle trips by trip length. Vehicle trips are important not only in terms of evaporative emissions, but also exhaust emissions, since average speeds tend to be lower for shorter trips (RITES/ORG 1994). Thus, knowing the distribution of M2W vehicle trips by trip length would enable the determination

[15] In this regard, recall the discussion on Conformity of Production (CoP) limits in Chapter III.

[16] Software such as Analytica (Lumina Decision Systems 1999) would be ideally suited for dealing with these and other uncertainties and variabilities that have been discussed, and in investigating scenarios.

of the effect of reducing long as opposed to short trips, as would happen in shifting M2W vehicle trips to public transit.

Some pollutants not originally considered in the analysis might be generated as a result of certain policies. These pollutants must also be included in the model. Also, it would be desirable to consider unintended side-effects, in the interests of overall policy effectiveness. As discussed in Chapters III and IV, catalytic cracking and reforming to produce unleaded gasoline increase levels of benzene, xylene, toluene, and other aromatics and olefins. Thus, while lead emissions are minimized, benzene emissions will likely increase, particularly in engines without catalytic converters. And xylenes and other olefins are much more reactive in producing ozone than most HCs. The use of MTBE (methyl tertiary butyl ether) to compensate for lead removal and reduce benzene and aromatics, can cause increased reactive HC and NO_x emissions in engines without catalytic converters, thus aggravating the ozone problem. Fuel volatility reductions would help reduce evaporative emissions, but reductions below around 50 kPa can increase exhaust VOCs, particularly at low temperatures on non-fuel injected vehicles on oxygenated fuels (Calvert et al 1993; Faiz et al 1992 and 1996; Humberto Bravo et al 1991).[17] It is for all of the above reasons that air toxics such as benzene and aldehydes have been included in the model in Figure 5.7.

Finally, since certain policy alternatives targeted at M2W vehicle emissions can transfer M2W vehicle trips to other motorized modes, we must also include in the analysis other pollutants not initially targeted that these modes may generate. Also of course, certain policies like fuel quality improvement will positively affect emissions from gasoline-powered modes other than M2W vehicles as well. To summarize the last few paragraphs: interdependencies between pollutants and modes must be kept in mind when estimating emission impacts of various policy alternatives. The foregoing also shows the usefulness of considering the effect of each policy alternative in terms of a wide range of pollutants from various sources system-wide in a disaggregated fashion.[18]

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[17] These issues are pertinent in the Indian context, since oxygenating agents such as MTBE will be allowed in Indian gasolines from 2000. Also, fuel volatility will be controlled (Appendix IV). Lastly, a considerable proportion of vehicles in the Indian fleet will likely be non-fuel injected, and without catalytic converters, for a long time.

[18] In this connection, it is instructive to note the results of a comparison made between emissions from a 1988 diesel engine with a ceramic particulate trap, and a 1991 diesel engine with an oxidation catalytic converter

In addition to capturing effects such as emissions deterioration over time due to increased vehicular activity and factors such as vehicle age and speed, it would be desirable to account for vicious circles and iatrogenies that typically manifest themselves over the long term. Estimating emissions year by year over the long term, as proposed in the policy-analytic framework, would help achieve this goal.[19] Following are a couple of examples of such vicious circles and iatrogenies. Fuel efficiency improvements can not only be neutralized by increased vehicle activity, they can actually induce increased vehicle activity by lowering driving costs (Shalizi and Carbajo 1994), thus causing increased emissions, at least from sources other than vehicle exhaust. Infrastructure investment to relieve congestion would likely lower per-vehicle emissions (except perhaps in terms of trip-end evaporative emissions). But over time, as vehicle activity increased due to suppressed demand, congestion would likely revert to its original level, with increased emissions from all sources.[20]

Estimating emissions year by year over the long term would also help determine the rapidity with which policies lower emissions, and whether these emissions improvements are sustained over time. This would help in differentiating between, for example, fuel quality and vehicle technology improvements. While fuel quality improvements might not be as effective as vehicle technology improvements in reducing per-vehicle emissions, the former would begin to reduce emissions from all vehicles (and the fuel distribution system) as soon as they

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(Bagely et al 1993). Despite a substantial reduction in weight of total exhaust PM, the total number of particles from the more advanced 1991 engine was 15-35 times greater than from the 1988 engine when both were operated without emission control devices. This shows that fine particles, a serious health hazard, could be formed as a result of new technologies, even as PM mass is reduced, thus highlighting the importance of focusing not only on PM mass but also the number of particles.

[19] The duration over which emissions are determined due to various policies is, of course, quite different from that for which the impacts of those emissions need to be considered. Health effects due to pollutants such as asbestos, benzene and carbon dioxide begin to manifest themselves and develop well beyond the time the emissions occur, and can affect future generations.

[20] Perversely, per-vehicle emissions improvements can lead to system-wide deterioration over time. On the other hand, policies that reduce motor vehicle activity can produce emissions (and other) benefits because of this reduction, and also because of improved per-vehicle emissions from the remaining vehicles. As automobile numbers grew 2.4% annually between 1970 and 1987 in the USA, and congestion increased, highway expenditure grew at 15%. Even so, congestion is expected to intensify, as car travel becomes more inevitable, and other modes become less viable. Thus, despite per-vehicle emissions having been reduced 90% between 1977 and 1987, overall emissions are projected to increase almost 40%, and urban air quality is expected to worsen significantly, by 2010, because of increased vehicle activity and congestion, and slower vehicle turnover (Deakin 1990; Gordon 1991; MacKenzie et al 1992).

are introduced, as opposed to the latter, which would be phased in only as old vehicles are taken out of the fleet (Faiz et al 1992).

So far, we have addressed the matter of how to estimate emissions of various pollutants from M2W vehicle activity due to various policies. In the next section, we discuss issues related to determining and valuing the impacts of those emissions.

5.5.2 Determination and Valuation of Emissions Impacts

Determining the marginal health and welfare impacts associated with emissions reductions (or increases) due to various policy alternatives targeted at M2W vehicles would first entail determining changes in ambient concentrations of target pollutants as a result of the emissions reductions and increases, in order to use epidemiological models that correlate pollutant concentrations with these effects. Since there are multiple sources of air pollution, ambient concentrations of various pollutants as a result of emissions from transport and other sectors, as well as changes in these concentrations due to marginal changes in emissions due to the policy alternatives, would need to be determined over time. Apart from the fact that this exercise involves complex atmospheric dispersion and ozone formation modeling, capabilities for which may not be fully developed in the Indian context, a major constraining factor is the lack of a reliable and comprehensive emissions inventory required for estimating emissions from various sectors.

Assuming that it was possible to determine with some degree of certainty the changes in ambient pollutant concentrations due to policies targeted at M2W vehicles (or transport), determination of the resulting marginal changes in health and welfare effects over time, compared to the business-as-usual (BAU) scenario, would call for reliable epidemiological studies based on equally reliable indigenous health and air quality data.[21] But even if the

[21] The need for such epidemiological studies is borne out by the discrepancy between the annual air pollution deaths estimated for Delhi by Brandon and Hommann (1995), based on US dose-response data, and by Cropper et al (1997), based on indigenous health and air quality data, as discussed in Chapter II. Typically, epidemiological studies correlate observed health effects with one or more individual pollutants, and do not account for synergistic effects due to simultaneous exposure to multiple pollutants. While the bulk of air pollution related mortalities can be explained on the basis of PM_{10}, SO_2, ozone and lead (Brandon and Hommann 1995; Smith 1994), these effects are important. This is particularly so in the case of Delhi, for example, where high PM levels co-exist with high SO_2 and ozone levels. Further, as Chang et al (1991) observe, the health effects of atmospheric reaction products must be considered, in addition to those of direct vehicle emissions.

capability existed to conduct such studies -- which does not in the Indian context, as discussed in Chapter IV -- various air pollution impacts of interest, including mortalities and morbidities, crop loss, and damage to structures, have multiple causes, making it difficult to isolate the precise contribution of air pollution (Hardoy and Satterthwaite 1991), let alone that of transport or M2W vehicle emissions.[22] And even if it were possible to isolate the role of air pollution in terms of impacts, by means of quality studies based on reliable data, there is the issue of how truly the data reflects reality. In the case of hospitalizations as a measure of morbidities, for example, actual hospitalizations could likely be a vast underestimate in the Indian context, given that millions simply lack the capacity to access hospital care.

In short, determination of the marginal health and welfare impacts of various policy alternatives is subject to uncertainty and lack of information. As for valuing policy impacts, welfare economists suggest cost-benefit analysis (CBA) as an ideal methodology (Carbajo 1993; Pearce and Markandya in Faiz et al 1992). Operationalizing CBA would entail monetizing the health and welfare impacts avoided due to each policy, comparing these monetized benefits with the monetary costs of each policy, and selecting that policy with the maximum net monetary benefits discounted to the present by means of a discount rate. This process is fraught with various conceptual, operational and philosophical difficulties, as discussed below.

Of all the steps in the monetary valuation of policy impacts, the determination of monetary costs is perhaps the one that is least fraught with uncertainty. Quantifying environmental (and social) policy benefits in monetary terms, on the other hand, is difficult because environmental and social values are intangible, and hard to define. Further, environmental values such as clean air are not traded on markets. However, economists have devised methods for monetizing non-market values, as if hypothetical markets existed. These methods are based on revealed preferences, and expressed preferences, or contingent valuation (Pearce and Turner 1990). The assumptions underlying both methods are that a) individual preferences ought to be the basis of societal decision making, b) the market price that individuals are willing or

[22] The situation is complicated by the fact that total exposures due to transport, which is a function of the number of people exposed to transport pollution, the exposure duration, and transport pollutant concentrations, as opposed to exposures to other pollution sources, would need to be taken into account in order to determine the contribution of transport to health and welfare impacts.

observed to pay for environmental improvements is a true measure of individual preference vis-a-vis such improvements, or, in other words, the value of environmental quality improvement to them, and c) the value of environmental quality improvement to society is the aggregate of the willingness to pay of all individuals.

In the revealed preference approach, individuals' willingness to pay is determined by studying their actions in markets in which commodities or services are bought and sold, and in which the environmental value in question, which is not traded itself, is an attribute. For example, this approach would measure the willingness to pay for clean air by comparing the property prices of similar residential properties over a number of years, and/or property prices of a number of diverse properties at a point in time, and through multiple regression, isolate the effects of air quality on price by controlling for the effects of several other factors that also influence property price, such as access to services and facilities, property taxes, and other environmental factors such as noise level (Pearce and Turner 1990).

This is generally extremely difficult to accomplish in practice. In the Indian context, the difficulties would likely be compounded. It is likely that for the vast majority who are poor, the ability and therefore the willingness to pay, to move to areas of improved air quality, or for medical insurance, or treatment of air-quality induced illnesses, would be low. Further, they might be severely constrained in terms of choice of occupation, and workplace and residential location. In these circumstances, the assumption that observed behaviour in terms of willingness to pay is a genuine reflection of preferences, or of the value placed on human life, is unjustified. Ameliorative action would benefit the poor the most because they are the most severely affected by impacts, but, because of the very nature of the method and its assumptions, benefits to them would likely be severely underestimated.

An alternative means of valuing environmental benefits is the contingent valuation (CV) or the expressed preference method. In this method, large numbers of randomly selected individuals are asked to assume a hypothetical market for an unpriced good such as environmental quality and then to state how much they would be *willing to pay* (WTP) to either secure an improvement (or to prevent a loss), or be *willing to accept compensation* (WTAC) to either forego an improvement or tolerate a loss. This elicitation is conducted by means of questionnaires and surveys, or by experimental methods. For example, WTP for

improved air quality is determined by having respondents view pictures simulating various degrees of air quality (Gregory, Lichtenstein and Slovic 1993; Pearce and Turner 1990).

Underlying the CV approach is the assumption that monetary values for non-market goods exist in people's minds, and that researchers can find reliable and valid means to measure them. However, the elicitation of a single holistic response, in terms of WTP, represents a highly unrealistic cognitive demand. Though people feel strongly about environmental (and other non-market) values, these values are not numerically quantified, much less represented monetarily. Values such as the obligation to leave a clean and healthy environment to future generations are hard to justify in instrumental terms, because they are based on deep moral feelings. Further, people's environmental values are multi-dimensional, and because they find it difficult to make trade-offs between these dimensions, they often resort to simplifying strategies, which can lead to severe distortions in their expression of value (Gregory, Lichtenstein and Slovic 1993; Vatn and Bromley 1994; Hargrove 1989).

Even subtle changes in the manner in which CV questions are ordered and framed, the amount and nature of information provided, and other contextual factors, can lead to important changes in expressions of value. WTP can differ based on whether the respondent is asked how much she would be willing to spend on herself and her family, or what she believes government should spend on their behalf, or what government should spend on behalf of society, for a given level of reduction in risk. Expressed WTP would also differ based on what impacts of, for example, deteriorating air quality (impacts for the old, young, future generations, people living outside political jurisdictions, crop yields etc.) and what other societal needs respondents are told about and asked to consider before making their response (Dietz 1994; Gregory, Lichtenstein and Slovic 1993; Keeney, von Winterfeldt and Eppel 1990).[23]

CV elicitations force respondents to assess both facts as well as values. Even knowledgeable respondents have no way of knowing if what they say they would like to see government spend (for example) would be sufficient to effect the reduction in risk they are being asked to express WTP to achieve. Finally, while CV methods at least make people the

[23] In this connection, it is instructive to note that a 1987 study found that CV survey respondents dramatically changed their WTP for avoiding one day of coughing, from US$355.10 to US$1.39, when told to keep in mind budgetary implications (Shah, Nagpal and Brandon 1997).

judges of their own interests, they capture attitudinal intentions rather than actual behaviour. Several studies have shown that hypothetical WTP exceeds actual WTP, often significantly (Gregory, Lichtenstein and Slovic 1993; Keeney, von Winterfeldt and Eppel 1990; Lindsey and Knaap 1999).

In summary, elicitation of non-market values by means of CV is characterized by a range of conceptual and operational difficulties, including the fact that it is strongly determined by the specifics of the instrument itself. CV surveys are a process of value construction, rather than a neutral process of value discovery, with researchers functioning not so much as archaeologists, carefully uncovering what is there, but as architects, constructing as they elicit. Given all of the foregoing, there are doubts as to whether any CV study will be able to meet standard criteria of reliability and validity (Gregory, Lichtenstein and Slovic 1993).

Quite apart from the operational difficulties discussed, there are serious philosophical and ethical problems involved in using revealed or expressed preferences in terms of WTP to monetize the health, welfare and environmental benefits of policy alternatives. Because WTP is strongly affected by ability to pay, CBA effectively represents a 'dollar democracy', in which each person's vote is weighted by his or her income. Benefits and costs to higher income groups are valued more highly than those to lower income groups in determining the value to society of a given policy. Policies that favour the rich at the expense of the poor can be, and often are, 'cost-beneficial'. The fundamental moral issue, however, is whether, because of a public action, losses to one group, particularly the poor, can be justified by larger gains for others, particularly the rich. With respect to the environment, CBA assumes that its value to society exists only if, and to the extent that, there is WTP to see it preserved. People who have strong environmental values may place low emphasis on making high incomes. Their WTP, and that of the poor, would be a gross under-estimation of the value of the environment to them (Anderson 1985; Formaini 1990; McAllister 1980; Moore 1985).

These difficulties are particularly important in the Indian context, in which the benefits and costs of motorization, and the capacity to cope with those costs, are not evenly distributed in society, and risks and costs are imposed on the poor involuntarily. The rich, though most responsible for the emissions, are also most able to insulate themselves from their impacts. They may therefore have WTP only for those emissions impacts that affect them immediately,

and little if any WTP to address impacts on which they either have no information or are insulated from spatially or temporally (such as carbon dioxide emissions). CBA would thus justify control only if the rich were affected, and only of those aspects of pollution that they were not insulated from.

The choice of the discount rate can significantly affect how policy impacts are valued for future as compared to present generations, and thus, for example, the weightage accorded to policies to control pollutants such as carbon dioxide. The higher the discount rate, the less likely it is that policies with early costs to present generations, and late benefits to future generations, such as those to control carbon dioxide, will be selected. Discounting results in long-term environmental degradation being virtually ignored; even very low discount rates give no weight to even large impacts beyond 50 years (McAllister 1980).

Apart from the underlying value judgment that only those considerations that are monetary or monetizable are worth including in public policy analysis (Haines 1978), CBA assumes that simply summing up the un-coordinated preferences of individuals as consumers, in terms of willingness to pay, is a reliable means of gauging how to promote social welfare. These assumptions are particularly invalid when such preferences are either discerned from behaviour observed in a context characterized by constrained choices, or are expressed without reflection as to broader consequences. As Sagoff (1988 and 1994) points out, public policy decisions ought to be made after serious reflection and debate, based on moral principles and values, not individual preferences, and certainly not individual preferences in terms of WTP.

5.6 THE MULTIPLE-OBJECTIVES APPROACH

There are alternative means of estimating and valuing emissions impacts which may be relevant, in light of the difficulties discussed above, and of data generation and policy analytic constraints in the Indian context. Carbajo (1993) suggests that, while it is ideal to evaluate policy alternatives in a CBA framework, it is practical to do so in terms of cost-effectiveness (CE), by comparing the money cost per kilogram of reduced emissions, in view of these

difficulties.[24] The CE framework is particularly appropriate in the Indian context, since decision makers have to operate within tight budgetary constraints.

Carbajo (1993) also suggests the use of a weighted pollution index, instead of considering emissions of each pollutant individually. Doing so would help account for the combined effect of reductions (and increases) in the emissions of various pollutants due to policies. Thus, if alternative A reduced the emissions of a critical pollutant by a small amount compared to alternative B, it would be preferred to B, even though B reduced the emissions of a non-critical pollutant by a much larger amount than A. One option for weighting air pollutants in terms of health effects is to use the toxicity weighting factors developed by the World Bank (1992 World Bank data in Wijetilleke and Karunaratne 1995), and shown in the table below.

Pollutant	**Lead**	**NOx**	**PM_{10}**	**VOCs**	**SOx**	**Dust**	**CO**
Relative Weight	85	4.7	2.3	1.8	1.4	0.9	0.04

Source: 1992 World Bank data in Wijetilleke and Karunaratne 1995. Figures shown are to be applied to emissions of various pollutants in the same mass units.

Table 5.2 Approximate Toxicity Weighting Factors for Selected Pollutants

The factors in Table 5.2 rate individual pollutants for their health impacts, but it is unclear on what basis this rating was arrived at. For example, one wonders why PM_{10} has been assigned a lower weight than NO_x. Besides, as discussed in an earlier section (and also in Chapter II), there are other important air pollution impacts of concern, apart from health impacts. A good strategy would therefore be to weight emissions of various air pollutants, including those in Table 5.2, based on informed judgments of the potential of each pollutant to affect all local, regional and global health, welfare and environmental impacts of concern, for present and future generations.[25] Further, rather than assigning fixed weights, it would be desirable to select weights based on the need to reduce emissions of individual pollutants,

[24] According to Horowitz (quoted in Faiz et al 1992), "The linkage between air pollutant concentration and the harm caused by air pollution is so complex, difficult to study, and poorly understood that for most purposes *it is useful to avoid dealing explicitly with this linkage*." (emphases added).

[25] In this connection, the unit risk factors developed for various carcinogenic air pollutants (including benzene, formaldehyde, and 1,3-butadiene) (Shah, Nagpal and Brandon 1997) would also be useful.

considering the relative importance of various emissions impacts, the contribution of individual pollutants to the impacts, and the local ambient level of pollutants, including secondary transformation products like ozone, *at the time*. After all, while lead is certainly important from the health perspective, there would be little sense in weighting it highly if its local ambient concentration were below the WHO guideline.

Weighting emissions of individual pollutants in a flexible manner as above, based on local current conditions and needs, would be in keeping with the stress placed in this dissertation on continual learning, flexibility and adaptive policy-making. At the same time, note that such weighting still involves many of the difficult trade-offs between emissions impacts (for present and future generations, for example) discussed earlier.

Each policy will likely have a different stream of monetary implementation costs for M2W vehicle users, vehicle and fuel manufacturing and servicing industries, and governments. Also, each policy will potentially have different welfare costs for users, in terms of travel opportunities foregone, and reduced access and mobility, travel comfort and convenience, and time savings, particularly among lower income groups. In this regard, consider the impacts of a policy such as fuel taxation that dramatically raised vehicle operating costs, for vehicle users living far away from their workplaces, in areas poorly served by public transit, and with no travel options other than their M2W vehicles. Such users would likely be forced to forego travel opportunities, and/or shoulder additional travel expenditure, and/or shift to less preferred modes like crowded public transit. Congestion pricing could have regressive effects by forcing low-income users to find alternative routes, while providing time savings for high-income motorists, who are better able to afford congestion charges. This would be the case particularly if revenues from congestion pricing were spent on road building rather than public transit (Hau 1992; Neale 1995).[26]

Policy alternatives targeted at motor vehicle emissions inevitably have wider transport system impacts apart from emissions impacts, and monetary and welfare costs to users, governments and industry. These impacts include congestion, energy consumption and land use. Policies that are aimed at motor vehicle activity, rather than merely vehicle emission

[26] Unless it was applied region-wide, congestion pricing would likely reduce congestion and emissions only in charging zones and times, and perhaps even increase overall vehicular travel and pollution over the long term (Neale 1995).

factors, would likely have congestion impacts apart from affecting emissions. Energy consumption impacts may result both from vehicle technologies aimed at emission factors, and from policies targeted at vehicle activity and transport system characteristics such as congestion. Tracking M2W vehicle fleet energy consumption year by year over the analysis period will help capture the effects on this parameter of the entry of new vehicle models, and changes with time in vehicle activity, vehicle age and speed. Policies involving transport infrastructure to either alleviate congestion, such as highway capacity addition, or to effect mode transfers, such as mass rapid transit, will inevitably have land use impacts. As well, such policies will likely result in the displacement of the urban poor.

Therefore, in addition to system-wide emissions over the long term, all related transport system impacts should also be considered in evaluating policy alternatives. This is important because these impacts are inextricably linked. Also, given the multiple demands on scarce resources in the Indian context, it would be desirable for emissions prevention and control policies to generate transport synergies as far as possible, with the overall aim of achieving an access and mobility system that is resource conserving, environmentally benign, safe, and socially just. Additionally, it should be noted that transport emissions prevention and control policies can generate impacts in sectors other than transport. For example, removing kerosene subsidies to prevent fuel adulteration will likely reduce transport emissions. But kerosene might become unaffordable for the large number of low-income households that use it as a cooking fuel, even in cities such as Delhi (GoI/ESCAP 1991; TERI 1997a). Thus, in the absence of alternatives, removing kerosene subsidies may have socio-economic and environmental impacts (in terms of increased deforestation and indoor air pollution), as the poor are forced to spend more on fuel, and/or revert to firewood and other traditional fuels. The foregoing demonstrates the importance of considering system-wide impacts of transport policies.

Policies targeted at transport emissions in India have been motivated by concern regarding the rapidly deteriorating air quality situation in Delhi and other major Indian cities. But these policies might be unnecessarily stringent in other areas of the country, yet will have cost and welfare impacts for users in those areas. Strictly speaking, these impacts also need to be

considered. Incidentally, this highlights the importance of the choice of a spatial system boundary for analysis, an issue that was raised in an earlier section.

To summarize: just as motor vehicle activity creates costs and benefits that are differentially distributed between different groups (including vehicle users, vehicle and fuel manufacturing industries, and the public at large), so do different policy alternatives to address the impacts of motor vehicle activity. It would be desirable to evaluate policy alternatives in terms of the range of impacts discussed, in a disaggregated fashion, for various multiple affected groups, over the long term, in order to compare alternatives sensitively. A multiple-objective (M-O) framework, based on Edwards and von Winterfeldt (1987), Hobbs and Horn (1997), Keeney (1988a and b; 1992), Keeney, von Winterfeldt and Eppel (1990), Keeney and McDaniels (1992), and others, is proposed for this purpose.

Briefly, the M-O approach consists in interacting with affected and interested groups relevant to the decision situation, to elicit the value dimensions on which the various groups would like to see policy alternatives evaluated, representing the values in the form of objectives for each group separately, integrating the objectives of each group into a common objectives hierarchy for all groups, defining measures or attributes by means of which to judge the extent to which the objectives are achieved by various alternatives, assessing objective functions incorporating trade-offs between objectives from various groups, and combining these objective functions with expert assessments of policy impacts in terms of the measures,[27] to generate a multiple objective evaluation of alternatives from each group's perspective (Keeney 1982; Keeney 1988a and b; Keeney 1992; Edwards and von Winterfeldt 1987; Keeney, von Winterfeldt and Eppel 1990; and Keeney and McDaniels 1999).

Whereas CBA monetizes non-market values to make them comparable to other monetary benefits and costs in the analysis, the M-O framework integrates multiple values by measuring economic values for which markets exist in monetary terms, and non-economic values for which they do not, in terms appropriate to them, rather than in monetary proxies. This is based on the recognition that monetization of non-market values may be difficult and

[27] As indicated in Figure 5.7, expert assessments may incorporate judgments as to the factors to be considered in estimating vehicular activity and emissions, changes in these factors over time due to various policy alternatives, and how alternatives will perform in terms of multiple objectives generated, including emissions impacts and implementation costs.

inappropriate. Whereas CBA assumes that values for non-market goods exist, and can be discovered and measured, the M-O approach recognizes that people's values are multi-dimensional, that they are typically constructed rather than merely reported, and that they are strongly affected by context. So, whereas CBA would ask WTP questions of hundreds or even thousands of people randomly selected, the M-O approach would involve detailed interviews with a few representatives of a handful of affected and interested groups representing a wide range of views. Thus, the M-O framework would accommodate multi-dimensionality of values and substitute depth for the CBA's breadth.

The M-O framework would allow alternatives to be evaluated in terms of multiple objectives reflecting the interests and concerns of various affected and interested groups, explicitly accommodate choices in terms of trade-offs between objectives by different groups, and enable one to clearly see how these trade-offs will affect the performance of various policy alternatives for each group. This is important because, as Keeney (1988) points out, it is essential to balance the interests of affected groups if policies are to have a fair chance of success when implemented. Further, alternatives can be creatively modified in light of key trade-offs of affected groups, to make them more attractive and effective over the long term. In the Indian context, M-O would enable the vitally important equity issue to be addressed explicitly. This is in direct contrast to CBA, which analyzes policy impacts in the aggregate while ignoring distributional impacts. Finally, M-O, instead of merely measuring preferences of individuals as *consumers*, in terms of WTP (as CBA does), is more amenable to determining objectives that they as *citizens* believe would be good for society (Edwards and von Winterfeldt 1987; Gregory, Lichtenstein and Slovic 1993; Hobbs and Horn 1997; Keeney 1982; Keeney 1988a and b; Keeney 1990 and 1992; Keeney, von Winterfeldt and Eppel 1990).

Of course, the M-O approach does not eliminate the many difficulties discussed earlier in connection with the CBA framework. These difficulties relate to the selection of the range of emissions impacts to focus on, the spatial and temporal boundaries for analysis, and prediction of policy impacts. Indeed, these difficulties are inevitably common to any analytical framework. However, the technical and philosophical problems involved in the monetary valuation of policy impacts, which is unique to the CBA framework, are obviated. Perhaps

most importantly, unlike in the CBA, value judgments (in terms of trade-offs, etc.), are made explicitly and are therefore open to scrutiny.

5.7 CONCLUSIONS

The analytical framework proposed in this Chapter will hopefully enable effective prioritization of air pollutants, vehicular and transport system sources, and key urban transport and technological contributory factors for control action, and evaluation of policy alternatives targeted at transport air pollution for long-term cost-effectiveness in the Indian context. The framework focuses on air pollutant emissions due to vehicle activity, system wide. It proposes that policies be evaluated as they would be implemented, under real-life conditions, rather than in a friction-free world, and therefore explicitly considers issues typically relegated to the policy implementation phase. The framework takes into consideration key urban transport and technological contributory factors, and in-use conditions and variabilities that critically influence emissions in the Indian context. Implementation issues, such as deterioration in emissions performance over time due to in-use vehicle user operation and maintenance choices, and ineffective monitoring and enforcement, and vicious circles and side effects that typically manifest themselves over the long term, are considered. In view of the lack of reliable information in the context, uncertainties are considered explicitly, on the basis of informed expert judgments.

The framework proposes a multiple objectives approach for evaluating policy alternatives. Besides obviating the need to monetize non-financial policy benefits, which would be problematic in the Indian context, the approach enables the consideration of a wide range of emissions and other policy impacts system wide over the long term, and environmental, economic and other objectives reflecting the interests and concerns of multiple actors and affected groups, including users, vehicle and fuel manufacturers, government decision makers, and the public at large, thus allowing a sensitive discrimination between a wide range of preventive and curative policy alternatives.

Explicitly considering institutional constraints and implementation issues, multiple policy impacts for and objectives of multiple actors and affected parties, should not only minimize the risk of failure, but increase the chances of long-term policy success, while also helping

generate transport synergies. Lastly, the framework stresses the importance of subjecting the policy-analytic process to constant self-reflective re-examination and refinement, in the light of experience, thereby enabling continual learning and adaptive policy-making and implementation.

The remainder of this dissertation reports on policy-relevant research conducted by the author on M2W vehicle air pollutant emissions in Delhi. Chapter VI presents the results of elicitations of M2W vehicle user preferences, choices, and motivations related to vehicle purchase, operation, maintenance and disposal, and of their perspectives on how they would be affected by and would respond to various policy alternatives, and explores the implications of these results for policy-making and implementation. Chapter VII proposes and structures multiple objectives and measures for the purpose of characterizing the impacts of policy alternatives, along the lines suggested here.

CHAPTER VI

M2W VEHICLE USER CHOICES AND PERSPECTIVES: IMPLICATIONS FOR AIR POLLUTION PREVENTION AND CONTROL

6.1 INTRODUCTION

6.1.1 Rationale and Objectives

In Chapter IV, we discussed how the institutional setting for policy-making and implementation with regard to transport air pollution prevention and control in India is characterized by a multitude of actors and jurisdictions with fragmented, overlapping, and conflicting roles, responsibilities and interests, and constrained technological, financial, and administrative resources. Even without these constraints, transport air pollution tends to be intractable, because of its multi-point nature. Also, while technological issues inevitably play an important role, transport air pollution is critically influenced by the choices of millions of vehicle users. Lastly, the effectiveness of prevention and control policies ultimately depends on how users are affected by and respond to those policies. This is particularly important in the Indian context, given the significant proportion of users with low incomes. Transport air pollution is thus effectively characterized by millions of actors, rendering moot the common policy-analytic perspective of a single decision maker.

An investigation of the human dimensions of transport air pollution, along with a consideration of relevant technological and institutional issues, would therefore contribute to a better understanding and more effective resolution of the problem. The urban transport literature focused on the LIC context is replete with studies of mode choice and travel behaviour, and of the effect on these of urban transport policies. Examples of such studies in the Indian context include Khisty (1993), Maunder (1981), Maunder (1982), Maunder (1983), Maunder et al (1981), and RITES/ORG (1994), which is referred to in this and other chapters. However, little if any research attention has been paid, to the author's knowledge, to vehicle user behavioural factors as they specifically relate to transport air pollution, or to user perspectives on emission prevention and control policies. Additionally, the urban transport literature does not address the complex technological and policy-analytic issues involved in transport air pollution.

In contrast, the environmental policy analytic literature focusing on transport air pollution (for example Faiz et al 1992, Faiz et al 1996, and Shah, Nagpal and Brandon 1997) does a commendable job of addressing technological and policy-analytic issues. But this literature does not adequately consider key daily travel choices and motivations on the part of vehicle users, and institutional issues such as land use that determine the nature and scope of motor vehicle activity and play an important role in transport air pollution.[1] The environmental policy literature therefore tends to take the transport air pollution problem as a given, and does not pay enough attention to preventive measures focusing on the motor vehicle activity component of the problem.

This Chapter attempts to address and bridge these gaps in the two literatures. Some behavioural issues have already been touched upon in earlier chapters, including fuel adulteration, and users circumventing and/or subverting the burdensome, corruption-ridden in-use emissions testing. Based on information gathered from a questionnaire survey of, and in-depth interviews with M2W vehicle users in Delhi, this Chapter discusses user choices related to factors contributing to transport air pollution, and user perspectives on how they would be affected by and respond to various policy alternatives targeted at M2W vehicle emissions. The Chapter then explores the implications of these user choices and perspectives for policy-making and implementation, particularly in light of the institutional capabilities and constraints discussed in Chapter V.

6.1.2 Research Questions

The specific research questions that this Chapter addresses are:

- What are the important M2W vehicle user and user household preferences, choices, and motivations with respect to vehicle ownership, mode choice, daily travel, and vehicle purchasing, operation, maintenance, disposal and replacement that influence M2W vehicle activity and air pollutant emissions in Delhi?
- What are M2W vehicle user perspectives on various current, proposed and possible technological and regulatory policies, in terms of how they would be affected by and

[1] Neither does it adequately reflect the inter-dependence of transport air pollution and other transport impacts, as discussed in Chapter V.

would respond to these policies? How would users rate these policies? What measures would likely make these policies more attractive to users? What are user perspectives on public transit and bicycle commuting, and what measures would likely make these modes more attractive to them?

- What are the implications of these vehicle user choices and perspectives for policy-making and implementation with regard to transport air pollution prevention and control in the Indian context? How can these policies be better designed in light of this study?

Note that the research described in this Chapter moves the focus away from technological factors such as the vehicle, fuel and oil, to the vehicle user. Further, it describes, as well as probes motivations underlying, user preferences, choices and behaviours. The unit of analysis is the *user household.* Daily travel activity is studied in terms of all modes including M2W vehicles, in order to explore the role of other modes, particularly transit, in M2W vehicle ownership and usage. User perspectives on technological and regulatory policy alternatives as well as public transit and bicycle commuting are investigated. Lastly, the research explores linkages between user behavioural choices and perspectives and the technological and institutional factors discussed in previous chapters, thus addressing the gap between the urban transport and environmental policy analytic literatures.

The research would be helpful in modeling system-wide emissions due to M2W vehicle activity more effectively, and in developing preventive and curative measures to target not readily apparent but important user behaviours and emission sources, based on a keener understanding of user behavioural factors contributing to vehicular activity and per-vehicle emissions. It would also be helpful in more effectively modeling policy impacts for users, so that more attractive policies may be designed. Lastly, the research is intended to serve as an input in developing multiple objectives for M2W vehicle emissions prevention and control policy alternatives in Chapter VII.

6.2 METHODOLOGY

6.2.1 Research Instruments

In order to answer the research questions, the author conducted a questionnaire survey of, and in-depth interviews with M2W vehicle users in Delhi in late 1997. The study, as well as the

related research instruments, including the Informed Consent Form, questionnaire, and interview protocol (presented in Appendices VIII to X) were approved by the Behavioural Research Ethics Board of the UBC Office of Research Services and Administration. The research purpose, objectives and procedure were discussed with, and permission to conduct the study was obtained from, researchers at the Indian Institute of Technology, Delhi (IIT Delhi), which was the local institution with which the author was affiliated for the purposes of the IDRC award which partly funded the study. The IIT Delhi researchers were also requested to critically review the research instruments and offer suggestions for improvement. Some modifications were made based on their feedback, the most important of which was the addition of the section on road safety in the questionnaire survey (see below).

The questionnaire survey instrument (Appendix IX) covered the following issues:

- users' household details, income, vehicle ownership, and monthly transport expenditure;
- users' daily travel, most common destinations, mode choices, journey distances and times;
- factors influencing modal choice and M2W model selection;
- M2W vehicle disposal and replacement plans;
- users' views on bus service in Delhi, their bus usage, bus service availability and journey times between residence and workplace as opposed to by M2W vehicle, reasons for traveling by M2W vehicle or bus to work, improvements to bus service that would make it more attractive, and whether or not users would give up their M2W vehicles if bus service were improved;
- users' views on bicycle commuting in Delhi, their bicycle usage, and improvements that would make cycling more attractive;
- road accidents in which users had been involved in Delhi, and details of these accidents.

The in-depth interviews with users, the instrument for which is presented in Appendix X, explored the following issues:

- M2W vehicle purchasing, operation, maintenance, disposal and replacement preferences, choices and motivations;
- users' views as to the causes and effects of deteriorating urban air quality in Delhi, and their awareness and perceptions of vehicle emissions control measures currently in place;
- desirable characteristics of emissions prevention and control policies from their viewpoint;

- users' willingness to pay for vehicle technology and fuel quality improvements, and the minimum acceptable vehicle scrappage period; preferences among, and how they would be affected by and would respond to, these alternatives; and trade-offs in terms of benefits they would expect to receive in order to accept increased costs and that would make these alternatives more attractive to them.

6.2.2 Study Participants, Household Characteristics and Vehicle Ownership

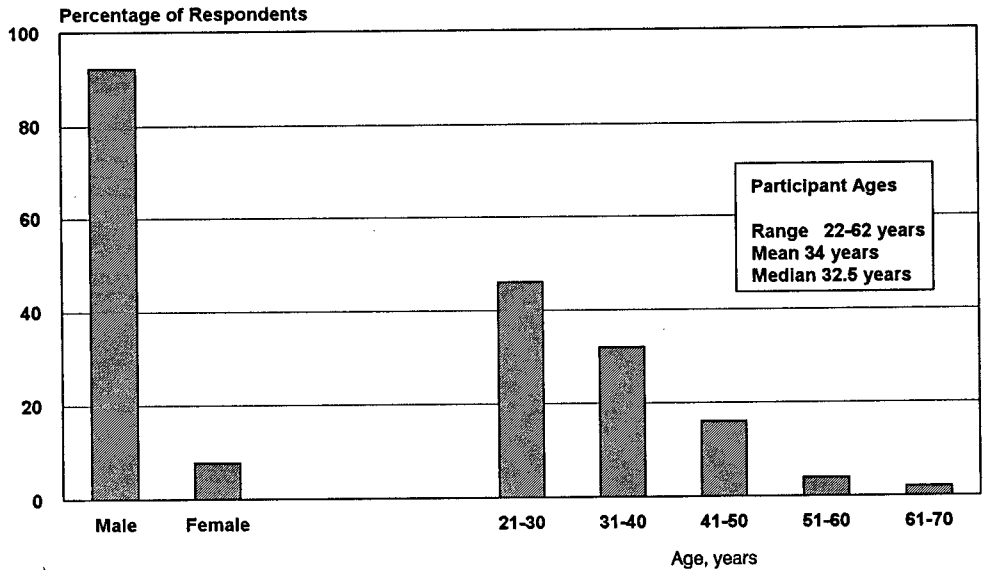
Several considerations influenced selection of study participants. First, all of them obviously had to be M2W owners and users. Time and resource constraints necessarily limited their number. Participants would have to be willing to spend a total of 1.5 hours to answer the questionnaire and to engage in the interview. And they would need to be easily available for follow up. This requirement became especially critical in view of the decision to conduct the survey and interview at separate times (see below). For all of these reasons, it was decided to recruit volunteers at IIT Delhi, Tata Energy Research Institute (TERI), the All India Institute of Medical Sciences (AIIMS) and the Armed Forces Research and Referral Hospital, with the help of personnel at these institutions. Some participants were also recruited in residential areas in the adjoining state of Uttar Pradesh, from where people commute daily to and from Delhi.

In all, 51 M2W vehicle users participated in the study. Figures 6.1 to 6.5 depict the distribution of the participants in terms of gender, age, household size, earners per household, and total and per capita household income. Also presented are the corresponding data from the RITES/ORG (1994) survey for the purposes of comparison.

Only four of the 51 participants were female. One reason for the low female representation may be that females were in a minority in the institutions where participants were recruited, though there is a large and growing number of female employees in many Indian workplaces, particularly in offices.

Survey of M2W Vehicle Users in Delhi, 1997

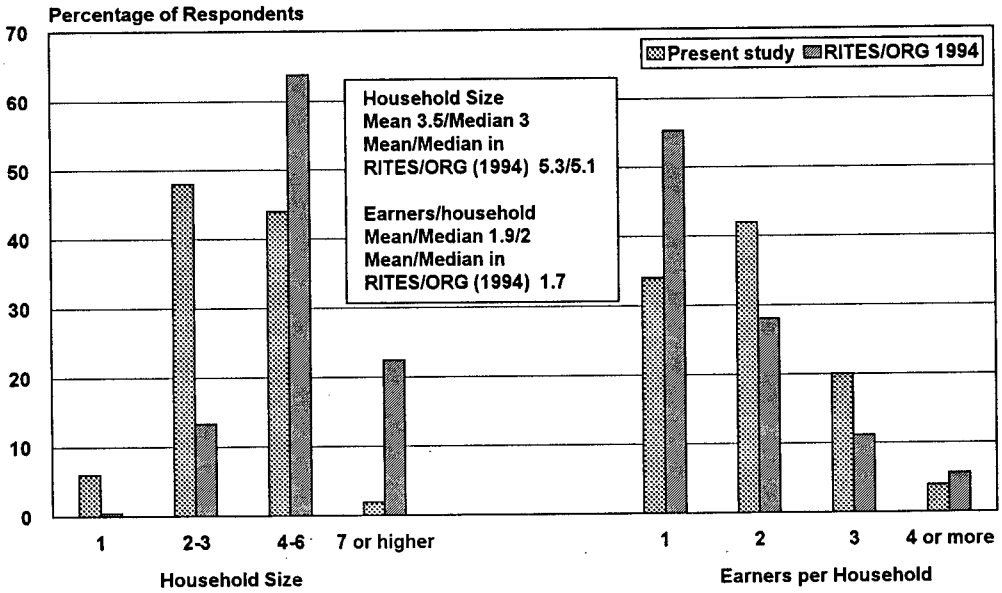
Figure 6.1 Gender and Age Distribution of Participants



n = 51 for gender, 50 for age. M2W Vehicle -- Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997).
mgb00

Survey of M2W Vehicle Users in Delhi, 1997

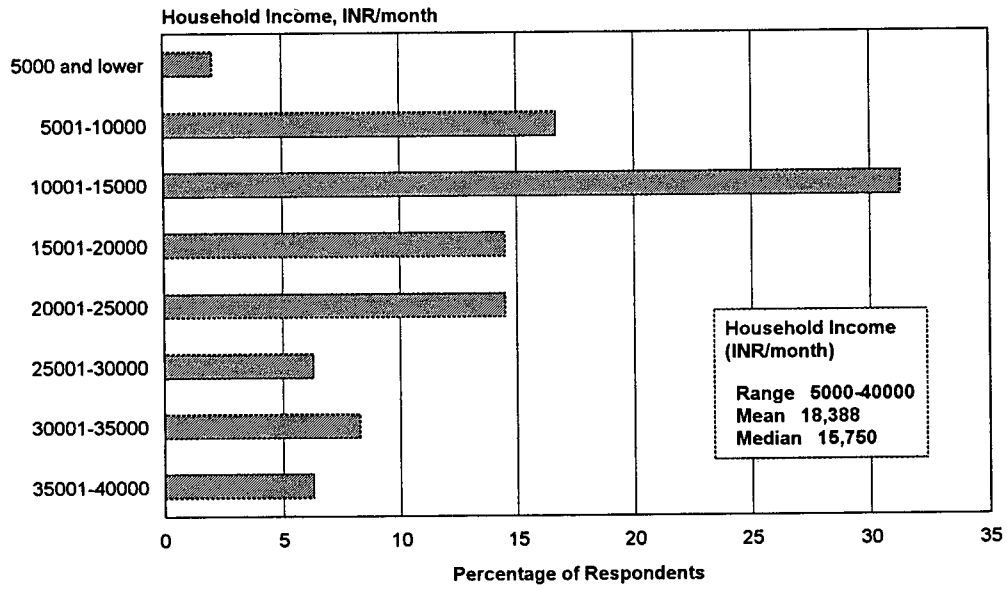
Figure 6.2 Distribution of Participants by Household Size and Earners per Household



n = 50 for present study, 18721 for RITES/ORG (1994). M2W Vehicle – Motorized two-wheeled vehicle. Sources: Author's survey and interviews (1997); RITES/ORG (1994).
mgb00

Survey of M2W Vehicle Users in Delhi, 1997

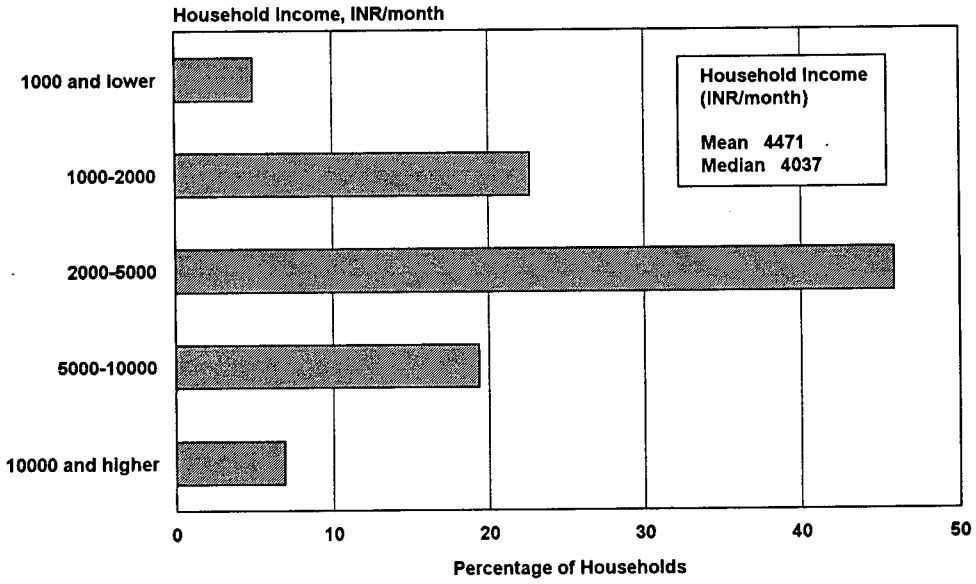
Figure 6.3 Distribution of Participants by Household Income



n = 48. M2W Vehicle – Motorized two-wheeled vehicle; INR – Indian Rupees. Source: Author's survey and interviews (1997).
mgb00

Survey of M2W Vehicle Users in Delhi, 1997

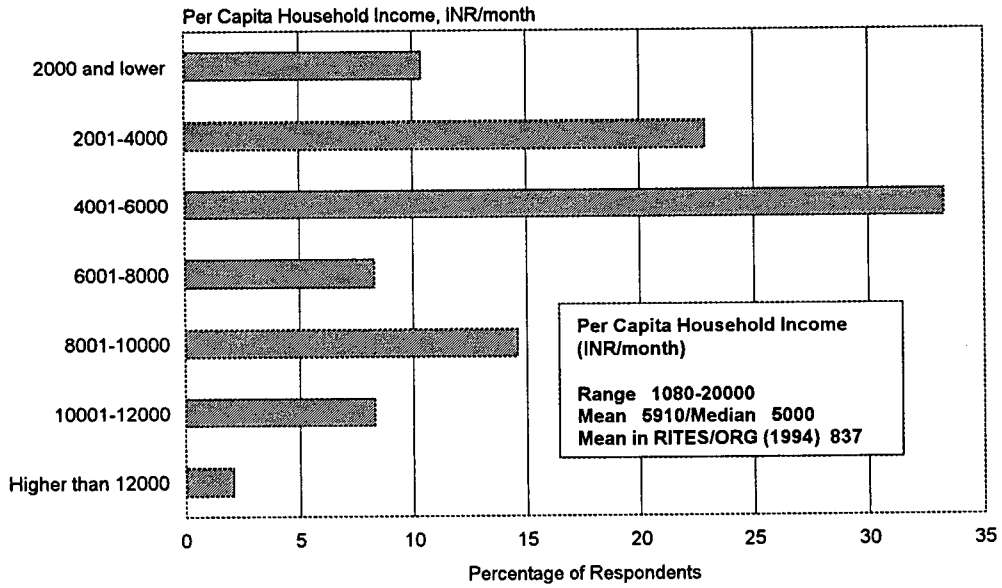
Figure 6.4 Distribution of Survey Households by Household Income in RITES/ORG (1994)



n = 18721. M2W Vehicle – Motorized two-wheeled vehicle; INR – Indian Rupees. Source: RITES/ORG (1994). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.5 Distribution of Participants by Per Capita Household Income



n = 48. M2W Vehicle -- Motorized two-wheeled vehicle; INR -- Indian Rupees. Sources: Author's survey and interviews (1997); RITES/ORG (1994).
mgb00

No data on the gender distribution of Delhi's M2W vehicle users are available, but the percentage of females among the study participants is also likely reflective of the predominance of males among M2W and other personal motor vehicle drivers (but not users) in the Indian context.[2] Participants' households included 16 joint families,[3] representing nearly one-third of the study sample. This fact is interesting from an urban transport perspective. The decline in joint families has important implications for vehicle ownership and use, as indeed for consumption generally. Five of the participants were single males. In comparison with RITES/ORG (1994), the study sample had a higher percentage of smaller households, a larger number of earners per household, and higher household incomes (Figures 6.2-6.5), and thus higher per capita incomes. This pattern was likely due in part to the recruiting procedure discussed earlier. Additionally, the present study focused only on M2W vehicle users as

[2] Public transit usage is likely high among females. Also, a significant proportion of public transit users are likely females, with important implications for public transit design. Unfortunately, no study that the author is aware of, including RITES/ORG (1994), breaks down travel on various modes by gender.

[3] Joint families are here defined as couples and their families, living together with siblings and their families and/or aged parents.

opposed to the RITES/ORG (1994) survey, which included many low-income households owning no motor vehicles. Further, and perhaps most importantly, urban incomes (and vehicle ownership) likely increased rapidly between 1991, the year for which income data was quoted in RITES/ORG (1994), and when economic liberalization was initiated in India, and 1997, the year of the present study.

Table 6.1 details the distribution of vehicle ownership among the participants. Interestingly, there was a tendency for participants to leave out bicycles (and old disused motor vehicles) in their questionnaire responses, even though they were expressly directed to include all household vehicles. Another important point from a methodological perspective was the tendency for participants to either include vehicles belonging to family members (such as parents) living in separate households that they used, or to exclude vehicles belonging to extended family members living in the same household. All such omissions and additions commonly came to light in the follow-up questioning during the personal interviews.

Around 49 and 14% of the participant households owned one and two M2W vehicles respectively (but no cars), and the remaining 37% owned at least one car in addition to their M2W vehicle(s). Only 28% of the households owned one or more bicycles (Table 6.2).[4] Cycle ownership was only 34.4% of households even in the RITES/ORG (1994) survey, which included all income groups.

In the same survey, which included many households with no motor vehicles, around 16% of the households owned cars. Further, as discussed in Chapter V, those with incomes of INR (Indian Rupees) 2000 and above in that survey, roughly corresponding to the participants in the present study, accounted for 72% of all households, and around 93% of total household M2W vehicles and M2W vehicle trips. Finally, around 15% of the M2W vehicles, and 36% of the cars belonging to all households in the present study were second hand. Notwithstanding the foregoing, the sample in the present study is by no means representative of all M2W vehicle users in Delhi.[5] However, it may be considered adequate in terms of achieving the

[4] All but one of the households owned a refrigerator, all but two a television set.

[5] Note in this regard that even the large-scale RITES/ORG (1994) study on travel behaviour in Delhi was focused on the residential population of the Delhi urban area only, and did not cover the homeless, and floating populations (RITES/ORG 1994).

study objective, namely to gain insights into vehicle user choices and motivations with relevance for transport air pollution, and into how users would be affected by and respond to various policy alternatives targeted at M2W vehicle emissions, in order to inform policy-making and implementation in the Indian context. Indeed, while resource constraints were an important consideration, the sample size was also the result of a conscious decision to have a small number of participants, and to engage them in a detailed survey and in-depth one-on-one interviews. Lastly, the fact that M2W vehicle technology and fuel quality improvements and vehicle scrappage similar to those posed as hypotheticals in this study were being or were proposed to be implemented at the time of the study, contributed to its relevance.

Survey of M2W Vehicle Users in Delhi, 1997

Table 6.1 Vehicles Owned by Participants' Households

Vehicles Owned	Number of Participants	Mean Per Capita Household Income (INR)	Number of 2nd hand M2W Vehicles	Number of 2nd hand Cars
1 M2W Vehicle	17	4879	5	
1 M2W Vehicle + 1 Bicycle	7	5000		
1 M2W Vehicle + 2 Bicycles	1	1500		
2 M2W Vehicles	5	5667	1	
2 M2W Vehicles + 1 Bicycle	2	5000		
1 M2W Vehicle + 1 Car	12	7606	1	4
1 M2W Vehicle + 1 Car + 1 Bicycle	3	8333	1	1
2 M2W Vehicles + 1 Car	2	8500		1
1 M2W Vehicle + 2 Cars + 1 Bicycle	1	5250		
1 M2W Vehicle + 3 Cars	1	-		2
Total	51		8	8

n = 51. M2W – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

6.2.3 Implementation of the Study

Most of the M2W vehicle users who were requested to participate in the questionnaire survey and in-depth interviews were more than willing to do so. However, many participants were concerned about the time commitment they would have to make. The original intention was to have 5-6 users complete the questionnaire and then participate in a focus group discussion immediately afterward. But this plan could not be implemented because participants were

dispersed geographically. Further, almost all the participants wished to be interviewed individually, preferably at their desks, and when they were free. Lastly, many participants canceled appointments for interviews on several occasions.[6] For all of these reasons, it was decided to have participants complete the questionnaire first, and then conduct in-depth discussions with each of them individually at their convenience. It was also decided that the author should conduct all of the interviews himself. Though time-consuming, this procedure paid dividends in terms of the richness of the information obtained. Conducting the interviews after going through questionnaire responses enabled the author to encourage participants to clarify and expand on questionnaire responses, if they so wished, and to probe the motivations underlying the preferences and choices expressed.

Participants' informed consent was obtained prior to their participation in the study. All participants were thanked with a diary.[7] Questionnaires were returned by 50 participants. Individual interviews were held with 29 of them. The remaining 22 who could not be interviewed personally were requested to complete a supplementary questionnaire instrument (Appendix XI), which contained the most important questions from the interview protocol. Fifteen participants responded to these questionnaires. One person returned the supplementary questionnaire completed but not the main questionnaire. Effectively then, 44 of the 51 participants completed the main questionnaire, and were also either interviewed or completed the supplementary questionnaire (Table 6.2).

	Number of Participants
Completed main questionnaire + were interviewed	29
Completed main and supplementary questionnaires	15
Completed only main questionnaire	6
Completed only supplementary questionnaire	1
Total	**51**

Table 6.2 Breakdown of Participant Response to Study Instruments

[6] To make matters worse, there was a major bus strike in Delhi in November 1997, following a Supreme Court ruling mandating strict licensing requirements for bus drivers after a tragic accident in which a bus with a hundred school children plunged into the Yamuna. Because of the strike, several of the participants did not attend work, and interviews scheduled with them had to be postponed. While frustrating, this event alerted the author to the fact that many M2W vehicle users commonly use the bus for their journey to work, a fact that is discussed later in the chapter.

[7] Money payments were rejected as a means of expressing gratitude for participation, because of their inappropriateness in the Indian context.

Eliciting information from interviewees is, as Gregory et al (1993) point out, a matter of *architecture* rather than *archaeology*, in the sense that responses are not *unearthed* readily formed and intact. Rather, they are *constructed* and *shaped* in the process of interaction between the interviewer and respondent, by the content of questions, and the manner in which they are posed. In terms of the present study, open-ended responses were encouraged to several questions in the main and supplementary questionnaires. The face-to-face interviews were conducted as a conversation between equals, rather than as a mere question-and-answer session between interviewer and interviewee. The interviews were characterized by a free ranging discussion of the transport air pollution problem and policies to address it, within the larger context of user household daily travel activity and living, with questions and responses clarified by both the author and participants, in order to capture their precise meanings. Participant responses were forthright, carefully considered, and often detailed, complex and nuanced. This reflected the complexity of the issues involved, and of participants' perceptions of and responses to them.

Several participants challenged the premise of certain questions, such as those related to willingness-to-pay (WTP) and mandated vehicle scrappage. In several instances, they also chose to respond to questions as *citizens* rather than as *consumers*. Following are some examples: 'This concept of WTP for clean air is foreign to Indians. Just because I say I will not pay anything extra does not mean that I am not concerned about air quality. I am definitely concerned, but I can pay only what I can afford." And, 'I can afford ..... rupees (or afford to dispose of my vehicles in ... years), but what about low-income people? You have to think about them". Such responses serve to reinforce the value of the study in terms of gaining insights into the interests and concerns of Delhi's M2W vehicle users.

Many participants expressed the view that engaging in the survey and in-depth interviews was an interesting and even educational experience for them, since they were forced to think explicitly about how they make choices.

6.2.4 Analysis and Discussion of Study Results

All survey questionnaire, interview and supplementary questionnaire responses were entered on a spreadsheet. Responses were analyzed on the basis of measures of central tendency,

maxima and minima, and ranges. Additionally, an attempt has been made to convey the rich complexity of participant responses, based on extensive notes made by the author during the in-depth interviews.

The discussion of results below covers the following broad areas: mode choice; daily travel activity; vehicle purchase, operation, maintenance, disposal and replacement; and participant perspectives on policy alternatives. For each of these areas, the specific questions in the survey questionnaire (Appendix IX), the interview protocol (Appendix X), and/or the supplementary questionnaire (Appendix XI) on which the discussion is based are reproduced. Pertinent methodological issues, such as how non-responses and outliers were treated, are discussed. The relevant sample size in each case is indicated in the related graphic, which presents the descriptive statistics. The results are presented, followed by a discussion of their implications for transport air pollution, and for policy-making and implementation.

6.3 RESULTS AND DISCUSSION

6.3.1 Factors Contributing to Choice of M2W Vehicle as Travel Mode

The Introduction stressed the importance of addressing user motivations, and institutional issues such as land use that influence motor vehicle ownership and usage, which is a critical component of the transport air pollution problem. This section discusses user motivations that drive M2W vehicle ownership and usage in Delhi, based on participant responses to the questions shown in Table 6.3.

Results The factors that participants most frequently indicated as influencing choice of residential location were affordability, and the fact that they were living in their family homes, typically in extended families. As noted earlier, 16 participants reported living in joint families. Most participants expressed serious concerns about unaffordable housing close to work. Rents had apparently increased 2-3 times in a mere 3-6 years, even for small homes. According to many participants, this was due to the entry of multinational corporations, which paid huge salaries to their employees. Because of this situation, many participants reported living far from their workplaces. The mean journey-to-work (JTW) distance reported by participants was 14.9 km, and around 35% reported living 20 kilometres or more from their

workplaces (Figure 6.6). Many participants reported living on the outskirts, where rents were 3-6 times lower than in South Delhi. Several commuted daily from the adjoining states of Haryana and Uttar Pradesh. Less than 25% reported living five kilometres or less from work (Figure 6.6). Many of these participants lived in government allotted quarters. One participant complained that because of high rents, his spouse was forced to work, thus necessitating additional household vehicle trips, not to speak of increased family conflict and stress.

Participants indicated that the most important problems associated with traveling in Delhi were congestion, poor bus service, air pollution, and lack of road safety. Other problems included long waits at intersections, and time losses. With regard to bus service in Delhi, the vast majority of respondents reported having used the bus at one time or the other in the city (Figure 6.7). Around 45% of respondents rated bus service in Delhi to be poor. Of the 30% who rated bus service as good, more than half used a limited seating, express charter bus service either exclusively or at least a few days monthly to and from work, and one participant lived close to work and was therefore largely not dependent on buses. Nearly 45% of respondents reported no substantial change in bus usage compared to five years earlier (Figure 6.7). Of the remainder, twice as many reported substantially higher usage five years earlier than presently as those that reported the reverse.

The most common bus service problems reported were extreme overcrowding, particularly during peak hours, and the lack of service reliability. Other problems included poor service during off-peak hours, lack of coverage, particularly on the outskirts, unsafe driving by and rude behaviour of personnel, long wait and journey times, and the poor condition of buses. Many respondents remarked on the sexual harassment female passengers had to deal with, and the hazard of pickpockets. Many also indicated that the private 'Blue Line" buses, because of the profit motive, stopped to pick up passengers at unscheduled stops, causing over-loading and inordinate journey times, and that the police were often bribed to avoid being fined for overcrowding. On the other hand, the publicly owned DTC buses often did not stop even at designated stops. For these reasons, it was impossible to travel with ladies, children and the elderly.

Issue	Questions
Choice of residence location, and influencing factors; distance between residence and work	Please indicate the locality and the street in which your home is (situated). (MQ, under Personal Information) What are the factors that determined your choice of residence location? If you live far from your place of work, why do you do so? (IP, Q7; SQ, Q3) Trip distance between residence and work (MQ, under Daily Travel)
Problems associated with travel in Delhi generally	What do you see as the main problems related to travel in Delhi, and how have these influenced your choice of vehicle modes and models? (IP, Q5; SQ, Q2)
Opinions and usage of bus and cycling facilities	Have you ever used a bus in Delhi?; What is your opinion of the quality of the bus service between your residence and your most common daily destination?; What according to you are the main problems with bus service in Delhi?; How many times have you ridden in a bus in the last month?; How many times did you ride in a bus in a month five years ago? (MQ, under Perceptions of Bus Service in Delhi) Have you ever cycled in Delhi?; What is your opinion of bicycle commuting in Delhi?; What according to you are the main problems related to bicycle commuting in Delhi?; How many times have you cycled in the last month?; How many times did you cycle in a month five years ago? (MQ, under Perceptions of Bicycle Commuting in Delhi) Are other modes accessible to you? Buses? Bicycles? If so, but you do not use them, why not? What according to you are the main disadvantages of these modes which prevent your using them? (IP, Q3)
Journey times by M2W vehicle and bus	What is the approximate journey time between your residence and your workplace: by bus; by motorized two-wheeler? and How long would it take you to walk to the nearest bus stop from where you live?; from your common daily travel destination? (MQ, under Perceptions of Bus Service)
Road accidents in which users were involved	How many times have you been involved in a road accident? Describe the most serious road accident in which you were involved. (MQ, under Road Safety in Delhi)
Factors that influenced users' choice of M2W vehicles for travel in Delhi	Name the two most important reasons why you chose a motorized two-wheeler as your vehicle for traveling in the city (MQ, under Motivations) Please indicate the importance of the (listed) factors that influenced your choice of motorized two-wheeler as your vehicle for traveling in the city (MQ, under Motivations) What according to you are the main advantages of the motorized two-wheeler which influenced your using it (in comparison to other modes)? (IP, Q1)

Note: MQ -- Survey Questionnaire (Appendix IX); IP -- Interview Protocol (Appendix X); SQ -- Supplementary Questionnaire (Appendix XI); Q -- Question.

Table 6.3 Questions Related to Mode Choice

Nearly 41% of the respondents reported never having cycled in Delhi (Figure 6.8). A majority of those who expressed an opinion on the city's cycling facilities rated them to be poor. Of the 14 respondents who rated them fair or good, six had never cycled in Delhi, 11 were not cycling at the time of the study, and three were cycling or used to cycle only in

secluded local neighbourhoods. Only one participant reported substantially higher bicycle use at the time of the study compared to five years earlier. This person lived far from the city centre. The most common bicycle commuting problems indicated were lack of road safety, rash driving by motor vehicle users, congestion, the lack of cycle lanes, long journey distances and times, and air pollution. Many respondents reported that cycling was simply unthinkable in Delhi. With regard to road safety, nearly 57% of respondents reported having been involved in one or more road accidents (Figure 6.9).[8]

The reasons indicated as most important in choosing a M2W vehicle for travel in Delhi were affordability of ownership, operation and maintenance, easy maneuverability in congested traffic, time savings, easy availability and purchasability, 24-hour accessibility, ease of parking and accessing hard to reach locations, the poor quality of bus service, independence, and reliability. Interestingly, many of these reasons anticipated the influencing factors participants were asked to rate in the questionnaire. Reliability in getting to destinations in time, door-to-door capability, minimizing journey time and 24-hour accessibility were rated as important by the most respondents, and status/prestige by the least (Figure 6.10).[9]

Discussion The rapid growth in M2W vehicle numbers and activity in Delhi and other Indian cities may well be enabled by rising family incomes, easy vehicle and credit availability, and driven by advertising and social pressures.

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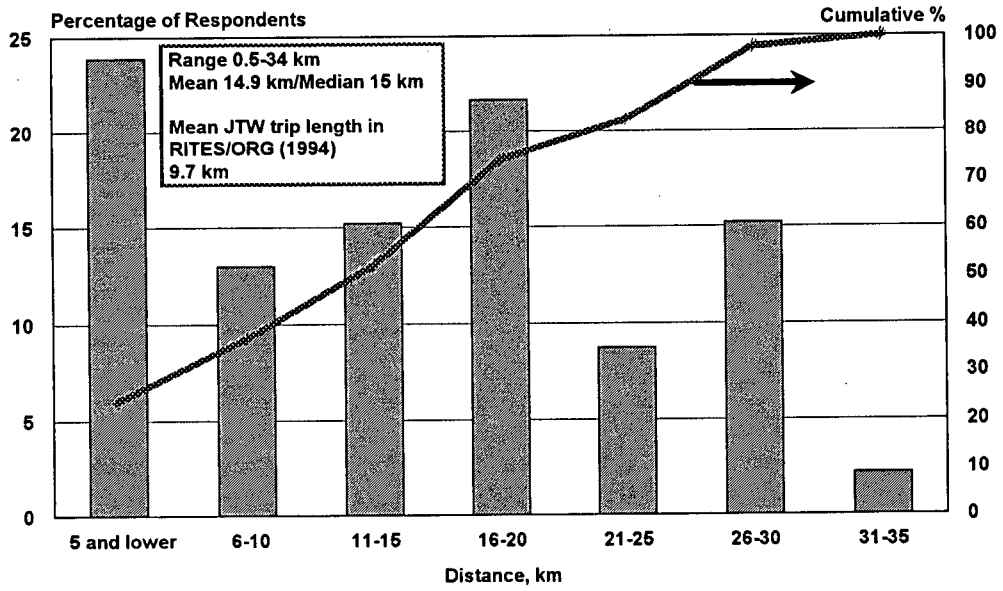
[8] Twenty-three participants described their most serious accident. A few interesting points emerge. Not one of the accidents was reported to the police. Many participants indicated that they believed reporting to the police would only make a bad situation worse. Several of the accidents were "hit and run" cases, with the perpetrators rarely being brought to book. Trucks were involved in many of the accidents. A number of the accidents involved animals. Incidentally, trucks and buses are most commonly responsible for road accident mortalities in Delhi (Mohan and Tiwari 1997; Mohan, Tiwari and Kanungo 1997).

[9] Following are some individual responses that serve to shed light on the range of influencing and enabling factors: "My husband has a good bus schedule to his workplace, but I do not, so we bought a scooter for my sake"; "A M2W vehicle allows me to reach the nooks and crannies of places" (an expressive way of saying ease of gaining access to hard to reach locations); "If it were not for an attractive financing scheme introduced by (my employer) just 1.5 years ago, which covered 80% of the vehicle cost, repayable in 54 installments at 12% of the unpaid balance, it would have been difficult for me to purchase my M2W vehicle".

Survey of M2W Vehicle Users in Delhi, 1997

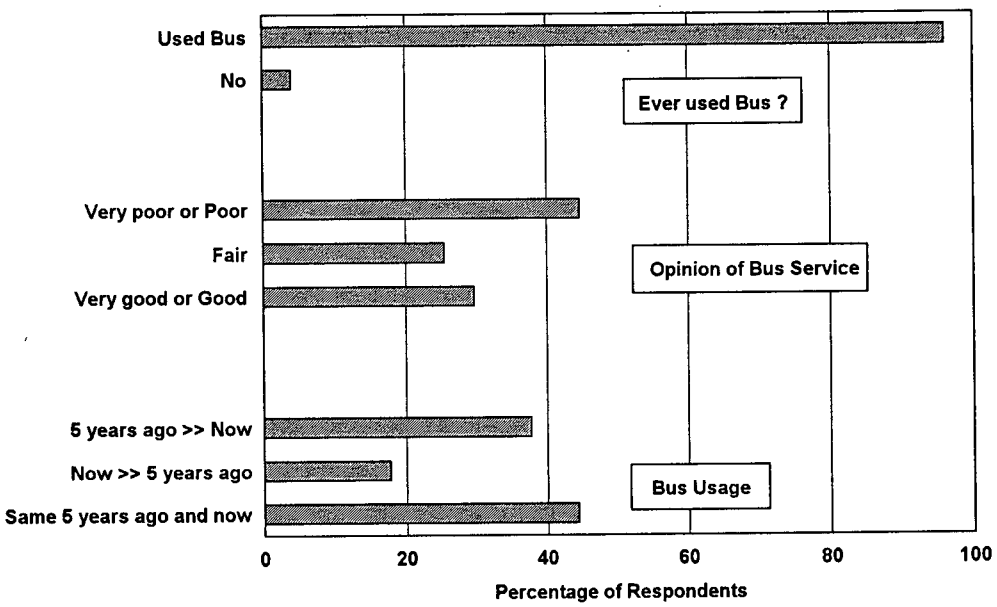
Figure 6.6 Participants' Journey-to-Work Trip Lengths



n = 46. M2W Vehicle – Motorized two-wheeled vehicle; JTW – Journey-to-Work. Sources: Author's survey and interviews (1997); RITES/ORG (1994). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

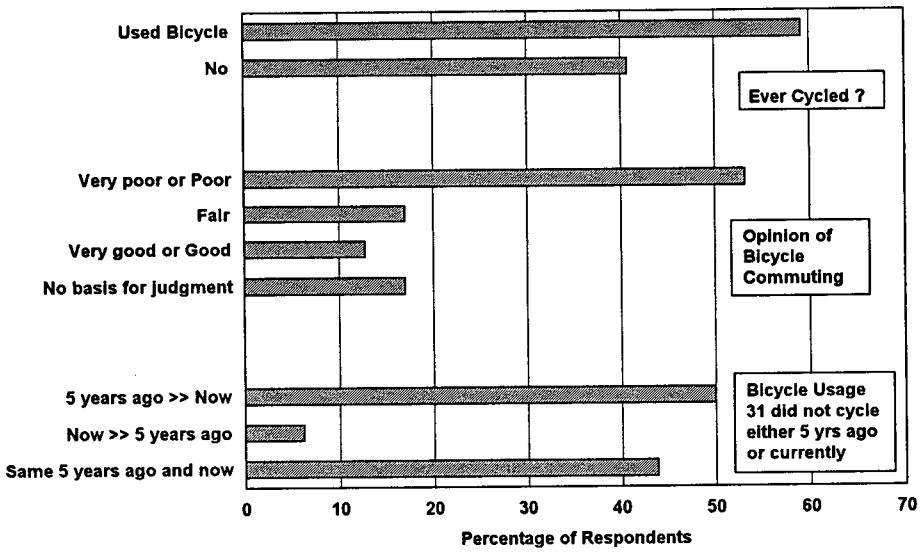
Figure 6.7 Participants' Opinions and Use of Bus Service



n = 51 for Bus Usage; 47 for Bus Service Opinion; 45 for Bus Use 5 years ago and now. M2W Vehicle – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

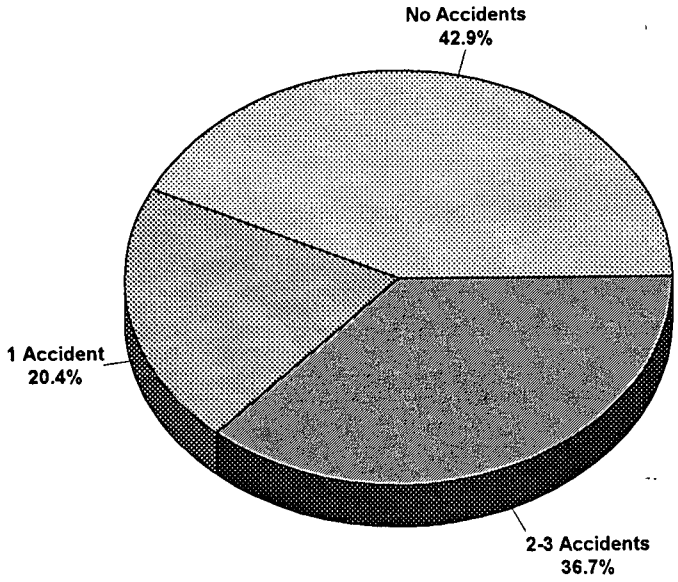
Figure 6.8 Participants' Opinions and Use of Bicycle Commuting



n = 49 for Bicycle Usage; 47 for Opinions on Bicycle Commuting; 16 for Bicycle Use 5 years ago and now. M2W Vehicle -- Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

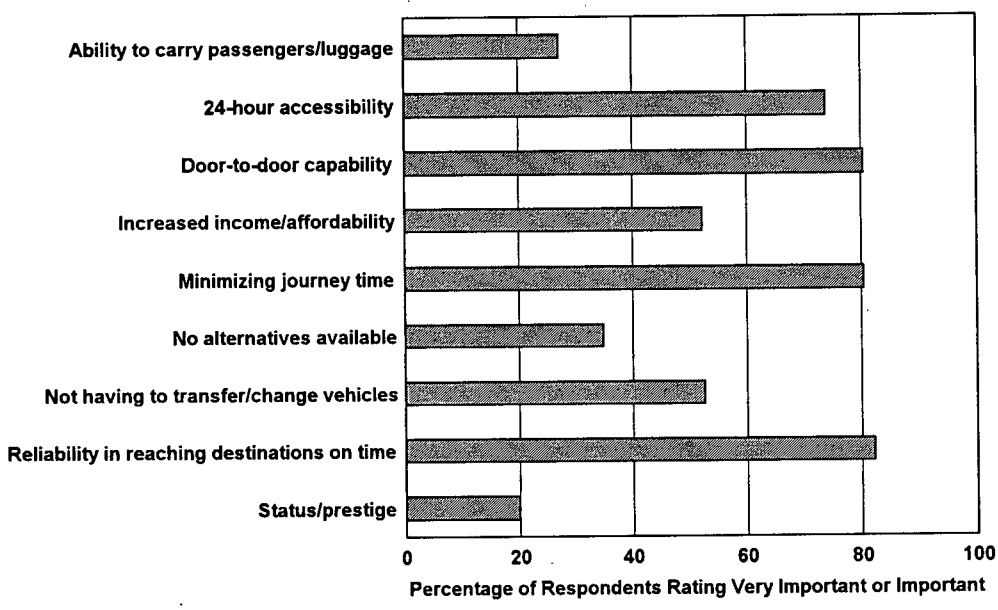
Figure 6.9 Participants' Involvement in Road Accidents



n = 49. M2W Vehicle – Motorized Two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

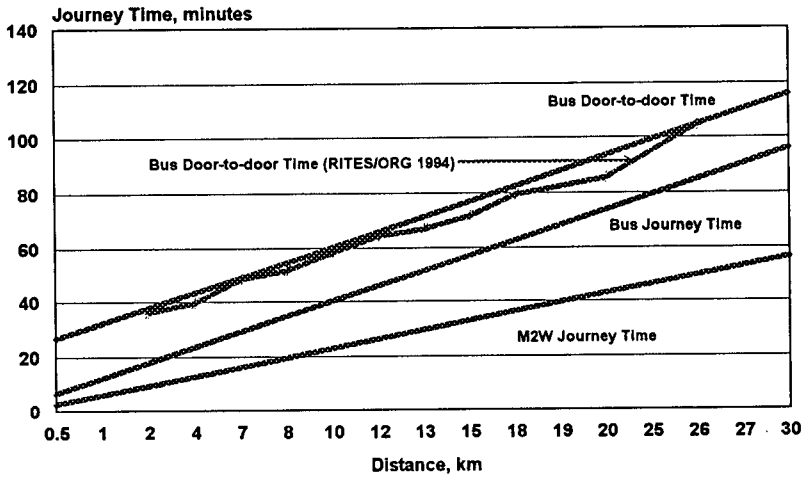
Figure 6.10 Rating of Factors Influencing Choice of M2W Vehicle as Travel Mode



n varies from 38 to 46 for various factors. M2W Vehicle – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.11 Participants' Journey Times for Work Trips – M2W Vehicle versus Bus



n = 49 for M2W, and 47 for Bus journey times. M2W Vehicle – Motorized two-wheeled vehicle. Sources: Author's survey and interviews (1997); RITES/ORG (1994). mgb00

But this growth is at least as importantly also a response to the circumstances people find themselves in, in terms of increasing home-work distances due to rapidly rising rents close to work, increasing congestion (due to motor vehicles), compromised access, lack of road safety, time losses, and poor bus service.

With regard to JTW distances, the mean reported by participants in this study (14.9 km), is much higher than the corresponding figure (9.7 km) reported in RITES/ORG (1994).[10] This may be because several participants commute long distances from their homes outside Delhi, whereas RITES/ORG (1994) focused on residential households within the Delhi Urban Area. Considering that tens of thousands commute to Delhi from outside the city, thereby contributing to transport air pollution, the JTW distances in RITES/ORG (1994) may be an underestimate from this standpoint. Attitudes toward bicycle commuting reported by participants merely reflect the rapid decline in bicycle mode shares (Figure 2.17 in Chapter II). This decline is not surprising, considering the poor road safety, as reflected in the large number of accidents reported by participants.

Personal motor vehicles have become a forced choice (and expenditure) in the face of the lack of viable options. Buses are used only as long as unavoidable, and since cars are out of reach of all but a few, a M2W vehicle is purchased as soon as possible.[11] In this regard, it is notable that the factors rated as important by the most participants relate to accessibility, reliability and journey time, all of which have been compromised by the travel problems discussed, and that the bus service does little to alleviate. Not surprisingly, M2W vehicle journey times reported by participants for the JTW compared favourably with those by bus, also reported by participants (Figure 6.11).[12] All in all, it is not surprising that M2W vehicles

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[10] The mean total daily kilometres traveled on the M2W vehicles in participants' households was 29.6 km. This figure is also higher than that quoted in other references, for example, Bose (1996).

[11] As one participant remarked, "if you make my life chaotic, a M2W vehicle is what I am forced to use". According to another participant, the M2W vehicle had become "the salaried person's best friend". He would ideally like to use his M2W vehicle only sparingly, and maximize bus use, on account of poor road safety. But because of the poor bus service, he is forced to use his M2W vehicle for all purposes, and with his wife and nine-year old son as passengers. Of course, M2W vehicles are not every "salaried person's best friend". While family incomes have certainly increased (for many but not all), so have M2W vehicle prices. An examination of prices over the years for new scooters in the present study revealed roughly a two-fold increase over just the last 10 years. Affordability has increased for some but not for all.

[12] It should be noted that in Figure 6.11, the journey times would approximate the door-to-door times for M2W vehicles, but not for buses. Door-to-door times were estimated for buses by adding the average walking time to and from bus stops of 6.2 minutes, which, incidentally, compared well with the 6.5 minutes reported in

are so much preferred. They are much faster than buses up to 25 kilometres and beyond (Figure 6.11),[13] and also no more than five minutes slower than a car (RITES/ORG 1994). Yet, they cost a fraction of what cars do.

6.3.2 Daily Travel Activity

This section focuses on daily travel activity on the part of M2W vehicle users and members of their households, in terms of the most common trip purposes, the modes used for these purposes, and the motivations for choosing these modes (including M2W vehicles). Among other things, the discussion in this section is intended to provide insights into the trip purposes for which M2W vehicle users would be willing to transfer to other modes, particularly public transit. The discussion is based on participant responses to the questions shown in Table 6.4.

Results All except two of the 51 participants indicated that their workplaces were their most common daily travel destinations; for the two, this was an educational institution. This break-down is merely a reflection of the participants recruited for the study. Unfortunately, travel destinations were not reported for all household members, in particular for housewives and the elderly. Thus, it is likely that shopping and other domestic trips were under-counted. But assuming that the most common daily trips for all household members listed as employed were work trips, and that those for all children of school-going age were education trips, work and education were the most common daily trip purposes for 54 and 20% of the household members respectively.[14]

RITES/ORG (1994), and the average wait time of 7.5 minutes (from RITES/ORG 1994), to the journey times reported by participants. Interestingly, this graph for buses matches well with that generated by using data from RITES/ORG (1994) exclusively.

[13] Note that the RITES/ORG (1994) graph for buses in Figure 6.11 was based on data that applied to all trips, whereas the graph based on the present study used data on JTW trips. This may partly explain why the door-to-door times are slightly longer in the latter case. It is likely that for long distances, the difference in journey and door-to-door times between bus and M2W vehicles would reduce, because over such distances, buses would likely use higher speed roads, with fewer stops.

[14] Of the 177 household members including the participants, there were 39 housewives and retirees, and 8 infants.

Issue	Questions
Most common and other trip purposes, for participants and household members	MQ, under Household Details and Daily Travel
Modes used for these purposes, by participants and household members	MQ, under Household Details and Daily Travel If you continue to use other mode(s), what purposes do you use them for and why, and for what purposes do you use your motorized two-wheeler, and why? (IP, Q4) Please list all vehicle modes you use -- two-wheeler, bus, auto, rickshaw, car, etc., and indicate the purposes you typically use each vehicle for (SQ, Q1)
Motivations for mode choice	(If bus service is available between where you reside and your place of work), if you use a motorized two-wheeler to work, why?; if you take the bus rather than your motorized two-wheeler, why?; What would the bus fare be? (MQ, under Perceptions of Bus Service in Delhi)

Note: MQ -- Survey Questionnaire (Appendix IX); IP -- Interview Protocol (Appendix X); SQ -- Supplementary Questionnaire (Appendix XI); Q -- Question.

Table 6.4 Questions Related to Daily Travel Activity

Nearly two-thirds of the participants conducted work and education trips on their M2W vehicles. But just over a quarter reported choosing to travel by bus either daily or on many days monthly (Figure 6.12). Close to half of these participants also had cars in their households. On the other hand, among household members for whom modes were indicated for their work and education trips, only around 18% reported using a M2W vehicle for these purposes. Nearly 40% reported traveling by bus daily, and another 14% at least some days every month (Figure 6.12).

Whereas the mean JTW distance for all respondents was 14.9 km, as already noted, it ranged from 16 to 30 km, and averaged 23 km, for those respondents who reported using the bus either daily or on most days of the month for this trip purpose. Several respondents indicated that they preferred to take the bus in order to insulate themselves from the congestion, air pollution and accidents caused by motor vehicles, and to reduce stress. One respondent said that when congestion was much lower five years earlier, he used to commute to work only by M2W vehicle, but had switched to buses because of the deteriorating traffic situation. Weather was also reported as a factor. Some respondents reported using the bus to and from work when it rained.

Respondents reported that they and their families used buses for many of their trips (including work trips, as noted), and in fact picked and chose from a wide range of modes, depending on trip purpose and destination, day of the week, and time of day. Their M2W vehicle or car, or occasionally a M3W vehicle or even rickshaw, was used for shopping and social trips, often with family, in the evenings or on the weekend.[15]

Discussion The predominance of work and education trips observed in this study is borne out by RITES/ORG (1994) as well. In that survey, these two purposes accounted for 52 and 43% of all trips respectively in Delhi.

It is notable that, while M2W vehicle ownership is at least in part a response to increasing congestion, time losses, and poor bus service, so much travel in M2W vehicle owning households should be conducted on buses. It is also notable that M2W vehicle owners should use buses precisely because of the same conditions contributing to M2W vehicle ownership. It is hardly surprising that bus modal shares have been growing, not declining (Figure 2.17 in Chapter II), despite the state of Delhi's bus service.

The higher bus usage rates for household members as opposed to the study participants is not surprising, considering their demographics,[16] the much higher share of education trips among the former, and the fact that bus usage for education trips is considerably higher than for work trips (RITES/ORG 1994). And after all, only one member can use the household M2W vehicle at a time. The significant use of buses by M2W vehicle owning households for work and education trips is also borne out by the RITES/ORG (1994) survey. According to this survey, 42% of such trips in these households, and 38% of trips for all purposes, are

[15] One participant indicated that he and his wife used to travel together to work on their motorcycle, which was also used for all other purposes. But after their child was born, they purchased a second-hand car, which they now drove daily to and from work, dropping off their child at the wife's parents' home en route. The motorcycle was now used for shopping trips with his wife, and his car for family trips. Another participant, who lived in Gurgaon in the adjoining state of Haryana, took a charter bus on most days with his wife, whose workplace in Delhi was close to the participant's, though it was more expensive than if they traveled together on their scooter. They left their infant child in the care of their maid, and if the maid was late, the wife traveled by bus, while the participant took his scooter to work.

[16] In the RITES/ORG (1994) survey, which showed that buses accounted for the largest proportion (42%) of trips of any mode in Delhi, nearly 60% of individuals surveyed were housewives, students, retirees, or unemployed persons. It is reasonable to expect bus usage to be high among these groups.

conducted by bus, as against only 23% of work and education trips, and 29% of trips for all purposes, by M2W vehicles.[17]

What is surprising is the bus usage by the participants themselves. One motivation for their choosing the bus instead of M2W vehicle for work trips could be distance. As noted, the mean JTW distance for participants using the bus either daily or on most days was higher than for all participants. Also, a comparison of JTW-related round-trip bus fares and M2W vehicle fuel costs reported by participants shows that buses were less expensive, especially for long distances, since bus fares did not increase proportionately with distance.[18]

The predominance of work and education trips, and the fact that a significant proportion of these trips are performed by bus in M2W vehicle owning households, demonstrates the potential for M2W vehicle trips to be transferred to public transit. The fact that these trips are typically conducted by people traveling alone heightens this potential. Also however, these patterns show the potential for increased M2W trips, should bus service become less attractive than it already is. Thus, maintaining good bus service as part of a well-integrated urban transport system is important for bus as well as for M2W vehicle and car users. This importance will increase as emissions prevention and control policies make M2W vehicle ownership and use more expensive. Transfer to public transit would most likely occur for long work journeys by single travelers, particularly if comfortable, reliable and punctual service were available. The economics of bus travel favour such transfers, and there appears to be willingness to pay for such service, as evidenced by the popularity of charter buses.

Lastly, the fact that M2W vehicle users pick and choose modes, depending on trip purpose and length, day of the week, and time of day, shows that mode choice is extremely complex, and also that personal motor vehicle *ownership* does not necessarily translate into *usage*.

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[17] Also, 23% of work and education trips, and 20% of trips for all purposes, were conducted by walk. Similar significant bus usage occurs even in car owning households (RITES/ORG 1994).

[18] Daily round-trip bus fares ranged from INR 2 to 36, and averaged INR 13.11. Given the mean round-trip JTW distance of 29.8 km, and average fuel economy for two-stroke M2W vehicles (see later section) of 37 km/L, daily fuel cost, at INR 23 per litre, works out to INR 18.52 per day. The economics of bus travel, given these figures, would be even more favourable for longer distances. But for more than one person traveling together to the same destination, M2W vehicles would be less expensive, with of course the added benefits of flexibility and door-to-door capability.

6.3.3 M2W Vehicle Purchase

So far, we have discussed user household choices and motivations related to selection of modes, and their daily travel activity. We now turn our attention to user choices, behaviours and motivations related to vehicle purchase, and implications for transport air pollution, and policy-making and implementation. Among other things, the discussion in this section is intended to help identify the aspects of user purchase choices that need to be considered to make policies more attractive and equitable, and therefore more effective. The discussion is based on participant responses to the questions shown in Table 6.5.

Issue	Questions
M2W Vehicle purchase choices and motivations	Vehicle Type, Manufacturer and Model (MQ, under Household Vehicle Details) Please indicate the manufacturer and model of the motorized two-wheeler you use; Name the two most important reasons that influenced your (or your family's) decision to purchase the particular motorized two-wheeler referred to above; Please rank the factors that influenced your (or your family's) decision to purchase the particular motorized two-wheeler referred to above; What kind of engine does the two-wheeler you currently use have? (MQ, under Motivations) What factors influenced your choice of the particular model of motorized two-wheeler you use? (IP, Q 8)

Note: MQ -- Survey Questionnaire (Appendix IX); IP -- Interview Protocol (Appendix X); SQ -- Supplementary Questionnaire (Appendix XI); Q -- Question.

Table 6.5 Questions Related to M2W Vehicle Purchase Choices and Motivations

Results Figure 6.13 shows how participants rated the importance of various factors influencing the choice of their M2W vehicle. Trouble-free service, safety, fuel economy and affordability were rated as important by the most participants (Figure 6.13). Interestingly, the same factors, in addition to easy and inexpensive serviceability, were most frequently mentioned by participants, when asked to name the two most important influencing factors in an open-ended question in the questionnaire.

The overwhelming majority (78%) of M2W vehicles owned by participant households were scooters, with motorcycles making up the balance (Figure 6.14). Several participants expressed the view that motorcycles were more suited to single males than families. Their reasons were that these vehicles have little provision for carrying extra passengers or groceries, and no spare tire. Also, women are liable to have their garments tangled in the exposed wheel spokes. Interestingly, the mean age of the 13 participants whose households

owned motorcycles was 29 years, as opposed to 34 years for all participants. Also, these 13 participants included all the five single males in the sample. Of the other eight, all except two were young and recently married, with no children or with infants.[19]

Only two among all of the M2W vehicles in the study households were four-strokes, and both of these were motorcycles. Mopeds, which are small, low-power, low purchase-price (INR 12-15,000) and operating-cost vehicles, are favoured by low-income users. None of the participants' households owned a moped. One participant, who had a moped for a brief period suggested that it was suited to use in small cities, and for travel in neighbourhoods, but not in Delhi, because of the city's high road speeds. Also, he said, mopeds were highly vulnerable to being stolen, as his was.

Another interesting aspect of M2W vehicle purchase choice is that nearly one-fifth of the M2W vehicles, and one out of every four scooters in participant households was a Kinetic Honda. This and similar models, which have recently been introduced, are easy to operate because of their clutchless, gearless drive, and because they are push-button, rather than kick-started (AIAM 1994b; AIAM 1997b; Kinetic Honda 1997). All four female participants owned a Kinetic Honda, and the wives of all but two of the other participants who owned this model were employed, and used it. Every owner of this model indicated it was purchased because it was easy for her (or his wife) to use it. One participant said that his wife had been fearful of even learning to drive a M2W vehicle until this model was introduced.

Discussion The predominance of scooters among participant households reflects their pre-eminent position among all M2W vehicles in Delhi (Figures 6.15 and 6.16). Incidentally, Delhi accounts for the most scooters sold nation-wide. Scooters are preferred by the vast majority of urban M2W vehicle users, particularly those with families, because these vehicles offer more luggage space than other M2W vehicle types, and the possibility of carrying more than one passenger. Besides, scooters are less expensive on average than motorcycles.[20]

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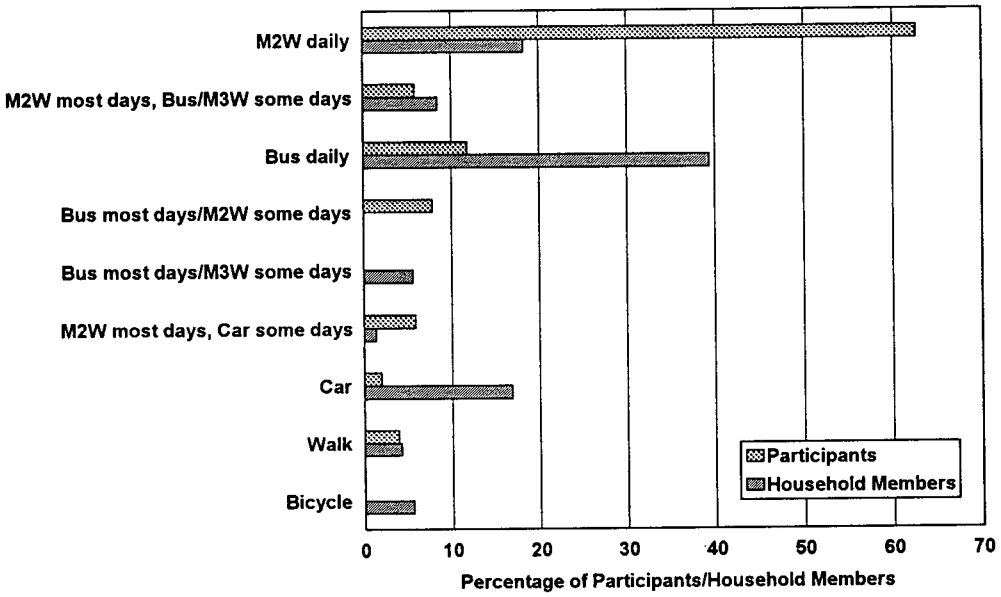
[19] Several of the motorcycle owning participants, particularly the single males, believed motorcycles were "zippy" and made them look "young and smart". According to one, " (real) men ride motorcycles". They also believed, with justification, that motorcycles, being more stable, were safer than scooters.

[20] However, the share of motorcycles is much higher nationally than in Delhi, and appears to be growing (Figures 6.15 and 6.16; Prasad 1999).

Survey of M2W Vehicle Users in Delhi, 1997

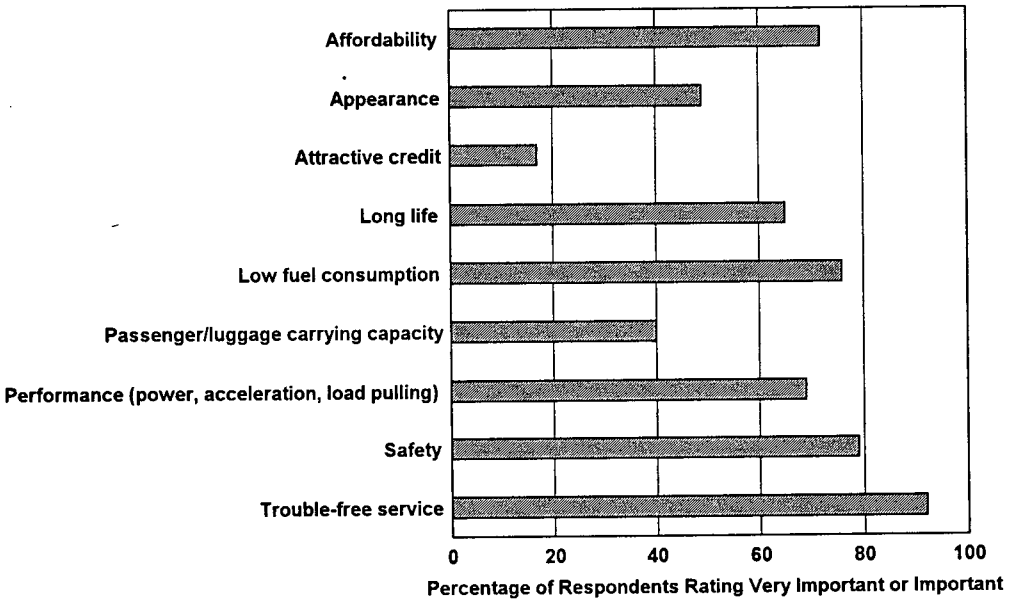
Figure 6.12 Modes Used for Work and Education Trips by Participants and Their Households



n = 51 for Participants, 71 for Household Members. M2W/M3W Vehicle -- Motorized two-wheeled/three-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

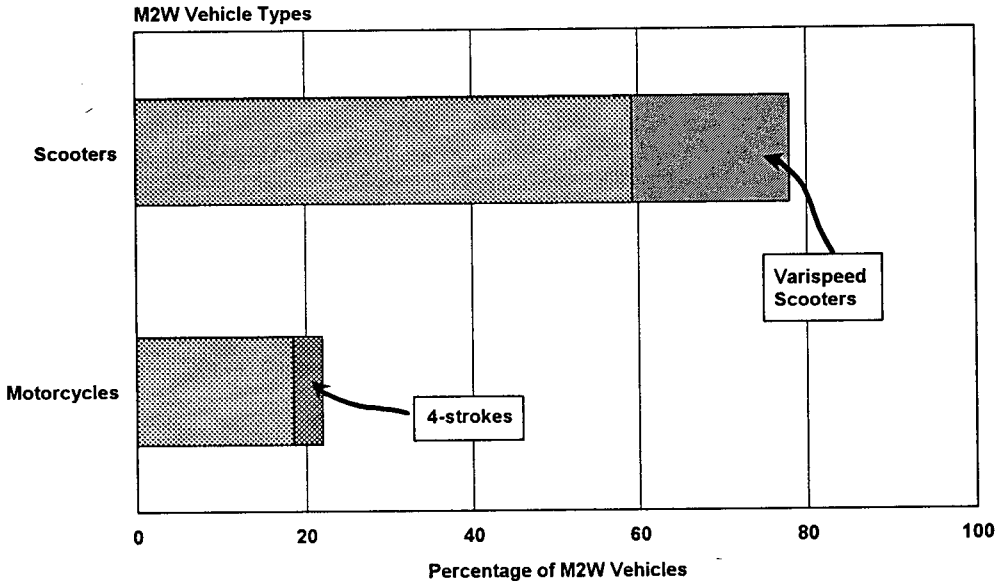
Figure 6.13 Rating of Factors Influencing Choice of M2W Vehicle Model



n varies from 47 to 50 for various factors. M2W Vehicle -- Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

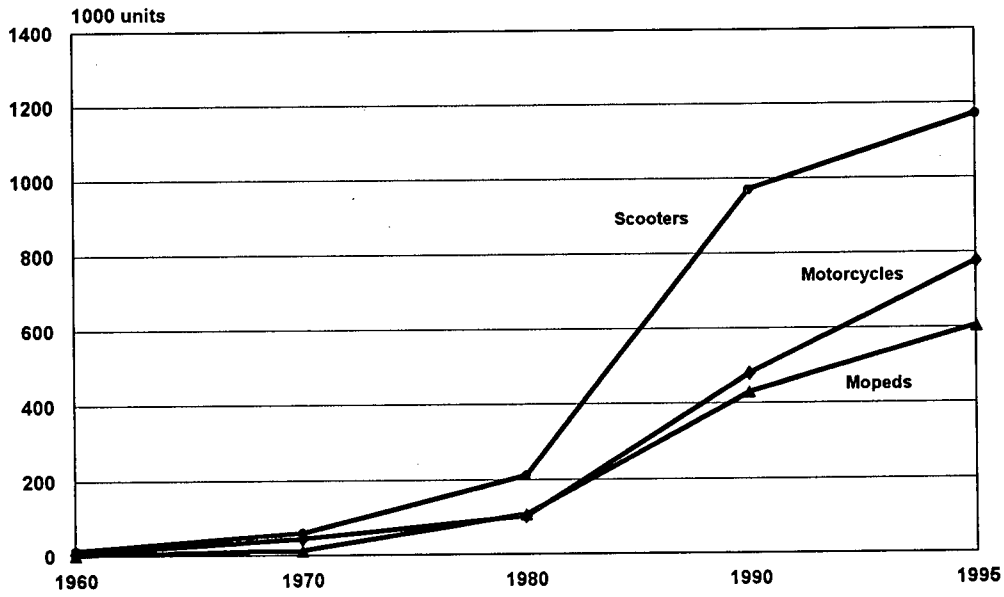
Figure 6.14 Distribution of M2W Vehicle Types in Participants' Households



n = 59; M2W Vehicle – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

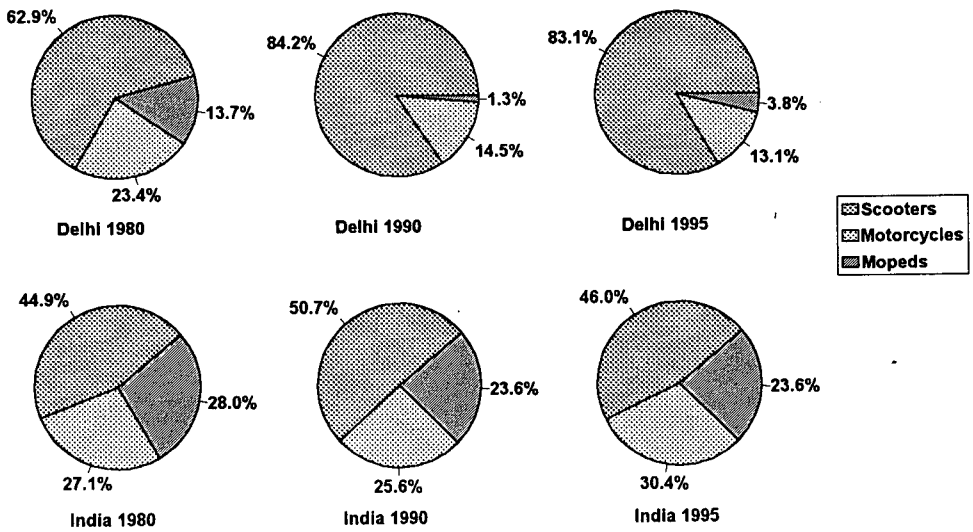
Figure 6.15 Annual Production of Different M2W Vehicle Types in India, 1960-1995



M2W Vehicle – Motorized two-wheeled vehicle. Sources: AIAM (1994a); AIAM (1995). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.16 Sales of Different M2W Vehicle Types in Delhi and India, 1980-1995



M2W Vehicle -- Motorized two-wheeled vehicle. Data for 1980 moped sales in Delhi is actually for 1983. Sources: AIAM (1994); AIAM (1995). mgb99

Mopeds are unpopular in Delhi (Figure 6.16), because of the city's much higher road speeds. Cultural reasons may also play a role, in that users in Delhi tend to prefer more rugged vehicles (Author's survey and interviews 1997; AIAM 1994a; AIAM 1995). The low representation of four-strokes among participants' M2W vehicles is not surprising, given that four-strokes have accounted for only 10-15% of national M2W vehicle sales until recently, as discussed in Chapter III, and that four-strokes have been available only on motorcycles (Narayana 1994).

The above patterns in ownership of M2W vehicle types have interesting implications for the implementation of vehicle technologies in response to tightened emission standards. Four-strokes are typically larger for the same power output than two strokes, as discussed in Chapter III. They can be easily accommodated on motorcycles, which have no space constraint. However, scooters have space constraints, and require extensive and expensive design and tooling changes to accommodate four-strokes (Author's interviews 1997). This is

why four-strokes have been available on motorcycles rather than scooters. But scooters are far more popular than motorcycles in Delhi.[21]

Mopeds may not be popular in Delhi, but they are in the rest of the country (Figures 6.15 and 6.16). Accommodating four-strokes on mopeds would be even more problematic than on scooters, because of even more severe space constraints. Catalytic converters can run as hot as 500 °C (Faiz et al 1996), and user safety would be an important issue on mopeds, for the same reason. The cost increase due to four-strokes and catalytic converters on mopeds would be much higher in percentage terms than on other M2W vehicle types. Thus, emission standards, mainly motivated by the rapidly deteriorating air quality situation in Delhi and other cities, will likely be unnecessarily burdensome on the large number of low-income moped users living in non-polluted regions of the country.

Lastly, the Kinetic Honda is a good example of how relatively simple technological innovations can quite dramatically affect travel choices. This and similar models are extremely popular among female users.[22] Because of such innovations, and increasing female work force participation and incomes, M2W ownership and use could increase rapidly, as women abandon an increasingly inconvenient (and oppressive) public transit, with important implications for transport energy and emissions.

Issue	Questions
Fuel and oil consumption patterns	Monthly expenses on fuel and oil (MQ, under Household Vehicle Details) How much do you spend on fuel and oil monthly for your two-wheeler? Is this reflected in the amount shown under fuel in the questionnaire?; How many kilometres per litre does your two-wheeler give? How frequently do you fill your fuel tank? How much do you fill each time? How much 2-T oil do you ask for along with the fuel? Do you specify the 2-T oil to be used? Or do you use your own 2-T oil? If so, which one? (IP, Q 14, 15, and 16; SQ, Q 9 and 10) In what form do you buy 2-T oil (loose, pouch etc.)? (SQ, Q10)
Vehicle maintenance choices	What servicing do you have done regularly, and who does it? (IP, Q 17; SQ, Q11)

Note: MQ -- Survey Questionnaire (Appendix IX); IP -- Interview Protocol (Appendix X); SQ -- Supplementary Questionnaire (Appendix XI); Q -- Question.

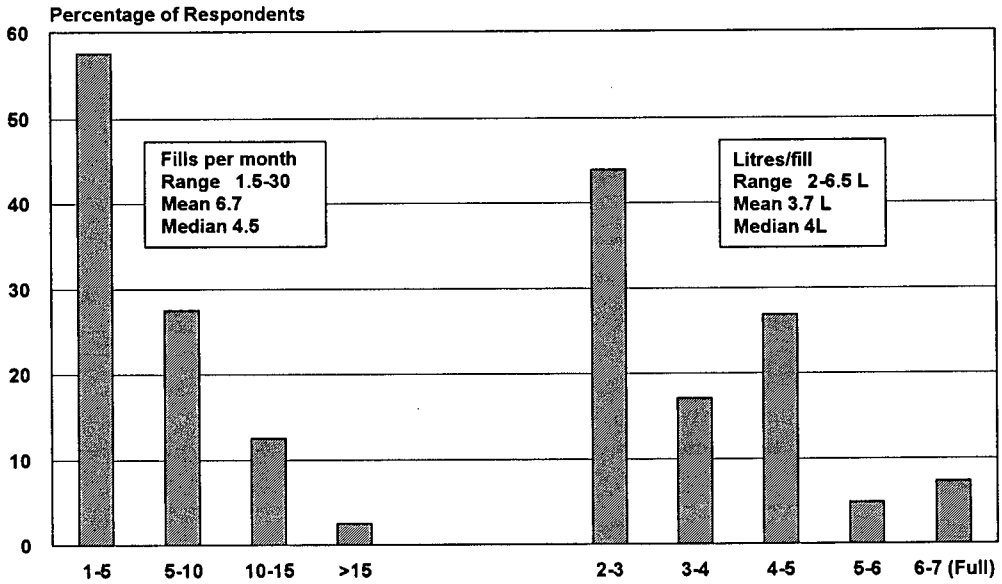
Table 6.6 Questions Related to M2W Vehicle Operation and Maintenance

[21] Four-stroke scooter models have been recently introduced (Prasad 1999), in anticipation of 2000 norms.

[22] A female professional suggested, in a conversation with the author, that the Kinetic Honda is liberating urban Indian women.

Survey of M2W Vehicle Users in Delhi, 1997

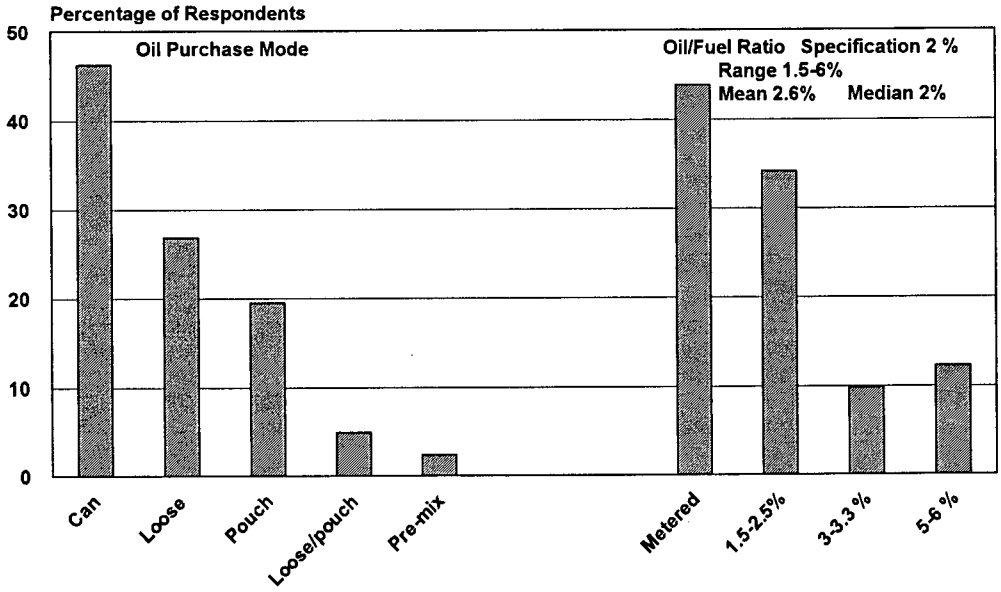
Figure 6.17 Frequency and Quantity of Fuel/Oil Fills on Participants' Vehicles



n = 40 for Fills per month; 41 for Litres/fill. M2W Vehicle -- Motorized two-wheeled vehicle. Data is for two-strokes in the sample. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.18 Oil/Fuel Ratios and Oil Purchase Mode Used by Participants



n = 41. M2W Vehicle – Motorized two-wheeled vehicle. Data is for two-strokes in the sample. Source: Author's survey and interviews (1997). mgb00

6.3.4 M2W Vehicle Operation and Maintenance

This section examines user fuel and oil consumption and vehicle maintenance patterns, because these parameters critically affect emissions as well as transport expenditure and vehicle life. The discussion is based on participant responses to the questions shown in Table 6.6.

Results Fuel economy figures reported for two-stroke M2W vehicles in the study ranged from 25 to 55 km/L, and averaged 37 km/L. The figures reported for the two four-stroke vehicles in the sample were 45 and 72 km/L.

The bulk of the respondents reported refueling their vehicles up to ten times monthly (or every three days), but around 15% refueled more frequently, with one refueling daily (Figure 6.17). The mean fill quantity reported was 3.7 litres, with 44% reporting three litres or under. Of the M2W vehicles used by the participants, 20 (the Kinetic Hondas and some motorcycle models including the two four-strokes) employed line-mixing or oil injection.[23] Counting only the two-strokes among participants' M2W vehicles which did not have either line-mixing or oil injection, and for which data was provided, only 39% reported purchasing their oil in either a pouch or a can, because of concerns about "loose" oil being adulterated.[24] One respondent reported purchasing his fuel and oil pre-mixed, at one of the few stations dispensing it in this manner in Delhi. The remainder purchased their oil loose.

Again excluding the two-strokes with line-mixing or oil injection, for which it may be assumed it was to specification (2%), oil/fuel ratio was found to be excessive on nearly two-thirds of the vehicles for which this data was provided. The oil-fuel ratio was two to three times higher than specification on nearly a fifth of the vehicles (Figure 6.18).[25] Curiously, the station where the lone participant purchased pre-mixed fuel-oil reportedly offered the option of a 5% oil/fuel ratio in addition to the specified 2% ratio, to cater for users who felt their vehicles "should get more oil". Indeed, one participant, an engineer, reported filling only one

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[23] In line-mixing, oil is metered directly into the fuel between the fuel tank and the engine. Oil injection involves oil being pumped directly into the intake manifold or other engine points (Faiz et al 1996).

[24] All participants whose vehicles had the line-mixing or oil injection facility also purchased their oil in cans, and Figure 6.18 reflects this.

[25] As noted in an earlier chapter, many M3W vehicle operators reportedly use an oil-fuel ratio of 10%.

litre fuel at a time, and adding as much as 50 ml oil, to give a ratio of 5%, because he believed this would improve vehicle startability.

Lastly, only around a quarter of the participants indicated that they had their M2W vehicles serviced regularly by an authorized dealer. Most participants reported maintaining their vehicles themselves, largely on an as-needed basis, and using the services of local mechanics, in the case of major repairs.

Discussion The fuel economy figures reported by participants for two-stroke M2W vehicles is significantly lower than the 54 km/L reported for two-strokes on the Indian driving cycle in the IIP (1994) study discussed in Chapters II and III. The self-reported figures in this study could well be more representative of the fuel economy under actual driving and maintenance conditions in the Indian context, with implications for real-life M2W vehicle emissions and energy consumption, and also for efforts to measure and model them. There was no discernible relationship with vehicle age. Thus, some old vehicles were reported to have high, and some new ones low km/L. Individual driving styles are undoubtedly a critical factor, but so also is vehicle maintenance regardless of age (Faiz et al 1992 and 1996), which shows the potential for well-run in-use emissions monitoring and control programmes.

Refueling frequency is obviously determined by vehicle kilometres, but it varied widely even for the same vehicle kilometres. Part of the reason for the high refueling frequency is that M2W vehicle fuel tank capacities are typically on the order of seven litres, as opposed to 40-50 litres on cars (AIAM 1994b).[26] But even so, M2W vehicle fuel tanks appear to be rarely topped up. One of the reasons for not filling to capacity may be the concern about fuel pilferage that some participants expressed. Whatever the causes, frequent refueling has important implications for fuel losses due to spillage and evaporative emissions, especially in the high temperature ambients in the Indian context. A back-of-the-envelope estimate, based on this study, is around 670,000 fills daily by three million M2W users in Delhi.

Both line-mixing and oil injection ensure optimum oil/fuel ratio and reliable lubrication, thus minimizing PM and HC emissions and optimizing oil consumption. But vehicles with

[26] Actually, fuel tank capacities range from around three litres on mopeds to around seven litres on scooters, and ten litres on motorcycles (AIAM 1994b).

these facilities are significantly less represented in the M2W vehicle fleet than in the sample. The majority of M2W vehicle users mix oil with fuel when refueling. Loose oil is best for this purpose, since oil quantity has to be calibrated depending on the fuel quantity, in order to maintain the specified oil/fuel ratio of 2%. Hence, the majority of M2W vehicle users also purchase their oil loose when refueling. Using oil from cans is cumbersome, because this involves measuring out oil depending on the fuel quantity intended to be purchased, and taking it to the fuel dispensing station. And pouches contain a fixed quantity of oil, typically 60 ml, and since fuel fill quantities vary, it is often the case that the resulting oil/fuel ratio is not as per specification.

All in all, frequent refueling, oil (and fuel) adulteration and high oil/fuel ratios in M2W (and M3W) vehicles have important implications for evaporative and exhaust PM emissions, and for efforts to measure and model them. Controlling gasoline volatility will of course mitigate the impacts of frequent refueling, but it may be possible to tackle excessively frequent refueling itself by offering discounts for full-tank fills, and designing vehicles to prevent fuel pilferage. The problem of excessive oil/fuel ratios will likely reduce as more M2W vehicles (including four-strokes) with line-mixing or oil injection, and also low dosage lubricating oils, enter the market. These relatively simple technologies have the potential to significantly reduce PM emissions from two-strokes. Vehicles with oil metering will also likely help reduce oil adulteration, because these will require oil to be topped up from cans rather than being purchased loose and mixed at each refueling. But in the interim, the use of loose oil in the large number of vehicles without a metering facility is an issue of concern.

According to vehicle industry representatives interviewed by the author, many users do not have their vehicles serviced regularly by authorized service stations, even during warranty, and in spite of free service coupons. Further, spurious spares are commonly used. New vehicle technologies to reduce emissions typically involve complexity and are sensitive to maintenance quality. Given that many users maintain their vehicles themselves, and the need for long-term policy effectiveness, easy maintainability and spare parts availability will become important. These features in turn have implications for design of technologies to withstand poor

maintenance, spare parts sales taxes, and training of servicing staff well in advance of introduction of new technologies.[27]

6.3.5 M2W Vehicle Disposal and Replacement

As discussed in Chapter III, vehicle age is an important factor in transport air pollution and energy consumption (Calvert et al 1993). It is therefore useful to investigate user choices and motivations related to vehicle service life, disposal and replacement. This section discusses these choices and motivations on the part of M2W vehicle users in Delhi, based on the questions in Table 6.7.

Issue	Questions
Current vehicle age	Year purchased (MQ, under Household Vehicle Details)
M2W Vehicle disposal and replacement choices and motivations	When do you propose to dispose of the two-wheeler you currently use?; When you dispose of your vehicle, which vehicle and model would you like to buy? (MQ, under Motivations) How many years do you expect to use your vehicle totally? Under what circumstances will you dispose of your vehicle?; When you dispose of your vehicle, what model and make will you buy and why? What will you be looking for most of all in your replacement vehicle?; If cost were no constraint, which vehicle and model would you get, and why? Which two-wheeler model and make, and why? (IP, Q 18, 19, and 20) How many years do you expect to use your present two-wheeler totally (from purchase to disposal) before you dispose of it? (SQ, Q12)

Note: MQ -- Survey Questionnaire (Appendix IX); IP -- Interview Protocol (Appendix X); SQ -- Supplementary Questionnaire (Appendix XI); Q -- Question.

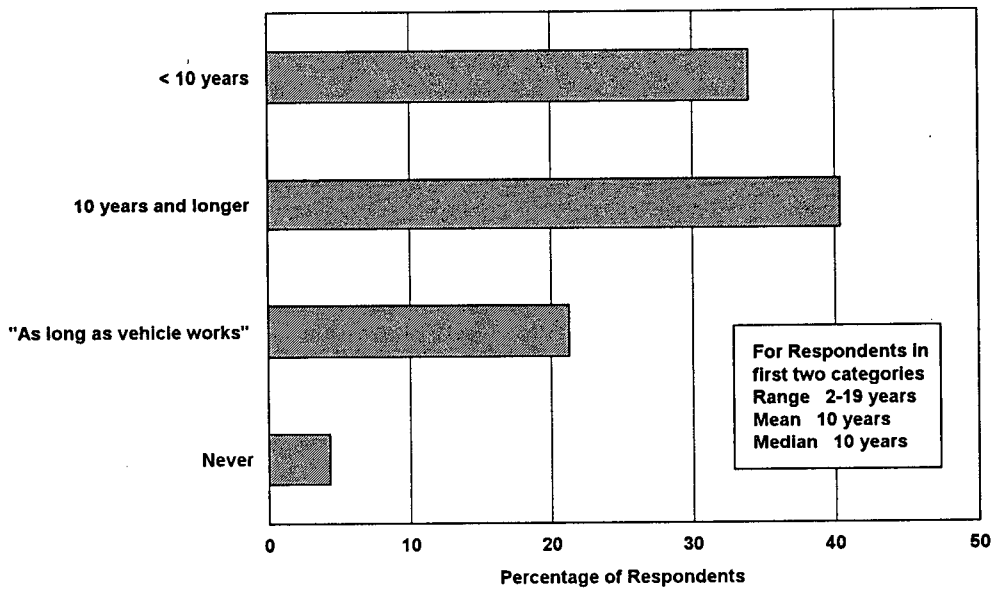
Table 6.7 Questions Related to M2W Vehicle Disposal and Replacement

Results Figure 6.19 shows the vehicle age at which respondents said they would consider disposing of their vehicles. Nearly two-thirds of the respondents indicated an intended vehicle disposal age of 10 years or longer, including a quarter who said they would never dispose of their vehicles, or would use them for as long as they worked (Figure 6.19).

[27] Repairs can be counter-productive if not done right. Since it is impossible for them to either own or control road-side garages, vehicle manufacturers are helping up-grade their equipment and skills (Author's interviews 1997).

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.19 M2W Vehicle Disposal Ages Planned by Participants



n = 47. M2W Vehicle – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

The majority of respondents who did not own a car, including some with low incomes, said they would ideally like to buy one if they could afford it, when disposing of their M2W vehicles. In addition to family pressures, motivations driving the desire to purchase a car included road safety, particularly when traveling with the family, and protection from air pollution. Most respondents however said they would realistically replace their M2W vehicles with newer M2W vehicle models. Many hoped to get a reasonable re-sale value for their old vehicles. The Kinetic Honda and four-strokes were the replacement models most frequently indicated. One respondent wished there were four-stroke scooters available, with the Kinetic Honda's driveability. Only one in five respondents not currently owning a motorcycle indicated they would consider buying one. Lastly, some who said they would likely purchase a car also indicated that they would retain their M2W vehicles, and continue to take the bus to work.

Discussion More than half the respondents who indicated an intended disposal age of 10 years or longer were in households owning only one M2W vehicle and no other motorized vehicle. Also, nearly half of those who intended to use their vehicles for as long as they

worked, had vehicles that were already 10-17 years old. It is likely that lower income users who have only one M2W vehicle (as is common), will use it for long periods of time before disposal. This has important implications for the effectiveness and distributional effects of mandated vehicle scrappage, and for emissions. It also demonstrates the need for an effective in-use emissions monitoring and control regime, given that mandated vehicle scrappage is likely to be ineffective, as discussed in Chapter IV. Lastly, the fact that users would likely retain their M2W vehicles, and continue to take the bus to work, even if they purchased a car, again demonstrates the complexity of mode choice, and that private motorized vehicle ownership need not necessarily translate into usage.

6.3.6 Participant Perspectives on Transport Air Pollution Prevention and Control Policies

So far, this Chapter has focused on travel activity and vehicle operation, maintenance and disposal choices and motivations with important implications for transport air pollution. In the final part of this Chapter, vehicle user perspectives on how they would be affected by, and would respond to, various emissions prevention and control policies are discussed. The rationale for focusing on these issues was provided in some detail in the introductory section of this Chapter, and will not be repeated here.

First, this section focuses on vehicle user awareness of and views on current policies, followed by their responses to specific policy alternatives involving vehicle technology and fuel and oil quality improvements, and vehicle scrappage. Participants' ranking of the policy alternatives are then taken up, followed by a discussion of participant views on measures that would enhance the attractiveness of the alternatives, particularly when implemented jointly. This is followed by a discussion of participant views on how their families' lives would be affected if they had to curtail the use, or give up ownership, of their M2W vehicles as a result of emissions policies, and desirable characteristics of M2W emissions prevention and control policies from their perspective. Lastly, given the importance of public transit to M2W vehicle users, and its potential to blunt the effects of emissions policies, the section closes with a discussion of participants' ranking of specific improvements to the bus service (and cycling facilities) in Delhi, and their willingness to use these modes if the improvements are made. The discussion in this section is based on the questions in Table 6.8.

Issue	Questions
User knowledge of four-stroke engines	What kind of engine does the two-wheeler you use have?; Can you name any motorized two-wheelers currently being sold in India that have four-stroke engines? (MQ, under Motivations) If your two-wheeler has a four-stroke engine, why did you choose it? (IP, Q11; SQ, Q7) Do you know the differences between vehicles with a four-stroke and a two-stroke engine, in terms of their performance, fuel consumption, emissions and cost? (IP, Q12)
Awareness of and views on current policies	Do you know what measures are being taken to improve urban air quality in Delhi? Do you think they are effective? Why or why not? How have these measures affected you? (IP, Q24 and 25; SQ, Q13)
Perspectives on vehicle technology improvements	How much do you think you could comfortably afford to spend on a new two-wheeler if you were buying one today? (IP, Q26; SQ, Q14); Does this figure assume re-sale of your present two-wheeler? If so, what is the amount you think you would get for it? (SQ, Q14) Given that motorized two-wheelers are a major contributor to air pollutant emissions from motor vehicular sources in Delhi; that air quality could be improved by more people using four-strokes or similar improved technology two-wheeler; and that two-wheelers with improved technology would likely be more expensive, how much would you be willing and able to pay for such a vehicle, over and above the amount you indicated in response to the previous question? (IP, Q27; SQ, Q15) How much would you be willing and able to pay for an improved technology two-wheeler over and above the amount you indicated in response to the previous question, if this improved technology two-wheeler gave 1.3-1.6 times improved fuel economy in addition to lowering emissions? (IP, Q28; SQ, Q16) What is the absolute maximum price that you would be willing and able to pay for a two-wheeler, if you were buying it today? If the price of a two-wheeler exceeded this amount, what would you do? (IP, Q29; SQ, Q17)
Perspectives on fuel-oil quality improvements	Improving fuel (and 2-T oil) quality is another way of reducing air pollutant emissions, but this will likely involve increased fuel cost. How much (either per month or per litre) would you be willing and able to spend on improved quality fuel and oil for your present two-wheeler over and above the current level, for improved air quality? (IP, Q31; SQ, Q18) How much would you be willing and able to spend on improved quality fuel (and oil) over and above the current level, on an improved technology two-wheeler, given that the fuel economy would be better by a factor of 1.3-1.6, and given also that such a vehicle would be more expensive? (IP, Q32; SQ, Q19) What is the maximum fuel plus oil cost (either per month or per litre) you think you could bear for your two-wheeler? (IP, Q33; SQ, Q20); If fuel cost went up by more than this, how would your family's life be affected? (IP, Q33)
Perspectives on mandated vehicle scrappage	Given that old vehicles generally tend to be more polluting than new vehicles: if government passed a law preventing vehicles older than a certain number of years from being driven in Delhi, what is the minimum service life that would be acceptable to you, from your point of view? At present, and with more expensive improved technology two-wheelers? (IP, Q34; SQ, Q21)
Ranking of policy alternatives	Please rank in order of acceptability (most acceptable, least acceptable, etc.) the following policies: a) a government mandate requiring only improved technology two-wheelers to be manufactured, and assuming the cost of these two-wheelers is 40,000 rupees; b) a fuel plus oil cost increase (for improved quality fuel) of five rupees per litre, and c) a law preventing two-wheelers older than 10 years from being driven in Delhi? (IP, Q35; SQ, Q22)

Issue	Questions
Measures to increase policy attractiveness	Based on our discussion, what kind of policies would you prefer, what would you be opposed to, and why? (IP, Q36) What sort of incentives would make a) more expensive improved technology M2W vehicles, b) more expensive improved quality fuel and oil, and c) a law preventing vehicles beyond a certain age from being used, more attractive to you? When these are implemented singly, and jointly? (IP, Q37; SQ 24)
Desirable characteristics of policies from users' perspective	From your point of view, what do you think ought to be the objectives for policies to control air pollution due to motorized two-wheelers in Delhi? (IP, Q38)
Impacts of policies on users' families	How important is it for you and your family to have the use of the motorized two-wheeler? How would your life and that of your family be affected if you did not have or could not operate a motorized two-wheeler? (IP, Q39; SQ, Q23) If vehicle operation and fuel costs increased, would it reduce your travel? Under what circumstances would you use your motorized two-wheeler more? (fuel cost, reduced congestion, etc.) (IP, Q42) If you were paying the same amount of money on fuel costs, but could travel twice as far, would you increase your commuting (for what purposes), or would you travel the same amount and save money? (IP, Q43)
Improvements to bus service and cycling facilities	Name the two most important improvements that you think ought to be made to bus service in Delhi that would make you use it/use it more; If you do not currently use a bus, would you do so if these and other improvements were made to the service?; Please indicate the importance of the (listed) improvements to bus service in Delhi that would make it more attractive; Even if bus service were improved dramatically, would you give up your motorized two-wheeler? (MQ, under Perceptions of Bus Service in Delhi) Name the two most important improvements that you think ought to be made to cycling in Delhi that would make you use it/use it more; If you do not currently use a bicycle, would you do so if these and other improvements were made to cycling facilities?; Please indicate the importance of the (listed) improvements to cycling in Delhi that would make it more attractive (MQ, under Perceptions of Bicycle Commuting in Delhi) Under what circumstances would you use buses/bicycles rather than your motorized two-wheeler, for which trip purposes, and why? Under what circumstances would you give up your two-wheeler for all purposes in favour of buses/bicycles? (IP, Q40) Now that you have become used to your motorized two-wheeler, would you stay with it (or even get a car), as long as you could afford it, regardless of the improvements made to the bus service? If fuel costs went up? If congestion increased significantly? (IP, Q41)

Note: MQ -- Survey Questionnaire (Appendix IX); IP -- Interview Protocol (Appendix X); SQ -- Supplementary Questionnaire (Appendix XI); Q -- Question.

Table 6.8 Questions Related to Perspectives on Policies

A few points related to the questions in Table 6.8 follow. User perspectives were elicited on technological as well as preventive measures. As noted earlier, policies and technologies similar to those posed as hypotheticals in the questions were being or were proposed to be

implemented, at the time of the study. In particular, note that new rules on vehicle scrappage were announced even as this study was being conducted, and the scrappage period mandated for two-stroke M2W vehicles (Appendix VII) was similar to that indicated in the question related to this issue in this study.[28] The issues in Table 6.8 are listed in the order in which questions relating to them were put to participants, except for the last issue, improvements in bus service and cycling facilities. However, the questions relating to this and each of the other issues in Table 6.8 are listed in the order in which they were asked.

The benefits of vehicle technology and fuel-oil quality improvements, in terms of improved air quality, were described in the related WTP questions, and participant responses give some indication of how vehicle users might value such improvements. However, the study is not intended to be a WTP survey in the conventional sense.[29] The WTP questions, and the order in which they were posed, were primarily intended to help gain an understanding of how M2W vehicle users might respond to such improvements, and how the attractiveness of these improvements might be enhanced by means of a fuel economy benefit. Further, because these and subsequent questions in Table 6.8 explore vehicle user perspectives on actual or realistic policies, and because many participants responded as *citizens* as well as *consumers*, their responses have the potential to be useful in informing policy-making and implementation.

The 1.3-1.6 figure in Question 28 in the Interview Protocol and Question 16 in the Supplementary Questionnaire is the approximate fuel economy improvement expected from four-strokes compared to two-strokes.[30] In this regard, the questions relating to participants' knowledge of four-strokes were intended to serve as a means of determining how this knowledge, particularly relating to fuel economy, influenced their WTP responses with regard to vehicle technology improvements.

With regard to fuel-oil quality improvements: both fuel and oil were included in the questions related to this issue, because they are typically mixed and burned in two-strokes, and both contribute to air pollution, as discussed in Chapter III. While the WTP responses of

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[28] However, note that the scrappage measure related to two-strokes (Appendix VII) is intended to be a one-time measure, with the objective of phasing out two-strokes once and for all. But the rule is not clear on how, for example, two-strokes fitted with catalytic converters, would be dealt with after 2007.

[29] The technical and conceptual difficulties associated with WTP questions relating to transport emissions prevention and control policies in the Indian context were discussed in Chapter V.

[30] The differences between two- and four-strokes are described in Chapter III.

several participants were in the form of INR/litre, those of others were in the form of total INR/month, which were then converted to INR/litre, based on individual participants' fuel consumption.

In relation to ranking of policy alternatives, it should be noted that while the alternatives were presented to participants as if they were mutually exclusive, they are typically applied simultaneously. This reality is reflected in the earlier questions relating to these alternatives. Also, note that the fuel efficiency aspect of improved vehicle technology was left out of the question on ranking alternatives, in order to see how vehicle technology improvement without this benefit would be rated by participants.

Participant views as to desirable policy characteristics were elicited directly in response to the question related to this issue in Table 6.8. But they were also based on discussions of the pros and cons of specific policies and technologies, such as in-use emissions testing, vehicle scrappage and four-strokes, on participants' ratings of factors motivating model (and mode) choice, and on their views on measures to enhance policy attractiveness. All of these perspectives were employed in the construction of multiple policy objectives, discussed in Chapter VII.

6.3.6.1 Current Policies

Results Every respondent was aware of the periodic "Pollution Under Control" (PUC) in-use emissions testing referred to in Chapter IV. However, many were unaware of other measures in place in Delhi at the time of the study, or unsure as to their purpose or effects.[31] Following, for example, are some participant views regarding vehicle emission standards and technologies: "I thought emission standards were only for Marutis (a leading car model)" and "Catalytic converters reduce only lead, not other pollutants". Typical views of unleaded fuel included "Unleaded gasoline is twice-purified petrol, and is pollution free", "I do not know how it helps, it has something to do with catalytic converters", and "Unleaded gasoline is only

[31] At the time of the study, the following measures were in place in Delhi: emission standards for different vehicle classes, unleaded gasoline for new four-wheeled motorized vehicles fitted with catalytic converters, reduced lead-level gasoline for all other gasoline-powered vehicles, low-sulphur diesel, and PUC in-use emissions testing for cars, M2W and M3W vehicles. A new M3W vehicle registration ban had just come into force, and vehicle scrappage laws were just being introduced (see Appendices III, IV and VII for details).

for Marutis, and is not suitable for M2W vehicles, which are not designed for it". Several participants were even unsure as to what precisely was being checked on the PUC test.

The PUC test has been critiqued in detail in Chapter IV, and the points made there will not be repeated. Suffice it to say, therefore, that the overwhelming consensus among participants was that the test was burdensome, unfair, and open to corruption and harassment, yet totally ineffective. It was no more than a "sham", an "eye-wash", just a "money-making gimmick", that served only to shift the responsibility from the vehicle manufacturers and government, where it rightly belonged, to the user. The only good thing participants could say about the test was that it made people more conscious of air pollution and their role in it, and that it created employment.

Discussion The fact that many participants were unsure as to what was being checked on the PUC test is noteworthy, considering that every M2W vehicle was required to undergo the test every three months. Such lack of awareness, which is likely far more widespread among the general population, can promote fraud, and has important implications for policy effectiveness. With regard to catalytic converters, the fact is that these devices can effect significant CO, HC and NO_x reductions (Faiz et al 1992). And rather than reducing lead, they require unleaded gasoline in order to function. Finally, it is interesting to contrast the reasons to which participants attributed the restriction of unleaded fuel to vehicles with catalytic converters, with the official reasons, viz., concerns about high levels of benzene in unleaded gasoline being emitted untreated in vehicles without catalytic converters, and supply constraints (Author's interviews 1997; CSE 1997; Lal 1996b; Lal 1996d; Mehta 1993; Nandi 1996a and b; Saikia Committee 1997a; Supreme Court 1996b).

6.3.6.2 Vehicle Technology Improvements

Results Responses to the questions relating to M2W vehicle technology improvements are represented in Table 6.9. New M2W vehicle affordability ranged from INR 13,500 to 40,000.[32] Several participants who indicated they could afford prices at the upper end said

[32] For the purpose of this and subsequent WTP questions, the two four-stroke M2W vehicle owners were asked to respond as if they were purchasing a two-stroke vehicle.

they could do so because of easy credit availability. Not surprisingly, several participants indicated that they expected to realize some re-sale value on their old vehicles when purchasing the new vehicles they were being hypothetically asked to consider.[33] Some participants indicated exceedingly high re-sale values for their old vehicles, some of which had been purchased second hand many years earlier. On the other hand, some stated they were not taking into account any re-sale value for their old vehicles in estimating new vehicle affordability.

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Table 6.9 Participants' WTP for M2W Vehicle Technology Improvements

	Number of Respondents	Range, INR	Mean/Median Values, INR	Comments
New Vehicle Affordability	41	13,500-40,000	30,146/30,000	
Re-sale Value Expected for Old Vehicle	24	0-27,500	8292/8250	Including 7 'zero' responses
WTP for AQ	32	0-20,000	4164/5000	Excluding 9 respondents, who factored in FE; including 8 'zero' WTP responses
WTP for AQ + FE	41	0-20,000	7430/7000	Including above 9 respondents; also including 2 'zero' WTP responses
Max. New Vehicle Affordability	41	17,500-50,000	38,024/38,000	

M2W Vehicle -- Motorized two-wheeled vehicle; WTP -- Willingness to Pay; AQ -- Air Quality Improvement; FE -- Fuel Efficiency Improvement; INR -- Indian Rupees. Source: Author's survey and interviews (1997).

Before discussing participant responses to the WTP questions, it is important to discuss their knowledge of four-strokes, in order to understand its effect on their WTP. Around 82% of the participants identified the engine type on their M2W vehicles correctly, including the two owners of four-strokes. 73% of the participants, including some who could not identify their engine type, named one or more four-stroke M2W models then available in the Indian

[33] As a result, participants to whom the supplementary questionnaire was administered were explicitly asked to indicate their expectations in this regard.

market. Further, nearly 70% correctly described the differences between two- and four-strokes. Several participants were intimately acquainted with the differences in fuel efficiency, emissions and vehicle performance, and also with the reasons for those differences. Some participants used the question related to the differences between two- and four-strokes as an opportunity to talk about their reasons for deciding against four-strokes (these views are discussed later).

Eight out of 41 respondents indicated zero WTP for four-strokes or similar technologies to improve air quality, over and above their new vehicle affordability. All the others indicated a positive WTP, which ranged up to INR 20,000 (Table 6.9). Although a large number of participants were acquainted with four-stroke fuel efficiency and other characteristics, only nine of 41 respondents reported having factored in improved fuel efficiency when indicating their WTP.[34] The mean WTP for four-strokes or similar technologies to improve air quality, including the zero WTP responses, worked out to roughly 14% of the mean new vehicle affordability.

Twenty-four respondents indicated a higher WTP for technologies that would deliver 1.3-1.6 times improved fuel economy in addition to lowering emissions than they had for air quality improvement alone. Two respondents indicated a zero WTP response, as they had previously for air quality improvement alone. Recall that nine participants factored fuel efficiency into their WTP for air quality improvement. For these participants, it was not possible to separate out their WTP for air quality improvement from their WTP for additional fuel economy improvement. In any case, the mean WTP for air quality as well as fuel economy improvement, including the zero WTP responses, worked out to 25% of new vehicle affordability. Mean WTP for the fuel economy benefit alone was therefore around 11% of new vehicle affordability, only slightly lower than for air quality improvement alone. Lastly,

[34] Also, 23 participants, including both four-stroke owners, indicated a higher WTP in response to the subsequent WTP question, which asked them to consider fuel efficiency in addition to air quality improvement. It may therefore be concluded that participants' responses to the first of the WTP questions were not influenced by expectations of fuel economy benefits, except for the nine participants referred to. In this regard, it is important to reiterate that questions regarding knowledge of four-strokes and differences between two- and four-strokes were asked before the WTP questions. Further, responses to these questions were merely recorded, not discussed with participants.

Table 6.9 shows the maximum vehicle price that respondents indicated they could afford, given the improvements just discussed.

Discussion The foregoing suggests that environmental policies involving higher costs can be made more attractive to vehicle users by offering a private benefit. It is likely that many M2W vehicle users in Delhi would accept higher costs for technologies that were more fuel efficient in addition to being less polluting.

The premium for air quality as well as fuel economy improvement should cover the likely vehicle price increase due to four-strokes being fitted on M2W vehicles (Author's survey and interviews 1997). However, this has to be set against the re-sale value that users would expect when disposing of their old vehicles, with which to partly finance their new vehicle purchase. Taking into consideration the mean expected re-sale value, the maximum vehicle price affordability indicated would have comfortably bought a scooter or motorcycle at the upper end, but would have been barely sufficient for a moped at the lower end. Old vehicle re-sale values would be affected by vehicle scrappage laws proposed to be implemented, with implications for the effectiveness of such laws, and for affordability of expensive new vehicle emissions control technologies. Lastly, many participants said they would seriously consider purchasing a car if the M2W vehicle price exceeded around INR 40,000 by very much. This implies limits to users' WTP for these improvements, and the need to control the costs of new technologies.

6.3.6.3 Fuel/Oil Quality Improvements

Results Table 6.10 represents participant responses to the questions related to fuel-oil quality improvements to achieve improved air quality. Out of 42 respondents, nine indicated zero WTP. Two respondents said they would be willing to pay as much as was necessary, and one said he would be willing to pay "anything reasonable". Excluding these three, but including the zero responses, the mean WTP for improved fuel and oil to reduce emissions worked out to around 17% of the approximate base price of INR 24.5 per litre of fuel-oil mixture at the time of the study.

Eleven respondents indicated a higher WTP for improved quality fuel and oil on a M2W vehicle with 1.3-1.6 times better fuel economy, than they had in response to the previous question, despite the fact that such a vehicle would be more expensive. These respondents included five out of the nine who had indicated zero WTP earlier. The prospect of improved fuel economy did not affect the WTP of 27 respondents, including four who had indicated zero WTP in response to the previous question. The mean WTP for improved fuel and oil quality on a M2W vehicle with 1.3-1.6 times better fuel economy worked out to 24% above the base price of INR 24.5 per litre of fuel-oil mixture. Thus, the marginal WTP for fuel-oil quality improvement provided it was accompanied by improved fuel economy, as opposed to fuel-oil quality improvement alone, was 7% of the base fuel-oil price. Finally, the maximum fuel-oil price participants said they could afford was roughly 30% more than the base fuel-oil price.[35]

Survey of M2W Vehicle Users in Delhi, 1997

Table 6.10 Participants' WTP for Fuel-Oil Quality Improvements

	Number of Respondents	Range, INR	Mean/Median Values, INR	Comments
WTP for AQ	39	0-24.50	4.20/4.00	Including 9 'zero' WTP responses; excluding 2 respondents who indicated no limit, and one who said "anything reasonable"
WTP for AQ on Improved FE M2W Vehicle	38	0-24.50	5.90/5.10	Including 4 'zero' WTP responses; excluding those excluded above, plus one respondent who said question was difficult to answer
Max. Fuel-Oil Price Affordability	40	24.50-49.00	31.83/29.83	Excluding two respondents who indicated no limit

M2W Vehicle -- Motorized two-wheeled vehicle; WTP -- Willingness to Pay; AQ -- Air Quality Improvement; FE -- Fuel Efficiency Improvement; INR -- Indian Rupees. Source: Author's survey and interviews (1997).

[35] It is likely that fuel-oil prices have already reached this level, due to recent global oil shortages.

Several participants pointed out that fuel economy benefits offered by expensive technologies such as four-strokes would be futile if increased gasoline costs were going to neutralize fuel economy gains. Further, they felt fuel prices were already excessive. At the same time, they felt that they would have no choice but to purchase fuel even if prices increased, because their vehicle use was unavoidable. As one participant remarked, gasoline was considered too expensive at INR 13/litre a few years earlier, and prices had doubled since then.

Discussion All in all, there will likely be more resistance to increases in fuel/oil rather than vehicle prices, because of the recurring nature of the former. At the same time, fuel-related policies involving price increases would be less susceptible to the "free rider" problem than vehicle-related policies, as a participant pointed out. At any rate, the maximum WTP indicated is impressive, and would cover all of the various fuel/oil improvements envisaged in the Indian context (Appendix IV).[36] However, it should be noted that over 20% of the respondents said they could tolerate no or only marginal fuel price increases. This percentage will likely be higher among the general population.

While approximately the same percentage of respondents indicated a WTP for vehicle technology and fuel-oil quality improvements to improve air quality, a much smaller percentage of respondents indicated a higher WTP for additional fuel economy enhancement in the case of fuel-oil quality compared to vehicle technology improvements. This has important implications for the effectiveness of vehicle and fuel policies when implemented jointly. But fuel price increases would be rendered less unattractive by vehicle fuel economy benefits, provided the associated vehicle price increase were not excessive.

Finally in the context of fuel price increases for M2W and other gasoline-powered vehicles, an expert the author interviewed was of the view that gasoline quality could be improved without any price increases, by reducing diesel subsidies. Doing so even fractionally would generate significant revenues (because of the large share of diesel in transport energy

[36] To put this WTP in perspective, fuel price increases in the USA for lead removal, and for aromatics, MTBE, olefin, T90 and sulphur control to roughly California Phase II reformulated gasoline levels were estimated at approximately 15% (Faiz et al 1996).

consumption -- see Chapter II), and encourage more fuel-efficient (and cleaner) diesel transport, with positive environmental as well as fiscal benefits.

6.3.6.4 Mandated Vehicle Scrappage

Results The last specific policy alternative on which participants' views were elicited was mandated M2W vehicle scrappage. Note that whereas they were earlier asked to state the vehicle age at which they planned to dispose of their M2W vehicles (Section 6.3.5, M2W Vehicle Disposal and Replacement), participants were now asked to indicate the minimum scrappage period acceptable to them, given that "old vehicles generally tend to be more polluting than new vehicles". Participant responses to this question are represented in Figure 6.20. Two-thirds of the respondents indicated a minimum acceptable M2W vehicle service life of 10 years or more. Another 14% indicated that no vehicle service life limit should be imposed. Some of these respondents refused to accept the premise of service life limits in the Indian context. They did not see why users should have to give up their M2W vehicles, which typically ran trouble free for 15-20 years, and pay more for a replacement vehicle, without the benefit of re-sale value for their old vehicles, as second hand markets collapsed. And after all, such measures did not exist even in affluent Western countries.

Many participants were of the view that enforced scrappage would be opposed strongly even in Delhi, and more so in the country-side. Two participants who opted for no service life limits felt that, if at all such limits were imposed, they should be on the basis of actual emissions performance rather than on a fixed number of years. Several participants indicated that the service life limit should be longer for more expensive advanced technology vehicles, for cars as opposed to M2W vehicles, and for regional cities and towns as opposed to metropolitan centres. Finally, one participant suggested that instead of scrapping the entire vehicle, components critical to emissions performance could be retro-fitted, to minimize costs and conserve resources.

Discussion Explaining the benefits of vehicle scrappage appeared to do little to change participant preferences regarding vehicle disposal. A smaller percentage of respondents opted for no mandated service life limit than indicated that they would use their vehicles as long as

they worked, or never dispose of their vehicles, in response to the question on M2W vehicle disposal discussed in Section 6.3.5. However, the median response in both cases was the same, and the mean was actually higher in the present case. This indicates how deep-seated the opposition to mandated vehicle scrappage is likely to be.

6.3.6.5 Ranking of Policy Alternatives

After having elicited their views on the above specific policy alternatives individually, participants were asked to rank them in order of acceptability. It is noteworthy that the alternatives (Figure 6.21 and Table 6.8) had been specified in terms that were almost identical to the maximum vehicle and fuel price affordability, and the minimum acceptable vehicle service life indicated by participants.

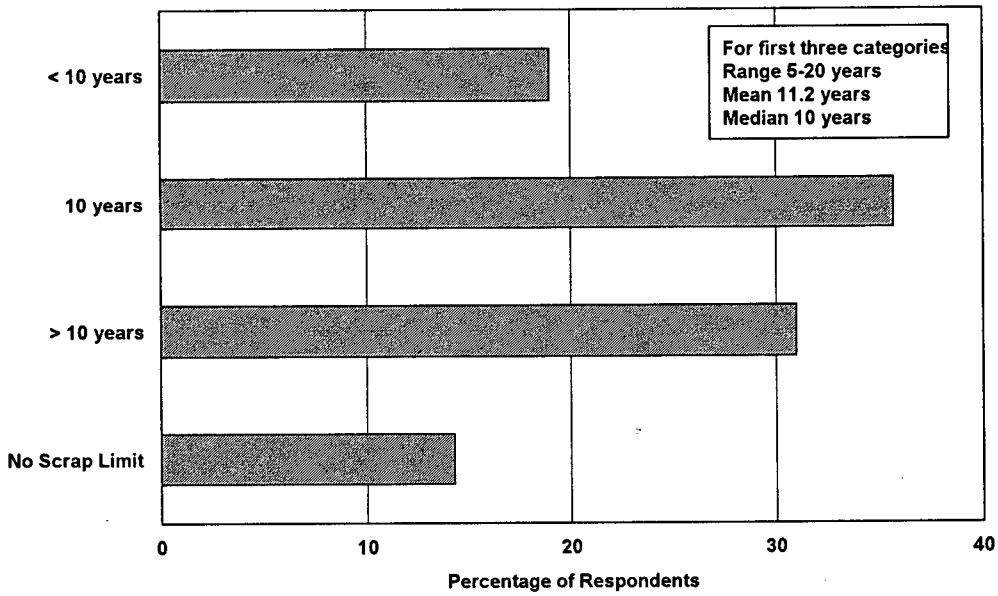
Results Of the 37 participants who responded, three did not rank the policies explicitly, but provided detailed replies on how their ranking might change depending on changes in policy characteristics, including fuel economy improvement. Their responses are incorporated into the discussion in the next section. One respondent ranked the alternatives equally. Figure 6.21 depicts the responses of the remaining 33 respondents who provided explicit rankings. Several of these respondents reported having found none of the policies acceptable, but ranking them nevertheless. A few reported basing their rankings on their concerns as citizens, rather than on their own self-interest as consumers.

Improved (and more expensive) M2W vehicle technologies, even without a fuel economy benefit, were ranked as the most preferred policy by the largest number of participants. Mandatory vehicle scrappage was ranked as the least attractive policy.

Discussion The rankings are not surprising, in light of the foregoing discussions on the individual policy alternatives. Unlike fuel price increases, vehicle price increases are largely "out of sight, out of mind", especially in the absence of mandated vehicle scrappage.

Survey of M2W Vehicle Users in Delhi, 1997

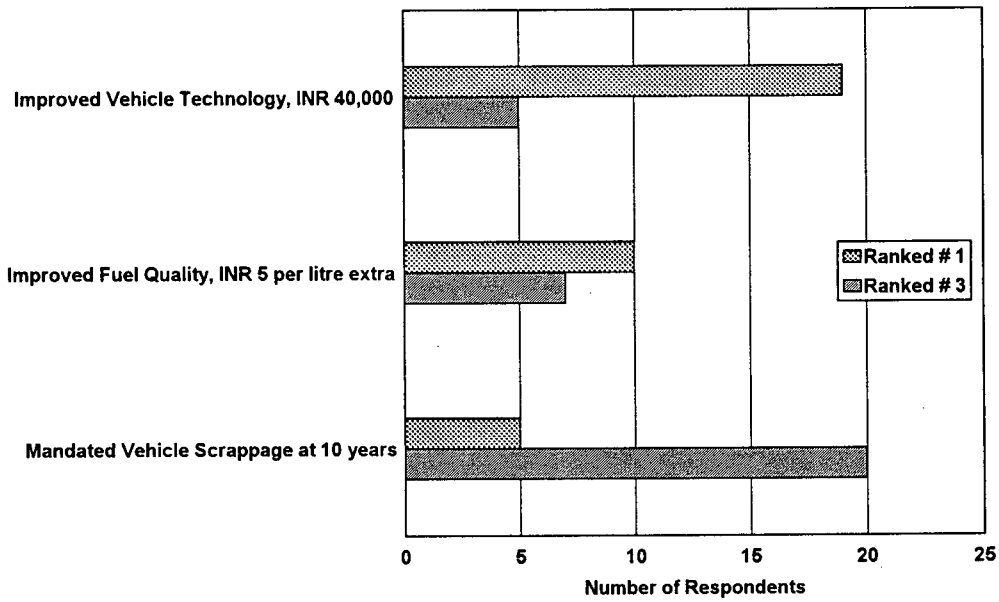
Figure 6.20 Minimum Acceptable Scrappage Period



n = 42. M2W Vehicle – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.21 Participants' Ranking of Policy Alternatives



n = 33. M2W Vehicle – Motorized two-wheeled vehicle; INR – Indian Rupees. Source: Author's survey and interviews (1997). mgb00

Fuel quality improvements involving higher costs are likely to be unpopular with low income and/or high-kilometreage users, because of their recurring nature, but not particularly so with higher income users or with those who use the bus for critical trip purposes such as work, and are thus not too dependent on their M2W vehicles.

6.3.6.6 Policy Impacts, Measures to Enhance Policy Attractiveness, and Desirable Policy Characteristics

This section discusses participants' views on how the above policy alternatives would affect their lives, measures to enhance policy attractiveness, and desirable policy characteristics from their perspective.

Results Policies related to vehicle technology, fuel-oil quality, and vehicle scrappage are in fact being implemented in combination. However, many participants said that policy alternatives *as described in this study* would need to be phased in incrementally, rather than implemented jointly, in order to be acceptable to the generality of users. When asked to describe acceptable combinations of policies, many participants downscaled the WTP they had indicated earlier for vehicle technology and fuel quality improvements, and insisted that a personal benefit such as fuel economy enhancement would be essential to make joint implementation of policies acceptable to them.

Participants indicated that being unable to use their M2W vehicles would cause their families major inconvenience and time losses, especially since the only other affordable motorized travel option, buses, were unreliable, overcrowded and slow. Most participants said that their travel would reduce only slightly if at all, in the event of fuel price increases. On the other hand, if travel costs went down (due to fuel economy improvements, for example), they would likely not travel more, but would rather internalize any fuel cost savings that might result from such improvements.

Not surprisingly, the consensus was that overall cost impacts due to policies should be minimal. Expensive vehicle and fuel technologies to minimize air pollution would be acceptable to users provided vehicle performance, reliability and service life, fuel economy, easy and low cost maintainability, spare parts availability, safety, and passenger and luggage

carrying capacity, were not compromised. In this regard, it is useful to note the issues participants said they considered when contemplating buying four-strokes. They felt that four-strokes were more fuel efficient than two-strokes, but had poorer "pick up" and performance, were prone to more frequent problems, and cost considerably more to own and maintain. In some cases, four-strokes required an engine overhaul in as little as three years, and only a few mechanics were able to service them.[37]

Participants also expressed the view that, if they had to bear higher vehicle and fuel costs, in-use emissions testing should be made less frequent, expensive, and burdensome. Measures such as in-use emissions testing and scrappage should be applied (and be seen to be applied) uniformly and fairly to all, and be free of loopholes that "free riders" could exploit, while others made sacrifices. As one participant said, he would not mind paying whatever was necessary for improved air quality, as long as everyone was made to share the burden, and there were real air quality improvements.

Participants made many suggestions to increase policy attractiveness. These included excise duty and sales tax concessions, and fuel efficiency rebates, to encourage production and purchase of low-pollution, fuel-efficient vehicles. To make emissions performance-based scrappage more attractive, and to promote timely vehicle disposal and rapid penetration of improved technologies, participants suggested a scheme to buy back old vehicles (which would help users realize re-sale value), and sell them after re-conditioning, in the hinterland. Another suggestion in this regard was that vehicle manufacturers could be given credits for implementing such a scheme.

Many participants, taking the *citizens'* perspective, felt that policy-making and implementation must consider the needs and capabilities of low income vehicle users, many of whom have no choice but to rely on their M2W vehicles. In their view, expensive policies must not be mandated without providing viable, low cost alternatives, like adequate public

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[37] Some specific participant views on four-strokes: "I needed a motorcycle for two years, because I will be buying a car afterwards. I decided that the fuel savings over two years would just equal the difference in capital cost, so I decided I might as well go in for a two-stroke, which has better pick-up, and no high frequency sound like the four-stroke"; "I would like to buy a four-stroke for its fuel economy, but I am worried about serious maintenance problems"; and "I did not consider a four-stroke because I wanted a zippy motorcycle" (as discussed, four-strokes were, at the time of the study, available only on motorcycles, and users who choose motorcycles typically do so because they perceive them to be more powerful than scooters).

transit. In this regard, a participant pointed out that a recent gasoline price escalation was strongly protested in Delhi, but not in Mumbai, where public transit is excellent.

Discussion The foregoing demonstrates the importance of co-ordinating policies to work effectively in tandem, from a technical standpoint, and also to account for how vehicle users will respond to policies when implemented in combination.

It appears from participant views that vehicle users would prefer policies that are applied fairly, and that minimize the need for burdensome initiatives on their part, by way of vehicle maintenance and presenting their vehicles periodically for in-use emissions testing (for example). Examples of such policies are line-mixing of fuel and oil on two-strokes, and fuel-oil quality improvements.[38] Costly emissions reduction technologies would not only be acceptable but could even be rendered attractive to users, if they offered personal benefits such as fuel economy improvements, while at the same time not compromising vehicle performance characteristics. These perspectives are useful in discriminating between technologies such as four-strokes, which offer fuel economy benefits, and catalytic converters, which do not necessarily do so. Fuel economy improvements would pay back any associated vehicle price increase, and also help mitigate the cost impacts of fuel-oil quality improvements. Conversely, more costly fuel-oil would make expensive vehicle emissions reduction technologies that deliver fuel economy benefits more attractive.

Vehicle fuel economy improvements will likely become more attractive, as sprawl increases and access and public transit availability degrade, and vehicle users become more dependent on their vehicles and travel longer distances on them, and consequently become more sensitive to fuel price increases. Fuel efficiency rebates calibrated to actual fuel economy performance would serve to intensify fuel economy efforts. Since users might delay disposing of their vehicles because of new, less-polluting vehicles being more expensive, such rebates would encourage timely disposal and promote more rapid penetration of improved technologies. This is particularly so in the case of M2W vehicle users, many of whom are

[38] Given that fuel-oil quality improvements become effective transport system wide as soon as they are introduced, but that they would likely be less popular than vehicle technology improvements, as evidenced in this study, there is a case to be made for building public awareness of the advantages of fuel-oil quality improvements.

price-sensitive. Vehicle features such as easy driveability would also increase the attractiveness of expensive new vehicles, particularly as more women enter the work force and begin to use M2W vehicles. Recall in this regard that the ideal M2W vehicle from one participant's viewpoint was a four-stroke scooter with the driveability of a Kinetic Honda.

The dilemma with regard to vehicle scrappage is that, in the absence of an effective scrappage regime that is enforced region-wide, poorly maintained and polluting vehicles would not be disposed of in a timely fashion, even by those who could afford to do so. Further, emission standards and other measures that increased costs, could delay even the scrappage that would have occurred voluntarily. On the other hand, enforced vehicle scrappage would be burdensome, especially for low income users who could not afford to replace their vehicles periodically, particularly in view of the absence of viable options to personal motorized vehicles. The potential for fraud would be great, given the institutional constraints discussed in Chapter IV. There are other issues as well. Recall that users would expect more expensive vehicle technologies to deliver a longer service life. But mandated scrappage, say every ten years, would negate this. Apart from again showing the importance of understanding how policies can affect users and how they will respond to them when implemented in combination, the foregoing demonstrates the need for effective in-use emissions monitoring and control.

A vehicle scrappage scheme based on emissions performance would be more attractive to users, than one based on a fixed number of years. While scrappage based on vehicle age would discriminate against well-maintained old vehicles, that based on emissions irrespective of age would serve as an incentive to quality maintenance, while preserving vehicle value, and thus also be more effective in reducing emissions. In this regard, note that while emissions increase on average with vehicle age, vehicle maintenance regardless of age is also critical (Calvert et al 1993; Faiz et al, 1992; Faiz et al, 1996). Thus, such a scrappage scheme would require a well designed and effective in-use emissions monitoring and control regime, linked to an equally effective vehicle registration regime.

Lastly, participant responses regarding how increased travel costs would affect travel activity are not surprising. According to the RITES/ORG (1994) survey, commuters value time savings more highly than cost, and discretionary travel (for social and recreational

purposes) accounts for only around 4% of all trips in Delhi. Further, congestion, which is increasing rapidly, would be a damper on non-essential travel, even if travel costs were low.

6.3.6.7 Public Transit and Cycling

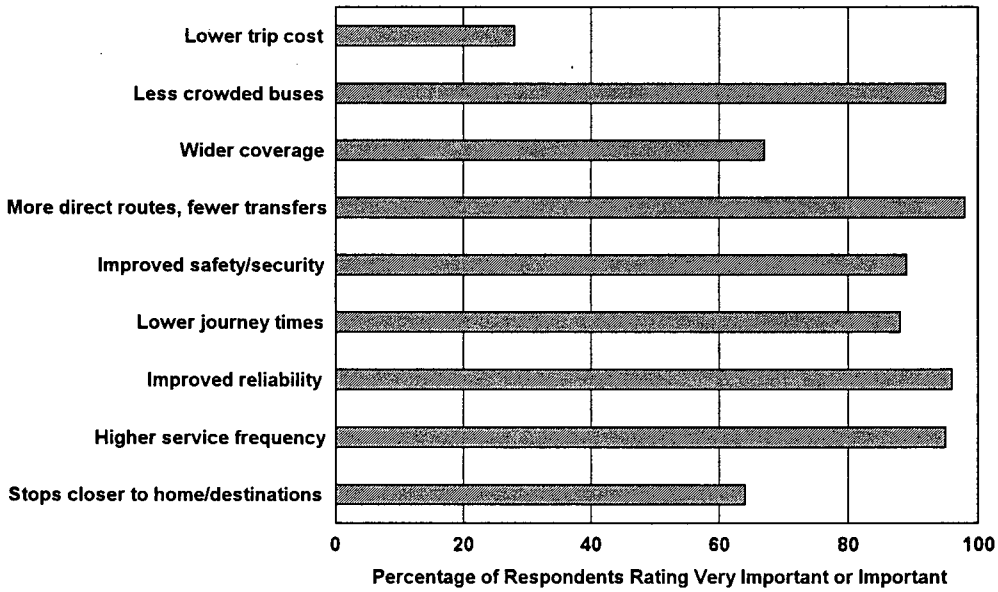
Results Figure 6.22 shows how participants rated improvements that would make bus service more attractive to them. Direct routes, improved schedule reliability, higher bus frequency, and less crowded buses were rated as important by the most respondents. Lower trip cost was rated as important by the least respondents. Other improvements suggested were safer bus operation, stopping only at designated stops, better vehicle maintenance, enhancing non-peak service, and making bus service less hostile to women (by providing "ladies specials", as in Chennai, for example). Several respondents suggested introducing higher capacity "double-decker" buses, rather than increasing the number of existing buses, to achieve these improvements without increasing congestion. Some participants stressed the need for thorough-going institutional reform of public transit in Delhi. They felt that it should be privatized, but strictly regulated. They believed ownership should not be fragmented as currently, and suggested that contracts could be auctioned on a regional or route basis.

The vast majority of respondents, including those not using buses for their work trips at the time of the study, said they would be willing to use buses, if service were improved along the lines they had suggested, but mainly for long distance and work trips. At the same time, three-quarters of the respondents said they would not give up their M2W vehicles even if bus service were improved significantly. This reluctance was due to the many advantages of M2W vehicles that have already been discussed, including their ready availability in emergencies and for short evening trips, their usefulness to users' family members, and finally, in the words of one respondent, because "buses are not available at 2 AM."[39]

[39] Of the 11 respondents who said they would give up their M2W vehicles, nine either had another M2W vehicle or car, or traveled by bus daily to work. One of these said he would never give up his car because of the prestige it conferred on his family. Only four of the 13 respondents who took the bus to work regularly said they would give up their M2W vehicles.

Survey of M2W Vehicle Users in Delhi, 1997

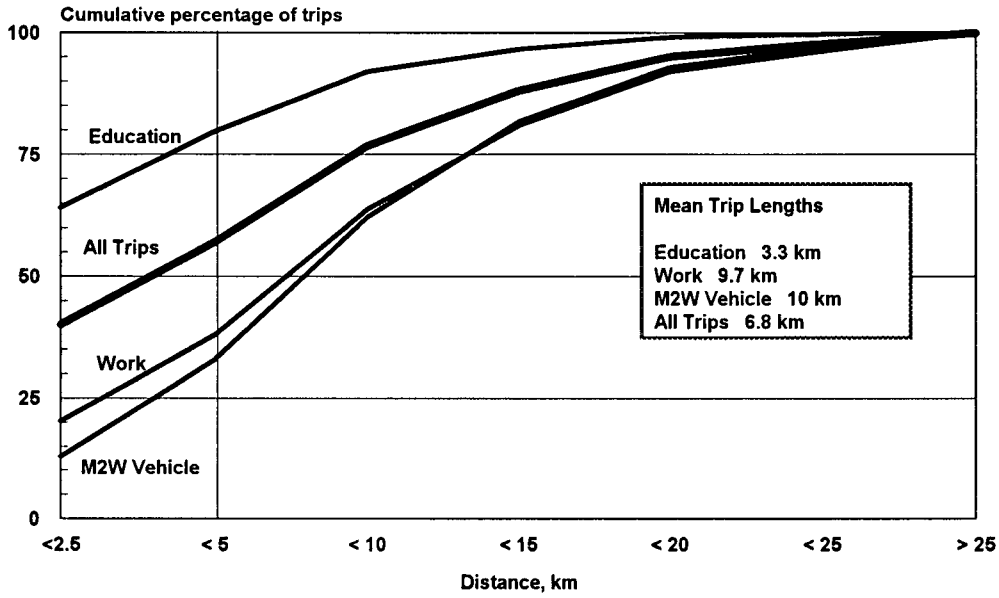
Figure 6.22 Rating of Bus Service Improvements



n varies from 39 to 45 for various factors. M2W Vehicle – Motorized two-wheeled vehicle. Source: Author's survey and interviews (1997). mgb00

Survey of M2W Vehicle Users in Delhi, 1997

Figure 6.23 Distribution of Trips by Distance in Delhi



M2W Vehicle – Motorized two-wheeled vehicle. Source: RITES/ORG (1994). mgb00

As for improvements to make cycling more attractive, dedicated bicycle lanes (to protect cyclists from motorized traffic) was rated as important by the most respondents, followed by reduction in time delays due to motorized traffic. Other suggested improvements included traffic management according priority to bicycles, enforcing motor vehicle driver discipline, improving bicycle quality, and ensuring secure bicycle parking. Nearly two-thirds of those not cycling at the time of the study said they would consider cycling, but only for short local shopping trips.

Discussion The foregoing results reconfirm the potential for transferring medium to long distance work-related M2W vehicle trips to buses, and demonstrate the importance of improving bus service in enabling this mode transfer. At the same time, the results show that M2W vehicle ownership would likely not decline, even if bus service were improved significantly.

Transferring medium to long distance JTW trips to bus would help minimize M2W vehicle emissions, because such trips form a significant proportion of all M2W trips (RITES/ORG 1994). Improving bus service along the lines discussed would benefit bus users, and also help mitigate emissions policy impacts for M2W vehicle users. It is interesting that trip cost was rated as a low priority in making buses more attractive to M2W vehicle users. This finding is corroborated by RITES/ORG (1994), which found that journey time was more important than travel cost in deciding to shift to mass transit.[40]

The importance accorded to improved schedule reliability and less crowded buses explains the growing popularity of, and underlines the need for, services such as those provided by charter buses, discussed in Sections 6.3.1 and 6.3.2. The potential for such services to reduce personal vehicle trips is underscored by the fact that regular buses are routinely overcrowded, and by the willingness of many car and M2W vehicle users, according to some participants, to pay as much as INR 800 monthly to switch to air-conditioned, reserved seating buses.

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[40] Only 5% of respondents in the RITES/ORG (1994) survey expressed willingness to pay more than 25% for a journey time reduction of less than 25%. Nearly 50% reported willingness to pay 25-50% more for an equal reduction in journey time, and 21% said they would pay more than 50% for a journey time reduction greater than 50%. Recall that the RITES/ORG survey covered a wider range of residential households than this study, in terms of income.

Given the study results, it is not likely that M2W users will switch to cycling in any significant way. Apart from dedicated bicycle lanes, perhaps the most important change that would promote cycling would be for motor vehicle owners to not consider cycling and cyclists as a nuisance, as one participant pointed out. There appears to be little interest in using bicycles, even for short distance trips, because of lack of road safety and congestion due to motor vehicles, and the lack of cycling facilities and bicycle-focused traffic management. Recall in this regard that the majority of road accident victims in Delhi are pedestrians and cyclists (Chapter II).

That users are unlikely to take to cycling to any great extent, even over short distances, has important implications for reducing M2W vehicle usage and emissions. Short distance M2W vehicle trips are important, because their contribution to total M2W vehicle energy and air pollutant emissions is disproportionate to their share of total M2W vehicle-kilometres, because of low speeds at low distances,[41] and the constancy of trip-start and trip-end (evaporative) emissions regardless of trip length. Although the average M2W vehicle trip in Delhi is 10.03 kilometres long, around 33% of all M2W vehicle trips are five kilometres or shorter (Figure 6.23). Many of these are not only shopping trips, for which the M2W vehicle is ideally suited, but also work and education trips.

Short distance travel is as important as long distance travel in terms of M2W vehicle usage and emissions, and also in motivating M2W ownership. Buses are not an attractive option for short distances, because of long walk and wait times relative to bus journey times. Further, while participants said they would consider switching to buses for long trips, it is for short distance trips that they did not wish to give up their M2W vehicles. This is likely because, although the potential for walking and cycling rather than using a M2W vehicle is considerable, as evidenced by the significant proportion of trips below 2.5 and 5 km in Delhi (Figure 6.23), M2W vehicle usage is forced upon users over these distances, because of compromised access.

[41] Speeds for all modes are low over short distances, because they are slowed down by the preponderance of walk and cycling over those distances. Speeds increase with distance, except for buses, for which the speed curve with distance is flat, as the RITES/ORG (1994) data shows. Over longer distances, motorized modes have far fewer slow-moving vehicles to contend with, plus they are more likely to take higher-speed routes.

Technological policies such as fuel volatility control certainly have an important role in limiting evaporative emissions, which form a significant proportion of total emissions over short distances. But in view of the foregoing, removing barriers to safe walking and cycling on neighbourhood streets would likely be beneficial, in minimizing the most polluting M2W trips, and in increasing average speeds for M2W vehicle trips that do occur over these distances and thereby reducing exhaust emissions. Further, as the RITES/ORG (1994) survey shows, walking and cycling (and travel by cycle rickshaws) account for nearly 39% of trips in Delhi even among residential households. As discussed in Chapters III and V, the shares for these modes would likely be significantly higher for the total urban population in Delhi, considering that every second person in that city lives in a slum (Singh 1997b).

6.4 CONCLUSIONS

The study demonstrates the utility in focusing on human dimensional in addition to technological factors associated with motor vehicle activity and emissions. Specifically, the study shows that understanding vehicle user choices and motivations, and how users are affected by and respond to policies, can contribute to more effectively modeling transport emissions, and designing policy packages that are attractive to users, and that therefore have a greater chance of success over the long term. Further, the study shows how integrating environmental policy and urban transport perspectives, by focusing on travel activity by various modes at the household level, can help identify technological-curative as well as preventive policies to blunt the impact of emissions policies, and minimize M2W vehicle usage and ownership. Last but not least, the study demonstrates the value of eliciting views and judgments on complex public policy matters involving technological issues from lay persons.

CHAPTER VII

STRUCTURING MULTIPLE OBJECTIVES AND MEASURES FOR POLICIES TO PREVENT AND CONTROL M2W VEHICLE EMISSIONS IN THE INDIAN CONTEXT

7.1 INTRODUCTION

In Chapter V, we discussed the need to consider a wide range of environmental, health, socio-economic, and other policy impacts for various actors and affected groups, and also other interests and concerns these actors and groups might have with respect to policies, to effectively address transport air pollution. Further, the multiple-objectives approach was proposed for discriminating between policy alternatives, and the approach was described in brief. But the multiple policy objectives to be considered were not specified.

In Chapter IV, we discussed the conflicting interests, concerns and agendas of various key actors involved in developing and implementing policies to address transport air pollution in the Indian context. It was argued that since the actors prefer policies that minimize implementation costs for themselves, their interactions are marked by conflict. Given this, it would be reasonable to expect each actor and affected group to have a range of objectives that they would like policies to achieve, from their own perspective. Further, there would likely be conflicts between the objectives of one actor or group and those of other actors and groups, as well as among the objectives of each actor or group.

Gaining an understanding of these multiple conflicting objectives from the perspective of various actors and affected groups, and the trade-offs they make between these objectives, would be useful in understanding the barriers to policy-making and implementation, and in designing policy packages that address the interests and concerns of all. This is particularly important, given that policy impacts are often unevenly distributed among actors and affected groups. Recall in this regard, from Chapter VI, the usefulness of considering policy impacts for, and the perspectives of, motor vehicle users, in designing policies that would be more acceptable to them. Finally, given the lack of effective inter-agency co-ordination, and the tenuous linkages between the policy-analytic and decision-making communities in the Indian

context (Kandlikar 1998), an integrative perspective on what is a multi-dimensional problem would be particularly valuable.

While generating multiple policy objectives would be useful, as discussed above, it is rather difficult to do in practice. Unfortunately, policy objectives for transport air pollution prevention and control are not well understood or articulated. Decision makers are often unaware of system-wide and long-term policy consequences, even from their own perspectives, let alone for affected groups with no influence over the decision making process. The lack of co-ordination among decision makers, and between decision makers and the policy-analytic community, also serves as a barrier. Finally, the diversity of policy alternatives that may be applied (Table 5.1), and the wide range of impacts each of these alternatives can have for different actors and affected groups, only serves to make a difficult enterprise even more difficult.

7.1.1 Chapter Objectives and Outline

In Chapter V, an argument was made for value-focused thinking, which essentially consists in being clear about and structuring values on which policy objectives should be based, rather than simply basing decisions on already obvious alternatives. Analytical methods to clarify and structure public policy problems characterized by multiple stakeholders with multiple conflicting objectives are well established, and have been applied to a diversity of policy situations in Western settings. These problem-structuring tools of value-focused thinking, which are discussed in the next section, directly involve stakeholders to clarify and structure key public values, and enable selection of alternatives that better serve these values (Keeney 1988b; Keeney, von Winterfeldt and Eppel 1990; Keeney 1992; Keeney and McDaniels 1992; Keeney and McDaniels 1999). This Chapter applies these tools to better understand the problem of M2W vehicle air pollution in the Indian context, and to identify and structure multiple objectives on the basis of which to systematically create, evaluate, implement and monitor policy alternatives for long-term effectiveness.

The problem-structuring tools of value-focused thinking have been used in only a few cases in the LIC context. Gregory and Keeney (1992) and McDaniels and Trousdale (1999) applied these tools to help decision makers and stakeholders clarify objectives and devise new

alternatives related to preservation and development in Malaysia and rural tourism in the Philippines respectively. But these tools have not been applied, to the author's knowledge, to a highly complex situation such as the one this dissertation addresses. At any rate, this is perhaps the first attempt at developing multiple policy objectives related to transport air pollution in the Indian context. In addition to fulfilling an important policy-analytic need in relation to this problem in this context, the Chapter also addresses the question of whether such tools can be applied to better understand and structure complex public policy problems in LIC contexts generally.

In the sections that follow, the methodology for eliciting, clarifying and structuring multiple objectives and measures for policies targeted at M2W vehicle air pollution is described. The multiple objectives and measures that were developed are presented, and the implications for policy-making and implementation are explored.

7.2 METHODOLOGY

7.2.1 The Multiple-Objectives Approach for Eliciting, Clarifying, and Structuring Public Values

The multiple-objectives approach directly involves actors and affected and interested groups to identify and structure multiple policy objectives, develop measures or attributes to gauge the achievement of these objectives, and investigate trade-offs representing stakeholder priorities among the objectives. Directly involving actors and affected groups, and explicitly accounting for their diverse objectives and trade-offs can serve as an effective means of enhancing involvement, improving communications, facilitating mutual appreciation of problem complexity and trade-offs, identifying and resolving conflicts, and fostering compromise and consensus among stakeholders. While the diversity of objectives might make conflict seem inevitable, it can actually be the key to creating alternatives that have the potential to be widely accepted. The objectives and measures, along with value trade-offs representing priorities among objectives, can be used to evaluate alternatives from the perspective of each actor and affected group. Policy packages that represent a win-win condition for all can be developed, thus enhancing the chances of long-term policy success

(Edwards and von Winterfeldt 1987; Keeney 1988b; Keeney, von Winterfeldt and Eppel 1990; Keeney 1992; Keeney and McDaniels 1992; Keeney and McDaniels 1999).

The multiple-objectives approach consists first of all in identifying the actors and other affected and interested groups relevant to the decision situation, and then interacting with them to gain a good understanding of this situation and of policy options, to arrive at a common problem structure that all groups can agree on. Next, the value dimensions on which the various groups would like to see options evaluated are structured in the form of objectives, for each group separately. Value elicitation is best done by engaging representatives of the groups in free-flowing and detailed discussions. Policy analysts can facilitate the process by using various cues. These include urging participants to consider what is important, and the information they would like to know, in making the decision, to make up wish lists, and explore the pros and cons of existing, proposed or hypothetical alternatives, in terms of their trade-offs and impacts. Participants can also be asked to consider impacts and objectives from the point of view of other interested and affected groups, and for society as a whole, in addition to those from their own perspectives (Edwards and von Winterfeldt 1987; Keeney 1988b; Keeney, von Winterfeldt and Eppel 1990; Keeney 1992; Keeney and McDaniels 1992; and Keeney and McDaniels 1999).

The goal is to clearly specify and structure values, instead of merely listing them. This may be achieved by first separating means from fundamental objectives, by applying the WITI or "why is this (objective) important" test. A fundamental objective is that for which the answer to this question is, because it is important. If the answer is that it is important because of its implications for some other objective, this is a means objective, and a fundamental objective can then be identified. It is important to avoid double counting by ensuring that fundamental objectives, on the basis of which alternatives will be evaluated, do not include means objectives, which are merely ways of achieving the fundamental objectives. Next, the fundamental objectives elicited are sharply defined, in other words, specified, in order to enable the impact of each option to be measured effectively. In the case of the fundamental objective "minimize environmental impacts", for example, the precise environmental impacts to be minimized are elaborated. Lower-level objectives collectively provide an exhaustive characterization of the higher-level fundamental objectives, so that alternatives can be

compared in terms of all important consequences. At the same time, it is ensured that objectives are mutually exclusive, again to avoid double counting. Lastly, it is ensured that objectives are not so broad that alternatives other than those in the decision context can influence their achievement. Conversely, if objectives do not discriminate between alternatives in the decision context, they are either ranked low or eliminated (Keeney 1992).

After multiple objectives are specified clearly and clarified, they are structured into a hierarchy for each group by aggregating them into categories, and a common objectives hierarchy for all groups is developed by integrating the hierarchies for each group. This involves judgment and finesse on the part of the analyst, because each objective in the hierarchy of each group is included either explicitly or implicitly, while at the same time achieving conciseness. All in all, structuring and clarifying objectives enables clearer and deeper understanding and communication of the full range of values pertinent to the decision problem (Keeney 1992).

The next step is to define measures or attributes by means of which to judge the extent to which the objectives are achieved by various alternatives. Measures are specified precisely, so that they convey precisely what the related objectives mean. They are easy to develop for cost objectives, but are more difficult to construct for other objectives. The complete set of lower level objectives along with their measures enables assessing an objective function appropriate for the problem, in terms of all important consequences. Structuring objectives and developing measures is an intertwined process. While clarifying objectives sharpens selection of measures, thinking about measures can help clarify objectives. Finally, measures guide data collection for evaluating alternatives (Keeney 1992).

After objectives have been structured and clarified, and measures developed for operationalizing objectives, objective functions incorporating trade-offs between objectives are assessed from various groups, by having them assign weights to the objectives. These objective functions are combined with expert assessments of the policy alternatives in terms of the measures, to generate a multiple objective evaluation of alternatives from each group's perspective. This process can also serve as a basis for mutual learning, and constructive discussions leading to a mutually beneficial compromise (Edwards and von Winterfeldt 1987;

Keeney 1988b; Keeney, von Winterfeldt and Eppel 1990; Keeney 1992; Keeney and McDaniels 1992; and Keeney and McDaniels 1999).

7.2.2 Methodology Used in the Present Study

The multiple objectives and measures presented in this Chapter in relation to policies to prevent and control M2W vehicle emissions in the Indian context were developed based on in-depth interviews conducted by the author in India in late 1997. These interviews were held with various individuals interested in and/or knowledgeable about the range of issues involved, and representatives of institutions whose actions have an important bearing on transport air pollutant emissions in the Indian context. These individuals included decision makers in various relevant government agencies at the national and local levels, senior executives in Bajaj Auto Limited and TVS-Suzuki Limited, two leading Indian M2W vehicle manufacturers, and in Indian Oil Corporation, the largest fuel and oil refiner and marketer in the country, and academics and researchers in the fields of environmental policy and urban transport. A list of interviewees is provided in Appendix V.

Interviewees' informed consent was obtained prior to interviews being conducted. The approach followed in the interviews, and the Informed Consent Form (Appendix VI), were approved by the Behavioural Research Ethics Board of the UBC Office of Research Services and Administration, and discussed with researchers at the Indian Institute of Technology, Delhi (IIT Delhi), the local institution with which the author was affiliated for the purposes of the IDRC award which partly funded the study.

The process of eliciting, clarifying and structuring policy objectives and measures typically involves interacting with representatives of various groups separately, jointly, and iteratively, and can therefore be quite time and resource intensive. The interviewees in the present case were geographically dispersed, and had extremely busy schedules. The author was able to meet with each individual no more than once or twice. During these meetings, several issues relevant to this dissertation were discussed, apart from policy objectives. Further, many of the individuals interviewed felt uncomfortable when confronted with the request to suggest policy objectives and evaluation criteria on the spot. Nevertheless, the interviews were extremely useful in developing objectives and measures with regard to prevention and control of M2W

vehicle emissions in the Indian context. These interviews focused on, among other things, technical and institutional factors contributing to emissions, considerations underlying current and proposed policies, likely impacts of policies on users and industry, implementation issues including financial, technological and administrative constraints on the part of various actors, and problems in terms of inspection, monitoring and enforcement. Many of these issues correspond to the cues that Keeney (1988b), Keeney, von Winterfeldt and Eppel (1990), Keeney (1992), Keeney and McDaniels (1992), and Keeney and McDaniels (1999) recommend for value elicitation, and that were discussed in the previous section. Also, the discussion of contributory factors, barriers and constraints suggested various means objectives, which in turn were used to develop fundamental objectives, by means of the WITI test.

The multiple objectives and measures presented in this Chapter were also based on the principles enunciated in Chapter V for the determination of policy impacts, and on insights gained from the work on M2W vehicle user choices and perspectives discussed in Chapter VI. In addition to user perspectives on policy impacts and responses, measures to enhance policy attractiveness, and desirable policy characteristics, issues and trade-offs users would consider in making choices regarding vehicle models such as four-strokes were also employed in developing objectives from the user perspective.

The multiple objectives and measures developed in this Chapter were primarily intended to be applied to technological and regulatory policies targeted at M2W vehicle emissions. However, it was decided that the objectives and measures should be able to accommodate a wide range of policies to address both the per-vehicle emissions as well as the vehicle activity components of the problem (see Table 5.1). As discussed in Chapter V, policies targeted at M2W vehicle emissions can have a wide range of emissions, socio-economic and transport system impacts over the long term for various actors and affected groups, and for future generations. Thus, for example, policies such as congestion management have the potential to cause access for non-motorized mode users to be compromised, apart from their implications for emissions from M2W and other motorized vehicles. In evaluating policies targeted at M2W vehicle emissions, therefore, it would be desirable to consider impacts for users of non-motorized modes (and public transit) in addition to those for M2W vehicle users. Lastly,

policies directed at M2W vehicles in Delhi and other major cities will inevitably have implications for M2W vehicle users in other parts of the country as well. The objectives and measures developed in this Chapter are therefore designed to be capable of discriminating among M2W vehicle emissions prevention and control alternatives broadly conceived as above, in terms of impacts that are just as broadly conceived.

7.3 STRUCTURING MULTIPLE OBJECTIVES

This section presents a multiple objectives hierarchy with regard to prevention and control of M2W vehicle air pollutant emissions in the Indian context. Multiple objectives were developed from the perspective of each of the three principal stakeholders related to the issue, namely decision makers, presumed to represent the interests of the public at large, M2W vehicle, fuel and vehicle servicing industries, and M2W vehicle users, and then integrated into the overall fundamental objectives hierarchy (Table 7.1), by applying the WITI test. In addition to presenting the multiple policy objectives, a rationale for them is provided as well.

The first objective in the hierarchy specifies the local, regional and global health, welfare and environmental impacts of system-wide air pollutant emissions due to M2W vehicle activity that policies should attempt to minimize. The importance of these impacts was discussed in Chapter II. The objective also reflects the desirability of policies to minimize emissions impacts rapidly, in order to win public confidence, while at the same time sustaining these reductions over the long term. This specification would help discriminate between fuel and oil quality improvements, which begin to take effect straight away, as opposed to vehicle technology improvements, which take much longer to show results, as noted in Chapter V. Further, stressing the long term would allow for in-use realities such as travel activity changes and vehicle emissions performance deterioration, and possible vicious circles and side effects, that may manifest themselves over time, to be considered. In turn, this specification would help discriminate between preventive and technological-curative policies.

The second objective reflects the desire of decision makers, the vehicle, fuel and oil, and vehicle servicing industries, and M2W vehicle users, to minimize the long-term costs of implementing policies, and specifies, from the perspective of each key stakeholder, the precise costs to be minimized. Thus, from the decision makers' perspective, the objective reflects the

need to minimize the costs of providing the various kinds of institutional support to ensure policy effectiveness. Such support tasks are specified: regulation, monitoring, and enforcement related to M2W vehicles, fuel and oil, and transport infrastructure provision. In the case of M2W vehicles, these tasks could include setting up and operating an effective I&M (inspection and maintenance) regime, and a reliable computerized system linking vehicle registrations and I&M. In the case of fuel and oil, these tasks could include setting up and operating mechanisms for monitoring and enforcement related to fuel and oil adulteration. Transport infrastructure requirements would be a critical consideration in evaluating policies such as highway capacity addition (to increase average speeds), and increasing public transit capacity (to effect mode transfers from M2W vehicles).[1]

Given the severely restricted institutional capabilities in the Indian context, it would be desirable to select alternatives that minimize not only the long term costs of providing, but also the need for, institutional support mechanisms to ensure policy effectiveness. For M2W vehicle and fuel and oil manufacturers, developing and implementing emissions prevention and control technologies, some of which may have to be imported, could involve considerable outlays of capital. In the case of improved quality fuels and oils, fuel dispensing stations might have to be re-designed and re-constructed, and evaporative controls implemented on various components of the fuel distribution system, in addition to developing and implementing refinery technologies. The importance of maintenance and servicing quality for the long-term effectiveness of new and often complex technologies, was stressed in Chapter VI. Ensuring good maintenance and servicing quality in turn would call for new equipment and training of service personnel, with associated costs. Lastly, the M2W vehicle industry could incur costs associated with warranty, vehicle re-call and liability due to ineffective and/or unsafe emissions prevention and control technologies. The objective therefore reflects the desirability of minimizing all of the above costs, from the perspective of the M2W vehicle, fuel and oil, and vehicle servicing industries.

Just as it is important to minimize the impacts of emissions system wide over the long term from the decision makers' perspective, it is important from the point of view of users, as

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[1] In the case of highway capacity addition, it is possible that increased travel activity by M2W (and other) vehicles may be induced over the long term. Evaluation of emissions and other policy impacts over the long term, as the proposed objectives hierarchy stresses, would account for such effects.

consumers, to minimize cost impacts of policies on a life-cycle basis. Therefore, based on the user perspectives discussed in Chapter VI, the objective is specified in terms of costs related to vehicle purchase, fuel and oil consumption, vehicle maintenance and servicing, and mandated vehicle I&M. In connection with the last cost item, note that users would strongly prefer that in-use emissions testing be less frequent, expensive, and burdensome. Strictly speaking, the need to preserve vehicle re-sale value should also have been included along with the other cost components. This was not done, since the objective was to *minimize life-cycle costs*, and re-sale value would actually need to be maximized in order to achieve this objective. To avoid confusion, therefore, re-sale value was included under the next objective, "minimize loss of M2W vehicle characteristics due to policies". Finally with regard to the life-cycle costs objective, it was decided that minimizing fuel and oil costs would help account for fuel economy advantages (and reduced oil consumption) offered by certain emissions prevention and control technologies, such as four strokes and line-mixing. Enhancing fuel economy was consequently not included in the objectives hierarchy, since this would have led to double counting.

The next three fundamental objectives in the hierarchy in Table 7.1, along with their sub-objectives, reflect key M2W vehicle user concerns, apart from the need to minimize long term capital and operating costs associated with policies. As discussed in Chapter VI, users would prefer that policies not compromise vehicle performance, reliability, easy maintainability and serviceability, spare parts availability, passenger and luggage carrying capacity, service life, and re-sale value. At the same time, the attractiveness of policies may be enhanced, if in addition to the foregoing characteristics not being compromised, they offered personal benefits such as improved driveability (and fuel economy).[2]

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[2] Interestingly in this regard, the AIAM expressed the concern that with M2W vehicle emission standards becoming ever more stringent, engines might become very sensitive and be prone to poor startability and driveability. Also, AIAM expressed the view that vehicle power could not be compromised, given that M2W vehicles in India are used not only for personal transport but also to carry goods (AIAM 1996b).

Overall objective: Minimize adverse impacts of system-wide air pollutant emissions due to M2W vehicle activity, and policy impacts, for current and future generations	
Minimize adverse impacts of system-wide air pollutant emissions due to M2W vehicle activity, Rapidly and over long term	Minimize loss of M2W vehicle characteristics due to policies
Health Impacts	Reliability
Premature mortalities	Vehicle performance
Morbidities	Service life
Physical Impacts	Maintainability and serviceability
Damage to crops	Passenger and luggage carrying capacity
Damage to structures	Re-sale value
Loss of visibility	Minimize injuries to M2W vehicle users due to policies
Environmental Impacts	Minimize inconvenience and loss of time related to restricted M2W vehicle ownership and usage and mode changes due to policies
Acidification	Minimize other transport system impacts due to policies over the long term
Climate change	Loss of access and time delays for users of non-motorized modes
Minimize long-term capital and operating costs of implementing policies	Land use
Government	Population Displacement
M2W Vehicles	Minimize vulnerability over the long term, with respect to
Regulation	Future scenarios
Monitoring	Regulatory changes
Enforcement (I&M)	Promote equity and fairness in applying policies
Fuel and oil	Between M2W Vehicle Users and users of other private motorized modes
Regulation	Between users of different M2W vehicle types
Monitoring	Geographically (inter-regionally in India)
Enforcement	
Transport infrastructure provision	
M2W vehicle and vehicle servicing industries-	
Technology development and implementation	
Training and equipment for maintenance and servicing	
Warranty, vehicle re-call and liability	
Fuel and Oil Industry	
Technology development and implementation	
Fuel/oil distribution network	
M2W vehicle users	
Vehicle purchase	
Fuel and oil	
Vehicle maintenance and servicing	
Mandated vehicle I&M	

Table 7.1 Overall Fundamental Objectives Hierarchy

One might wonder why maintainability and serviceability were included as a sub-objective, when minimization of maintenance and servicing costs was already considered under the life-cycle costs objective. This was done because the ease with which new technologies can be maintained and serviced, regardless of their cost, is in itself an important consideration, given the complexity of some new technologies, the lack of quality maintenance and servicing, and the tendency of many users to maintain their vehicles themselves, as discussed in Chapter VI.

The need to consider user safety impacts due to policies is stressed in order to account for, for example, the possibility of burn injuries due to catalytic converters on M2W vehicles (Faiz et al 1996).

Fostering transfers to less polluting modes, and even restricting M2W vehicle ownership and usage, are obviously desirable, from the standpoint of emissions reductions, but would involve inconvenience and loss of time for M2W vehicle users. Hence the objective "minimize inconvenience and loss of time related to restricted M2W vehicle ownership and usage and mode changes due to policies". This objective does not imply that such mode transfers must be limited, or that efforts not be made to restrict M2W vehicle ownership and usage, but rather that viable alternatives such as enhanced public transit service be provided, to make up for the inconvenience and loss of time.[3]

The next fundamental objective, "minimize other transport system impacts" reflects the importance, stressed in Chapter V, of considering the inter-dependence between transport air pollution and other transport impacts. Loss of access and time delays for users of non-motorized modes, land use, and population displacement are specified as the sub-objectives, because these would be important impacts of policies such as congestion management, particularly given the large proportion of urban poor and non-motorized mode users, the severe land shortages, and the need to control sprawl, in the Indian context. Another important transport system impact is energy consumption. Minimizing energy consumption is an important objective in itself, as discussed in Chapter II. Additionally, it is an important consideration in evaluating M2W vehicle emissions prevention and control policies and

[3] By the same token, the objectives "minimize loss of M2W vehicle characteristics", and "minimize other transport system impacts", are not to be taken to mean that deterioration with respect to the status quo is merely to be minimized. Indeed, it would be desirable for emissions prevention and control policies to actually improve conditions in terms of these parameters, if possible, in addition to minimizing emissions impacts.

technologies, since some of these would promote energy conservation in addition to lowering emissions, while others would not. However, energy consumption is already accounted for in the sub-objective "minimize (fuel and oil) costs" (for users), and is therefore not repeated here, in order to avoid double counting.

The next objective in the hierarchy, which relates to minimizing the vulnerability of policies due to future scenarios, reflects the desirability of ensuring that policies do not lose their effectiveness on account of future conditions other than those anticipated at the time of the evaluation.[4] Similarly, minimizing vulnerability to future regulatory changes would be a key concern, from the perspective of industry. Industry would far prefer implementing technologies that can be easily extended as emissions standards become more stringent, than those that cannot. The "minimize vulnerability over the long term" objective, as several others in the objectives hierarchy, reflects the importance accorded to implementation issues throughout this dissertation.

The last fundamental objective in the hierarchy in Table 7.1 relates to promoting equity and fairness in applying policies. Recall in this regard that vehicle users expressed the view that policy attractiveness may be enhanced by policies being applied uniformly and fairly to all. Fairness would thus make policies more acceptable and effective over the long run. While the first sub-objective relates to equity between M2W vehicle users and users of other motorized modes, the second stresses the importance of ensuring that policies do not disproportionately affect users of one M2W vehicle type compared to users of other types. This objective is particularly relevant in the case of mopeds, which cater for low-income users. The equity and fairness objective is important not only from the point of view of M2W vehicle users, but from a broad societal perspective. As discussed in Chapter IV, policies targeted at transport emissions, including emission standards, have been motivated by the rapidly deteriorating air quality situation in Delhi and other major Indian cities. But these policies might be unnecessarily stringent in other areas of the country, yet will have cost impacts for users in those areas. It is in the light of this consideration that the objective relating to geographical equity is included in the hierarchy. Applying this criterion might lead to emissions and fuel standards differentiated by region, for example. Policies targeted at M2W vehicles can affect

[4] Operationalizing this objective would call for anticipating in advance what these scenarios might likely be.

users of non-motorized vehicle modes as well, but equity between these users and M2W vehicle users is not included here, since access and time losses for users of non-motorized modes are already accounted for in the objectives hierarchy.

7.4 MEANS-ENDS OBJECTIVES NETWORK

It is useful to develop a means-ends objectives network, which shows the various means objectives that need to be achieved in order to attain the overall fundamental objectives. Means objectives need a network, as opposed to a hierarchy for fundamental objectives, since a single means objective can have implications for several fundamental objectives, and several means objectives can influence a single fundamental objective. Objectives in a means-ends objectives network indicate how higher level objectives can be better achieved, and are thus valuable in identifying policy levers. Value judgments are required to construct fundamental objective hierarchies, but knowledge of facts is needed to construct means-ends objectives networks. Fundamental objective hierarchies comprise objectives over which measures should be defined, whereas means-ends networks indicate the objectives and factors that should be considered in developing models to relate alternatives to their impacts (Keeney 1992; Keeney and McDaniels 1999).

Figure 7.1 shows the various means objectives to achieve the overall fundamental objectives developed in the previous section with respect to policies to prevent and control M2W vehicle emissions in the Indian context. The means objectives were developed based on the discussions in Chapters III to VI, and are presented in the form of strategies rather than as specific policies and technologies. There are other means objectives and linkages that could have been included in the figure, but only the most important have been shown, because of space constraints.[5] The fundamental and means objectives have been condensed, viz., the preference orientation and sub-objectives (in the case of the fundamental objectives) have been omitted, for the same reason.

First of all, Figure 7.1 attempts to show that there is a wide range of means objectives that need to be achieved in an integrated manner by multiple actors, including decision makers,

[5] For example, as noted in Chapter V, there are other means for minimizing emissions exposure and impacts, such as improving housing location, nutrition, and health care access. But the means indicated in Figure 7.1 relate only to system-wide emissions due to M2W vehicles.

industry, and vehicle users, in order to meet the fundamental objectives. The air pollutants to be targeted in order to minimize local, regional and global health, welfare and environmental impacts due to M2W vehicle emissions are specified. Each pollutant contributes to one or more of the emissions impacts to be minimized, and different policies will affect emissions of each pollutant to varying extents. Note that VOCs have been specified in addition to total HC, to reflect their importance in terms of ozone formation. Similarly, PM_{10} has been specified in addition to PM, since the former is critical in terms of health impacts and visibility, and the latter in terms of damage to structures.

The inclusion of air toxics (which include aldehydes and benzene) is relevant in terms of the need to anticipate undesirable side-effects, which was stressed in Chapter V. The addition of MTBE (methyl tertiary butyl ether) to Indian gasoline from 2000, in order to make up for lead removal (BIS 1995a; Appendix IV), is likely to cause increased aldehyde (and reactive HC and NO_x) emissions in vehicles without catalytic converters, thus aggravating the ozone problem (Humberto Bravo et al 1991). Similarly, unleaded gasoline can have a significantly high benzene content, depending on the refinery process used, as discussed in Chapter IV (Faiz et al 1996; Raje and Malhotra 1997). Lastly, CO_2 has been included in the interests of minimizing climate change impacts, and also as a proxy for energy conservation.

The means-ends objectives network in Figure 7.1 reflects the need to minimize in-use emissions of the above air pollutants system-wide due to M2W vehicle activity. It does so by first specifying the various M2W vehicle and transport system sources to be targeted. Both technological strategies, related to these sources, and targeting emission factors (in grams per vehicle-kilometre), as well as preventive strategies targeting the vehicle-trip and vehicle-kilometre components of the emissions problem, are included, along with various supporting infrastructural and institutional measures. In the case of M2W vehicle exhaust emissions, the need to control emission factors (in grams per vehicle-kilometre) at 80-100,000 kilometres is included as a means objective, to ensure emissions reduction over the long term at the level of individual vehicles.

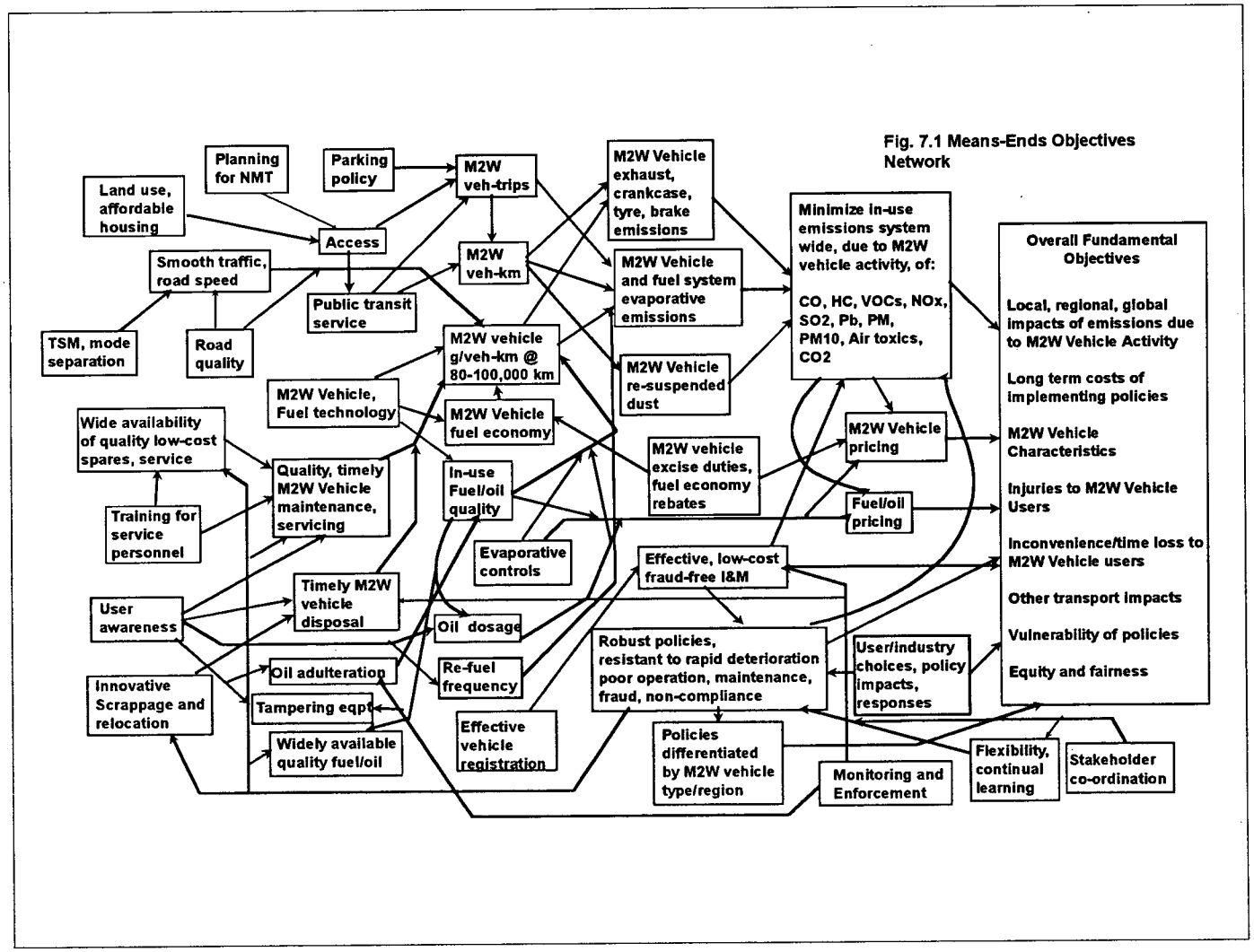

Fig. 7.1 Means-Ends Objectives Network

In-use realities and implementation issues are considered by including key user behavioural factors to be targeted for long-term policy effectiveness, such as oil dosage and adulteration, refueling frequency, quality and timely vehicle maintenance, servicing and disposal. Also included are the regulatory, economic and other institutional measures to be implemented by various actors to target these factors. These measures include wide availability of quality fuel/oil, spares, and vehicle servicing facilities, training of service personnel, effective monitoring and enforcement, fuel economy rebates, excise duty incentives, and innovative scrappage and relocation schemes.

Lastly, the means-ends objectives network in Figure 7.1 suggests some broad institutional approaches to better achieve the overall fundamental objectives. These include close co-ordination among stakeholders, attention to vehicle user and industry perspectives, and continual learning and flexible and adaptive policy-making. Examples of such policy-making could include policies differentiated geographically and by M2W vehicle type, and innovative scrappage and relocation schemes.

7.5 MEASURES

While fundamental objectives specify the important policy impacts to be considered, measures are necessary to actually evaluate, select and monitor policies. As stressed in Section 7.2.1, it is important that measures be such that data necessary to operationalize them be easily obtainable, given available resources. There would be little sense in measures that necessitated the expenditure of excessive amounts of time and resources in data gathering (Keeney 1992).

Table 7.2 presents measures to allow characterization of the impacts of M2W vehicle emissions prevention and control policies in terms of the overall fundamental objectives. These measures reflect the discussion on determination and valuation of emissions and other policy impacts in Chapter V, and on user perspectives in Chapter VI. Some of the measures in Table 7.2 were easy to develop, while others required knowledge of technical facts and urban transport issues, in order to capture the precise meaning of the objectives. Most of the measures are self-explanatory. Therefore, a detailed rationale for them is not provided here. But some comments are in order, with regard to specific measures.

First of all, note that the measures target impacts due specifically to the policy under consideration. The purpose of this stipulation is to ensure that impacts due to other factors are not attributed to the policy. Policy impacts are to be gauged relative to the business-as-usual (BAU) scenario. Finally, the need to take a long-term perspective in policy analysis is accounted for by measures targeting policy impacts annually, so that it would be possible to study how various policies were performing on the multiple objectives over, say, a 10-year period.

Measures were not constructed for the emissions impacts such as mortalities and morbidities, crop damage, and damage to structures, specified under the first fundamental objective. This is because of the considerable difficulties involved in measuring and valuing impacts, and in precisely identifying the contribution of transport policies to those impacts. These difficulties, which were discussed in detail in Chapter V, are formidable in the best of circumstances, but are rendered even more so in the Indian context, given its data collection and policy-analytic constraints.

The measure proposed therefore is an overall emissions impact which weights changes in emissions of individual pollutants specified in the means-ends objectives network, due to policies relative to the BAU scenario, based on informed expert judgments on the need to control the pollutants. The weights would reflect the relative importance of the impacts, and the contribution of individual pollutants to them, *at the time*. Weighting emissions of individual pollutants in a flexible manner, based on local current conditions and needs, would be in keeping with the stress placed in this dissertation on continual learning, and flexible and adaptive policy-making. In practical terms, it would help in making mid-course corrections to policies over time, to better ensure long-term policy effectiveness.

Measures clarify the meanings of, and the subtle distinctions between, different objectives (Keeney 1992; Keeney and McDaniels 1999). Indeed, developing the measures in Table 7.2 helped the author refine some of the objectives presented earlier. The maintainability and serviceability objective relates to the ease with which M2W vehicle users are able to address problems related to new vehicle technologies without resorting to the services of mechanics. The vehicle maintenance and servicing costs objective, on the other hand, relates to the actual costs of addressing those problems, in terms of, for example, spare parts. Similarly, the

reliability objective relates to the potential for new technologies to cause problems that disrupt vehicle service. On the other hand, the service life objective relates to the duration that vehicle users can operate new technology vehicles without prohibitively expensive maintenance and servicing. The passenger and luggage carrying capacity objective relates to the possibility that some new technologies could result in reduced ability in this regard.[6] On the other hand, the vehicle performance objective relates to any performance deterioration that might result due to new technologies, with the same passenger and luggage loading. Lastly, the equity and fairness objective, and its related measure, have interesting implications for creating flexible alternatives that are differentiated geographically and by M2W vehicle type. Perhaps only fuel and oil quality improvements could be implemented nation-wide,[7] in order to address the most serious impacts related to lead and particulates, with expensive M2W vehicle technology improvements restricted to the major cities with air pollution problems.

7.6 CONCLUSIONS

The multiple objectives and measures apply primarily to technological and regulatory policies targeted at M2W vehicles, but are relevant for other policies. Further, the objectives and measures may be adapted to accommodate a wide range of policies targeted at other modes and transport system components.

The multiple objectives and measures incorporate a wide range of environmental, health and welfare, socio-economic and transport system impacts over the long term. Because the objectives and measures integrate these impacts for and other interests and concerns of a wide range of actors and affected groups, they may be considered to represent a broad societal perspective that also takes into consideration long-term, system-wide effects. Since different policies would perform differently in terms of these multiple objectives, it would be possible to discriminate between a range of technological-curative as well as preventive policies.

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[6] For example, some M2W vehicle technologies can be accommodated more easily on a motorcycle, which tends to have a lower carrying capacity than a scooter. On the other hand, some other technologies can be fitted more safely on a scooter.

[7] This will happen in any case, as far as fuel is concerned, from April 2000 (see Appendix IV).

Fundamental Objectives	Measures for M2W vehicle emissions policy under consideration, and due specifically to the policy, relative to business-as-usual scenario
Minimize adverse impacts of system-wide air pollutant emissions due to M2W vehicle activity, rapidly and over long term	
Health Impacts	Overall Emissions Impact $= \Sigma\, w_i P_i,\ i = 1, n.$ P_i's are changes in annual system-wide in-use emissions due to M2W vehicle activity, in tonnes, of the individual pollutants specified in the means-ends objectives network; w_i's are weights to be assigned to each pollutant, reflecting its contribution to the specified impacts, the relative importance of the impacts, and the ambient level of the pollutant with respect to the WHO or other guideline.
Premature mortalities	
Morbidities	
Physical Impacts	
Damage to crops	
Damage to structures	
Loss of visibility	
Environmental Impacts	
Acidification	
Climate change	
Minimize long-term capital and operating costs of implementing policies	
Government	Change in annual system-wide implementation cost, INR (Indian Rupees)
M2W Vehicles	
Regulation	
Monitoring	
Enforcement (I&M)	
Fuel and oil	
Regulation	
Monitoring	
Enforcement	
Transport infrastructure provision	
M2W vehicle and vehicle servicing industries	
Technology development and implementation	
Training and equipment for maintenance and servicing	
Warranty, vehicle re-call and liability	
Fuel and Oil Industry	
Technology development and implementation	
Fuel/oil distribution network	
M2W vehicle users	
Vehicle purchase	
Fuel and oil	
Vehicle maintenance and servicing	
Mandated vehicle I&M	

Fundamental Objectives	Measures for M2W vehicle emissions policy under consideration, and due specifically to the policy, relative to business-as-usual scenario
Minimize loss of M2W vehicle characteristics due to policies	
Reliability	Change in annual fleet-wide M2W vehicle service disruptions
Vehicle performance	Change in M2W vehicle acceleration (m/sec/sec) and top speed (km/h)
Service life	Change in number of years until major overhaul
Maintainability and serviceability	Change in annual fleet-wide visits to mechanics for non-routine M2W vehicle servicing
Passenger and luggage carrying capacity	Change in number of passengers and quantity of luggage, in kilograms, that can be carried
Re-sale value	Change in median M2W vehicle re-sale value, INR
Minimize injuries to M2W vehicle users due to policies	Change in number of injuries to M2W vehicle users, fleet-wide
Minimize inconvenience and loss of time related to restricted M2W vehicle ownership and usage, and mode changes, due to policies	Change in number of trips transferred to slower modes annually by M2W vehicle users, and associated change in travel time annually, in hours, fleet-wide
Minimize other transport system impacts due to policies over the long term	
Loss of access and time delays for users of non-motorized modes	Change in number of trips foregone annually by users of non-motorized modes, and associated change in travel time annually, in hours
Land use	Change in number of hectares lost annually due to infrastructure to implement policy under consideration
Population Displacement	Change in number of persons displaced due to policies annually
Minimize vulnerability over the long term	
Future scenarios	High/medium/low
Regulatory changes	High/medium/low
Promote equity and fairness in applying policies	
M2W Vehicle Users and users of other private Modes	Percentage change in median annual implementation costs for users per M2W vehicle, compared to that for a car
Users of different M2W vehicle types	Percentage change in median annual implementation costs for users per scooter/motorcycle, compared to that for a moped
Geographically (inter-regionally in India)	Percentage change in median annual implementation costs for users per scooter and motorcycle in Delhi, compared to that outside the major cities

Table 7.2 Measures for Characterization of Policy Impacts

The objectives and measures have the potential to facilitate compromise among decision makers in government and industry and other actors, and help them work together to develop, implement and monitor effective policy alternatives, while minimizing adverse policy impacts for all. This is particularly important, given the conflictual nature of actors' interactions, and the lack of institutional mechanisms to consider society-wide policy impacts. Finally, the objectives and measures explicitly consider implementation issues and in-use realities. Robust policy packages may thus be developed that enhance the chances of effectively and equitably addressing the problem over the long term.

The measures, which have been developed with the express purpose of making them operationalizable given contextual constraints, will help decision-makers develop and implement effective policy monitoring programmes. The means-ends objectives network will aid in developing a wide range of technological, economic, regulatory and travel-demand reduction measures to be undertaken in an integrated manner by various actors, to more effectively achieve the multiple policy objectives.

In the spirit of continual learning and adaptive policy-making and implementation stressed in this dissertation, the objectives and measures presented in this Chapter are open to modification and refinement in the light of experience gained over time, to better measure policy impacts, and create better policy alternatives. Indeed, they have been developed to expressly allow policies to be continuously monitored and modified, so as to be responsive to changing needs.

Lastly, we turn to the question of the usefulness of the problem-structuring tools of value-focused thinking in the LIC context. The process of eliciting and structuring objectives and measures described in this Chapter has yielded a clearer understanding of the range of issues to be considered in order to more systematically evaluate and create better policy alternatives to address a complex problem such as transport air pollution in a context that is just as complex. No firm conclusion can be drawn from this one instance, but based on the experience gained as a result of this research, there is reason to believe that these tools have the potential to be used to better understand and structure complex public policy problems in the LIC context.

CHAPTER VIII

CONCLUSIONS

8.1 INTRODUCTION

This dissertation has addressed the problem of air pollution from M2W vehicles in the Indian context in its environmental, socio-economic, technological, institutional and human behavioural dimensions, and has presented the results of policy-relevant research related to M2W vehicle emissions in Delhi, in order to promote a deeper understanding of the problem, and to inform policy-making and implementation. Specifically, the dissertation has analysed technological and institutional contributory factors in Chapter III, critically examined the institutional setting, in terms of actors' roles, responsibilities and interactions, and constraints and barriers, in Chapter IV, and proposed an analytic framework for systematic thinking and effective policy-making and implementation in Chapter V.

Based on a questionnaire survey of, and in-depth interviews with M2W vehicle users in Delhi, Chapter VI explored the implications of vehicle user choices related to daily travel and vehicle purchase, operation, maintenance and disposal, and of user perspectives on various policy alternatives. Finally, Chapter VII proposed multiple objectives and measures to characterize the impacts of policies to address M2W vehicle air pollution in the Indian context, based on in-depth interviews with decision makers in government and industry, and on insights gained from the elicitations of vehicle user perspectives.

In this concluding chapter, the author summarizes the insights gained from the dissertation research, and offers his perspectives on the implications of the research for air pollution from M2W vehicles, and its prevention and control, in the Indian context. The author also makes recommendations for more effective policy-making and implementation in relation to transport air pollution, urban transport and other urban environmental issues in that context. Finally, the author offers suggestions for further research.

8.2 TECHNOLOGY-POLITICAL INSTITUTION-HUMAN BEHAVIOUR INTERACTIONS

The analysis of contributory factors in Chapter III and the results of the vehicle user elicitations in Chapter VI show that transport air pollution inevitably involves technological issues, but is also influenced by choices that millions of vehicle users make on a daily basis, and by the political-institutional setting that in part influences those choices.

Thus, for example, the rapid growth in M2W vehicle activity in Delhi is shown to result from rising incomes, and easy vehicle and credit availability, but also from factors such as unaffordable housing close to work, compromised access and road safety due to motor vehicle activity, increasingly unreliable and inconvenient public transit, and inadequate provision for non-motorized modes. Similarly, while rising female work-force participation contributes to growing M2W vehicle ownership and usage among women, user-friendly vehicle technologies also play an enabling role.

The frequent re-fueling reported by many M2W vehicle users, which has important implications for evaporative emissions, is a result of small vehicle tank size, but is also due to user concerns over fuel pilferage. Poor in-use fuel and oil quality are a result of fuel and oil technology constraints, but are also due to adulteration resulting from relative fuel pricing and ineffective enforcement. And fuel price subsidization is in part responsible for the lack of investment in improved fuel refining technologies. Excessive oil-fuel ratios, which have important implications for exhaust particulate emissions, are in part due to the use of fixed quantities of oil with varying quantities of fuel, because of concerns over adulterated oil. Poor vehicle maintenance may be due to limited affordability on the part of vehicle users, but is also due to the burdensome and ineffective in-use emissions monitoring and control regime, and high spare parts taxes.

In view of the foregoing, the dissertation stresses the importance of considering interactions between technological, political-institutional, and human behavioural factors that contribute to per-vehicle emissions as well as vehicle activity. The dissertation also stresses the need to consider emissions from all vehicular and system-wide sources, and in-use vehicle operation, maintenance and disposal realities, in order to model transport air pollution and

energy consumption more effectively, and to develop curative as well as preventive measures to address the problem comprehensively and effectively over the long term.

8.3 THE INSTITUTIONAL SETTING

Addressing transport air pollution is challenging enough because of the large number and variety of motor vehicles and literally millions of vehicle users that are involved. But the multitude of agencies and actors with fragmented, overlapping, and conflicting roles, responsibilities, interests and agendas makes a challenging task even more difficult. Further, actors' interactions have been characterized, at least until recently, not only by the lack of co-ordination, but by conflict. Most importantly, the various agencies and actors face restricted financial, technological, and administrative resources for the provision and maintenance of clean vehicles and fuels and adequate transport and public transit infrastructure, and for effective policy analysis, implementation, monitoring, and enforcement. In short, the institutional setting is characterized by constraints that contribute to or exacerbate transport air pollution, as well as hamper the ability to understand and address the problem effectively.

Various critical institutional barriers and constraints are discussed in the dissertation. One of the most important is the inability to effectively control in-use vehicle emissions, due to unclear emissions durability requirements, decentralized testing and repair, inadequate resources to monitor testing stations, and the lack of linkages between vehicle registration and inspection. Motor vehicle activity generated by neighbouring states contributes significantly to transport air pollution in the Delhi region, but there is little inter-state co-ordination in terms of land use and transport policy. The neighbouring states have encouraged development close to Delhi, in order to take advantage of the city's employment opportunities. However, the agency responsible for land use in Delhi lacks the resources to control unplanned development in fringe areas, partly due to its own financial position having been weakened because it has not collected betterment charges from private developers. The growing inadequacy and inconvenience of public transit, which contributes to growing personal motor vehicle ownership and usage, is in part due to constrained resources for expansion. Also, however, the large number of small private owners who operate the significant proportion of buses in Delhi, have little ability or incentive to invest in proper maintenance, because they operate

under a regulated fare structure. Overcrowding and poor fleet maintenance serve to shorten bus life, thus further exacerbating the poor transit availability situation. Lastly, effective control action is hampered by the fact that many of the actors, being government agencies, are difficult to effectively regulate, as in the case of the publicly owned oil refineries and public transit organizations.

The dissertation argues that, in the face of rapidly deteriorating air quality in Delhi and the other major cities, hasty ad hoc decisions appear to have been made, with little attention to implementability or to institutional support mechanisms, and with long-term consequences not having been thought through. While conveying the illusion of action, many policies are likely to be costly and burdensome, yet ineffective in addressing transport air pollution, let alone urban air quality. The lack of resources for quality information generation and policy analysis has contributed to this situation, but it is likely that the confrontational public interest litigation process has also played a role. Conflict between actors has in part resulted from a perceived lack of a rational basis for policies, which in turn is due to the lack of reliable information.

8.4 VEHICLE USER PERSPECTIVES

The dissertation argues that policy ineffectiveness is in part due to lack of attention to how vehicle users and industry are affected by and respond to policies. It is this lack that motivated the elicitations of vehicle user perspectives on policy alternatives reported and discussed in Chapter VI. The study demonstrates that, just as understanding vehicle user choices related to daily travel activity, and vehicle purchase, operation, maintenance and disposal can help model transport air pollution more effectively, understanding how vehicle users are affected by and respond to policies can contribute to designing attractive policy packages that have a greater chance of success over the long term.

The vehicle user elicitations, along with the RITES/ORG (1994) travel survey data for Delhi, show that M2W vehicle use is motivated in large part by the lack of other convenient and affordable options. A large proportion of M2W vehicle trips are performed by lower income users, and the bulk of M2W vehicle trips are work related and therefore unavoidable. Restricting vehicle ownership and usage would adversely affect daily family life. The

dissertation therefore argues that, while it is important to address M2W vehicle emissions, because they contribute significantly to transport air pollution, it is also important to minimize adverse policy impacts for vehicle users, particularly those with low incomes. The low affordability and lack of viable options on the part of many users makes it all the more important to understand how users are affected by and respond to policies, to ensure long-term policy effectiveness and equity.

The fact that vehicle users would find expensive vehicle technologies to minimize air pollution acceptable, provided vehicle characteristics such as performance, reliability, service life and low cost maintainability were not compromised, and that users would find technologies attractive if they also offered fuel economy benefits, may be used to more effectively discriminate between policy and technology alternatives. For example, while four strokes would provide fuel economy benefits, an important user concern, catalytic converters might not necessarily do so. Catalytic converters on M2W vehicles might compromise user safety, another user concern. Further, catalytic converters raise emissions durability worries, given poor operating conditions and enforcement.

Combining user perspectives on policies with their vehicle purchase preferences raises interesting implementation issues. Four-strokes, which are bigger than two strokes for the same power output, can be fitted easily on motorcycles, which have no space constraint, but require extensive and expensive design and tooling changes on scooters, which are preferred by the vast majority of M2W vehicle users in Delhi and other urban centres, because of their higher passenger and luggage carrying ability, and their lower cost. Accommodating four-strokes or catalytic converters would be even more problematic and proportionately more expensive on mopeds, which are small, low cost vehicles catering for lower income users, and which, while used little in Delhi, are popular in the rest of the country. Thus, emission standards, motivated by the rapidly deteriorating air quality situation in Delhi and other cities, could be unnecessarily burdensome for the large number of low-income moped users living in non-polluted regions.

The vehicle user perspectives demonstrate the importance of co-ordinating technological, economic and regulatory policies, as well as of considering how vehicle users would respond to different kinds of policies when implemented in combination. Thus, for example, while it

would be important, given vehicle operating conditions, to ensure good quality air filtration and ignition systems for the effective functioning of catalytic converters, it would also be necessary to control fuel and oil adulteration. Given the complexity of new vehicle technologies, poor maintenance, and resistance to scrappage, it would be important to ensure low spare parts taxes and training of vehicle servicing staff. An effective but less burdensome in-use emissions monitoring and enforcement regime, ideally incorporating centralized testing and decentralized repair, linked to an effective vehicle registration system would be necessary. Emissions durability and warranty mandates could also be considered. Given the growing importance of female M2W vehicle users, features such as improved vehicle driveability would encourage timely disposal and replacement.

The user elicitations yielded various creative solutions to enhance policy attractiveness. One such solution was a vehicle scrappage scheme based on emissions performance, rather than on a fixed number of years, to serve as an incentive to quality maintenance, while preserving vehicle value. Such a scrappage scheme would of course require an effective in-use emissions monitoring and control regime, once again highlighting the need for policy co-ordination. A system to buy back old vehicles and sell them after re-conditioning in the hinterland would make emissions performance-based scrappage more attractive, and promote timely vehicle disposal and rapid penetration of improved technologies. Offering credits to vehicle manufacturers would serve as an incentive to implement such a scheme.

The foregoing shows the importance of explicitly considering in policy analysis issues that are typically relegated to the policy implementation phase. This approach will enable institutional mechanisms to be put in place to anticipate and address problems, and to support policies well in advance of their introduction. At the same time, this approach would enable the development and implementation of policies that minimize reliance on expensive technologies and institutional support mechanisms, and that are insensitive to poor operating conditions. Such policies would not only minimize the risk of failure, they would in fact have a better chance of long-term effectiveness, given contextual realities and constraints.

It would be desirable to implement policies that deliver results rapidly, to ensure public support, while also being cost-effective over the long term. Fuel-oil quality improvements and low dosage oils on two strokes are good examples of such policies. They would target critical

and neglected factors such as evaporative emissions due to frequent re-fueling and excessive oil-fuel ratios, and would help minimize pollutants of concern such as particulates, volatile organics and air toxics. They would produce rapid results, since they would take effect fleet-wide as soon as they are introduced, unlike vehicle technology improvements. Finally, they would be 'fit and forget" in nature, and would be insusceptible to the 'free rider" problem, all of which would enhance vehicle user acceptability.

8.5 POLICY-ANALYTIC FRAMEWORK

Given the possibility of transport air pollution policies being burdensome and expensive yet ineffective, because of long term consequences not having been thought through, and lack of co-ordination, there is need for a systematic and integrative approach that reflects the complexity of the problem, and is sensitive to contextual needs, capabilities and constraints. It is this need that the dissertation attempts to fulfill, by proposing a policy analytic framework and multiple objectives and measures to inform policy-making and implementation. While the analytical framework and multiple objectives and measures apply primarily to technological and regulatory policies targeted at M2W vehicles, they may be adapted to accommodate a wide range of policies targeted at all modes and transport system components.

Among other things, the framework incorporates a systematic methodology for estimating air pollutant emissions due to policy alternatives. The methodology reflects the need to minimize system-wide emissions due to vehicle activity, over the long term. The framework stresses the importance of evaluating policies as they would be implemented, rather than assuming a friction-free world. Therefore, the framework explicitly considers key urban transport, technological and user behavioural contributory factors and in-use conditions and variabilities that critically influence emissions. Thus, for example, emission factors are required to reflect real-life vehicle operation and fuel/oil conditions, and deterioration in emissions performance over time due to increased vehicle activity, congestion, and vehicle age. Also considered are the effects of variations in monitoring and enforcement and maintenance levels on emissions for different policy alternatives. The framework calls for emissions to be estimated in terms of a wide range of pollutants, to account for unintended side-effects, such as increased aldehyde emissions in engines without catalytic converters, and thus the increased

possibility of ozone formation, due to the use of MTBE to compensate for lead removal. In view of contextual constraints in terms of information generation and policy analysis, uncertainties are considered explicitly, by allowing for informed expert judgments with respect to various parameters.

Similarly, because of policy analytic constraints, and practical, theoretical and philosophical difficulties associated with monetizing non-financial policy benefits in the Indian context, the framework proposes cost-effectiveness as a basis for estimating and valuing emissions impacts due to policy alternatives, with individual pollutants weighted to reflect their contributions to local, regional, and global health and welfare, environmental and other impacts of concern over the long term. Further, because policies can have transport impacts other than those related to air pollution, including congestion, energy consumption, land use, access and mobility losses, and a range of cost and welfare impacts for various actors and affected groups, the framework proposes that policy alternatives be evaluated in terms of multiple objectives reflecting these impacts, and the diverse interests and concerns of the actors and groups, to address transport air pollution effectively and equitably over the long term.

The multiple objectives and measures proposed in Chapter VII reflect a wide range of policy impacts as discussed above. As for emissions impacts due to various policies, the dissertation proposes that they be measured by weighting emissions of individual pollutants due to each policy, based on informed expert judgments on the current need to control each pollutant, considering the relative importance of various emissions impacts of concern, the contribution of individual pollutants to the impacts, and the local ambient level of pollutants.

Because a wide range of policy impacts are considered over the long term, and because different policies would perform differently in terms of these impacts, the multiple objectives approach would enable discrimination between a range of technological-curative as well as preventive policies. The long term perspective would help determine the rapidity with which policies lower emissions, an important consideration in winning public confidence, and also whether these emissions improvements are sustained cost-effectively, given vehicle activity increases, contextual realities, and vicious circles that may manifest themselves over time. Thus, for example, it could be shown that whereas highway capacity addition might reduce

emissions in the short run by increasing average road speeds, but might compromise access for non-motorized mode users, displace the urban poor, and increase motor vehicle activity and emissions in the long run, improving public transit service would reduce M2W vehicle usage and emissions over the long term without causing any of the above adverse impacts. Considering urban transport factors such as the distribution of vehicle trips by trip length would enable the emissions effect of reducing long as opposed to short trips, as would happen in shifting M2W vehicle trips to public transit, to be determined. Lastly, explicitly considering uncertainties will enable decision makers to explore the implications of changing scenarios in key technological and human dimensional variables.

Because they integrate the concerns and interests of various actors and affected groups, the multiple objectives will help develop policy packages that represent a win-win condition for all, thus enhancing the chances of long-term policy success. The multiple objectives will also enable the vitally important equity issue to be addressed explicitly. In this connection, note the stress placed on equity and fairness in the multiple objectives hierarchy, not only between users of different M2W vehicle types, and between M2W vehicle users and users of other modes, but also from a broad societal standpoint. Applying the equity and fairness criterion might lead, for example, to the flexible application of M2W vehicle emission standards so as not to unduly burden the large number of low-income moped users living in non-polluted regions. Perhaps only fuel and oil quality improvements could be implemented nation-wide, in order to address the most serious impacts related to lead and particulates, with expensive M2W vehicle technology improvements restricted to the major cities with air pollution problems.

The analytical framework and multiple objectives and measures will hopefully enable an integrated assessment of the long-term environmental, socio-economic and equity impacts of policies, and thus more effective policy-making, implementation and monitoring, in relation to transport air pollution in India.

8.6 INSTITUTIONAL REFORM AND CAPACITY-BUILDING

Because transport air pollution and its causes transcend political, sectoral and disciplinary boundaries, it is desirable for the institutional framework to take a national, cross-sectoral,

interdisciplinary perspective. Since co-ordination between technological, regulatory and economic policies is essential, and since these policies are determined by, or affect multiple actors, it is desirable to involve all the actors right from policy development through to implementation, to co-ordinate action for long term policy success. The actors include vehicle and fuel manufacturers, and government agencies at the national, regional, and municipal levels with responsibility for public health, air quality monitoring, transport planning, roads and transport system management, in-use emissions monitoring and control, and vehicle registration. To consider all transport impacts in an integrated fashion, and to address fundamental in addition to technological contributory factors, representatives of agencies responsible for transit, land use and non-motorized transport should also be involved.

In this regard, the Standing Committee on Implementation of Emissions Legislation, with all the major actors and testing and R&D agencies represented, to resolve conflicts, and the more recently instituted, and similarly constituted Inter-Sectoral Committee to formulate an integrated Auto-Oil-I&M programme for 2005 (Author's interviews 1997; MoEF 1991 and 1997), are steps in the right direction. So also is Anil Agarwal's suggestion (CSE 1996) that an adequately funded commission, comprising experts and public individuals, and operating at arms' length from the Ministry of Environment, be set up to deal comprehensively, and with a long-term perspective, with transport air pollution. This commission would organize independent studies to monitor the effectiveness of regulatory actions, and advise the CPCB, which in turn would be made an executive agency, with enforcing powers.

The institutional framework should ideally help decision makers and other actors to identify key issues over which they can carry on an informed debate leading to a mutually beneficial consensus, rather than merely mandating standards and technologies without any thought to implementation. This requirement in turn highlights the importance of various actors gaining mutual appreciation of each other's perspectives, interests and concerns. The problem-structuring tools of value-focused thinking are ideally suited to this purpose since they allow stakeholders to collaboratively understand and structure problems, resolve conflicts, and create better alternatives. Achieving these ends is particularly important in the Indian context, given the nature of actors' interactions hitherto. The experience gained as a result of developing multiple objectives and measures in this dissertation gives hope that these

tools can be usefully employed to achieve the above ends in relation to transport air pollution and other complex policy problems in India and other LICs.

While the institutional framework should allow for co-ordinated action, it should also be decentralized and flexible. Governments at the national and regional levels should focus primarily on policy analysis, prioritization of issues, long-range planning, regulating, and disseminating technical information, whereas roles such as policy implementation, monitoring and enforcement should be devolved to the local level, with adequate resources to support these activities. Also, while there is an useful role for the private sector (in providing, for example, inspection and maintenance services), the public sector should retain responsibility for monitoring and enforcement.

Policy-making and implementation should be adaptive and flexible, as exemplified by policies differentiated geographically and by M2W vehicle type, emissions performance based scrappage with buy back and re-location, fuel efficiency rebates to promote timely vehicle disposal and replacement, and weighting individual pollutants based on current local conditions and needs. Continual learning may be promoted by implementing a wide range of low-cost and complementary policies that target various dimensions of the problem, and drawing lessons from them. Implementing such measures would also obviate costly failures, enhance flexibility, and enable easy and inexpensive "mid-course corrections". As Brandon and Ramankutty (1993) point out, inexpensive, partial and up-gradable measures that achieve significant improvements early, are preferable to 'permanent' but expensive measures.

In the spirit of continual learning and adaptive policy-making and implementation, policies as well as problem definition, policy objectives and evaluation criteria should be subjected to constant re-examination. Note in this regard that the objectives and measures presented in Chapter VII are open to modification and refinement in the light of experience gained over time, to better measure policy impacts, and create better policy alternatives that are responsive to changing needs.

A previous paragraph stressed the need to involve all actors right from the policy development stage. It is just as important to involve vehicle users and the wider public, to gain an understanding of their priorities and concerns, and of society-wide policy impacts. It is particularly important to pay heed to the concerns of and impacts for groups who will be

affected by policies, but typically have no voice in the decision making process, such as non-motorized mode users. The multiple-objectives approach can be used to involve the public to adequately represent their interests and concerns, and to identify policy objectives from their perspective, and thus has the potential to contribute to participatory planning with regard to transport air pollution. In this regard, also note that, as demonstrated in this dissertation, perspectives and judgments can usefully be elicited on complex public policy matters involving technological issues from lay persons.

Ultimately, effective and equitable resolution of transport air pollution and other urban environmental problems depends on representative, responsive, competent and financially independent local governments. Institutional capacity needs to be built for reliable information generation, policy analysis, long-range planning, standards setting, and effective implementation, monitoring and enforcement. But even strong and responsive governments are unlikely to implement environmental policies without strong democratic pressure, based on an informed public understanding of issues.

The importance of public awareness is highlighted by the potential for fraud and policy ineffectiveness due to users being unclear about in-use emissions testing in Delhi. Lack of public awareness, and the inability to involve the public, can lead to misdirected public pressure and government action, and less support for long term policies such as fuel-oil quality improvements, which despite potential advantages are likely to be less popular than vehicle technology improvements, as evidenced in this study. Government obviously has an important role in building public awareness of air pollution and other environmental problems, and of the complexities, barriers and trade-offs involved in resolving them, but so do NGOs and the media. A particularly important role that these institutions can play is that of serving as "watch dogs", by conducting and broadcasting the results of investigations and studies that serve as a counterfoil to those conducted by government agencies, and that critique government policies. Finally, elicitations of lay perspectives can contribute not only to developing policy objectives that better represent public interests and concerns, but also to more effective public awareness efforts.

8.7 PREVENTION IS BETTER THAN CURE

Technological measures to address air pollution have an important role, but can involve considerable expenditure of financial, technological and administrative resources, and social control. Even without resource constraints, however, technological measures can be neutralized by increasing motor vehicle activity and congestion, as the US experience shows. Despite dramatic gains in pollution control and efficiency improvements over the years, overall US air pollutant emissions are projected to increase, and air quality is expected to worsen significantly in US cities in the next two decades. Similarly, despite financing for US highways increasing steadily over the last two decades, congestion has worsened, and is expected to continue to do so.

Transport is by no means the only source of air pollution, and neither is air pollution the only important transport impact. Road accidents cause a significant number of mortalities and morbidities in Delhi and other Indian cities, with health, economic and emotional impacts that very likely exceed those due to transport air pollution. Further, the poor majority benefit little if at all from motor vehicle activity (many cannot even afford subsidized public transport), but transport impacts affect them disproportionately. Pedestrians and cyclists account for around 61% of road fatalities in Delhi, and are also most affected by compromised access due to motor vehicle activity. Finally, as discussed in Chapter II, rapidly growing motor vehicle activity in India and other LICs has a wide range of regional and global impacts, including transport energy demand, which could increase as much as three times in as many decades.

Transport impacts in Delhi and other Indian cities are already exceedingly high, despite far lower absolute motor vehicle activity levels compared to the OECD. Road accidents in India cause far more fatalities than in North America, with a fraction of its motor vehicle activity. Further, transport impacts are not the only serious urban problems. Poor water quality, for example, likely does far greater and more easily preventable, damage. While urban demands multiply, the resources to address them dwindle. Indian cities do not have the wherewithal to accommodate even present levels of motor vehicle activity, let alone future growth.

Notwithstanding the foregoing, air pollution is arguably the urban environmental issue in Asian LICs that attracts the most media and policy attention, perhaps because it is a great leveler. And urban air pollution is most readily associated with transport, perhaps because

motor vehicles are the most visible source. Indeed, the urban transport problem increasingly tends to be framed almost exclusively in terms of air pollution. But given resource constraints and the fact that motor vehicle emissions and other transport impacts are inextricably linked, transport policies should, as far as possible, be designed to achieve synergies. These policies should ideally promote improved road safety, fuel economy, and equitable access in addition to improving air quality, with the overall aim of achieving an access and mobility system that conserves material, energy and land resources, is environmentally benign, safe, and socially just, and that promotes rather than hinders community life and conviviality.

If the above objective is to be achieved, motor vehicle activity should be targeted in addition to per-vehicle emissions. In this regard, it is worth pointing out that, while the entry of foreign vehicle manufacturers and foreign investment in infrastructure to accommodate motor vehicle activity would improve vehicle emissions performance, Indian cities might become locked into a system that makes motor vehicle activity inevitable, negating technological benefits in the long run, while creating a whole range of other transport and urban impacts.

Primacy should be accorded to minimizing personal motor vehicle activity, both through policies that discourage their use, as well as by providing attractive alternatives such as extensive, reliable and convenient public transit. The fact that a substantial proportion of trips are performed by public transit, including by members of M2W vehicle owning households, is an indication of the importance of this mode in the context (however, expanding services will not be easy, given the massive allocations required). Further, the willingness of M2W vehicle users to transfer to public transit for medium to long distance work-related trips, provided reliable and comfortable service is available, demonstrates the potential for minimizing M2W vehicle emissions, since such trips form a significant proportion of all M2W trips. This also shows the importance of maintaining good public transit service, not only for users of this mode, but also to mitigate emissions policy impacts for M2W vehicle users. Note in this regard that a recent gasoline price escalation was strongly protested in Delhi, but not in Mumbai, where public transit is excellent.

In addition to providing public transit that is extensive, reliable and convenient, adequate facilities must be provided for walking and cycling. It is because of growing congestion and

reduced access and road safety due to motorized traffic that large numbers use M2W vehicles, even over short distances. As discussed in Chapters V and VI, the potential for walking and cycling is great. Around 40% of all trips are within 2.5 kilometres, and walking and cycling (and travel by cycle rickshaws) account for nearly 39% of all trips even among residential households in Delhi, the most motorized Indian city. The shares for these modes would likely be significantly higher for the total urban population, considering that every second person in that city lives in a slum. Further, a sizeable minority of residential households does not own a personal motorized vehicle. For all of these reasons, walking and cycling are likely to remain the mainstay of the majority for many years. In addition to catering for the travel needs of the majority, planning for non-motorized modes would also help minimize short distance M2W vehicle trips, whose contribution to total M2W vehicle air pollutant emissions is disproportionate to their share of total M2W vehicle-kilometres, because of low speeds at low distances, and the constancy of trip-start and trip-end (evaporative) emissions regardless of trip length. It may be futile to expect M2W vehicle users to switch back to non-motorized modes, but usage can be hopefully dampened, at least over short distances. Finally, ensuring the viability of non-motorized modes is important for transit viability.

Thus, whereas transport policy focused on air pollution might be ineffective in reducing motor vehicle emissions in the long run, while leaving other transport impacts unresolved, an urban transport system focusing on access for the poor majority will likely produce air pollution benefits besides meeting other transport and urban livability objectives. Finally, preventive, and non-transport, solutions should be considered for the long term, such as affordable housing close to workplaces, and obviating rural-urban migration by investing in rural infrastructure.

8.8 SUGGESTIONS FOR FURTHER RESEARCH

There is currently no reliable accounting of the contribution of M2W vehicles and other modes and transport system components to air pollutant emissions, either for Delhi or the other Indian cities. The transport emissions inventories that do exist very likely account only for vehicular exhaust emissions, and are not representative of real-life conditions. The need for a comprehensive and representative emissions inventory cannot be stressed enough, since it

would provide a rational basis for prioritizing vehicle and transport system sources for control action. The lack of such an inventory contributes to conflict between various actors, and lack of public understanding and purposive government action, as discussed. Most importantly, from a public policy standpoint, it is not clear that the most stringent standards and policies are applied to the most important transport sources.

Emission factors need to be developed, through extensive and systematic testing, for various air pollutants from various vehicular sources, including exhaust, crankcase, brake and tyre, for evaporation from vehicular as well as fuel distribution system sources, and for re-suspended dust. Particulate emissions from various sources need to be differentiated by particle size, and in terms of natural and combustive origins. The emission factors should account for real-life vehicle operation and fuel-oil conditions, and vehicle age, maintenance level, and trip length distributions for various modes. Emission factors and fuel consumption data that are representative of real-life conditions will in turn require the development of equally representative driving cycles, as discussed in Chapter III.

The foregoing will require considerable technical and financial resources and will likely be time-consuming. But, given resource constraints, and the need for urgent action in the Indian context, there would be great value in estimating an emissions inventory based on available information. The stress should be on minimizing specification errors, by accounting for all contributory factors, in-use conditions, and variabilities that influence emissions in the Indian context, while accounting for measurement errors by employing ranges for various variables, based on informed expert judgments. An emissions inventory generated along these lines would serve as a basis for designing and prioritizing policy actions in a disaggregated manner, in terms of various system-wide sources for various modes, short and long distance trips, vehicle age and maintenance, and fuel and oil quality. Since urban transport is not the only air pollution source, an emissions inventory along similar lines for other sectors would be useful. It should not be the case that, after expensive measures have been undertaken to control transport emissions, there is no substantial reduction of air pollution impacts. Finally, exposure to, rather than merely emissions of, critical pollutants, is key in terms of evaluating the relative role of transport and other sectors in air pollution impacts.

The dissertation has presented some insights into M2W vehicle user choices in terms of vehicle operation, maintenance and disposal, based on a survey of and interviews with M2W vehicle users in Delhi, and has explored the implications of these choices for transport air pollution. In order to gain a better understanding of vehicle age and maintenance level distributions, and variations in critical factors like in-use fuel and oil quality, refueling frequency and oil-fuel ratios, it would be desirable to conduct a more detailed study based on a representative sample of vehicles and vehicle users. Such a study would contribute to more effective emissions measurement and modeling, and also help in designing in-use emissions monitoring and control and vehicle scrappage programmes.

In order to evaluate its utility as an aid to decision-making, the multiple-objectives framework presented in the dissertation may be used to characterize the long-term health, welfare, environmental, socio-economic and equity impacts of a set of policy alternatives targeted at M2W vehicle emissions in India. This assessment would incorporate a computer model, to estimate the emissions of various pollutants, and policy costs, over time. The model would reflect all the issues discussed above in relation to the policy-analytic framework. Software such as Analytica (Lumina Decision Systems 1999) would be ideally suited for this purpose, and would allow the implications of changing scenarios in key variables to be explored. The assessment would also incorporate informed expert judgments with respect to various model parameters, weighting of emissions impacts and pollutants and characterization of policy impacts in terms of multiple objectives, and the vehicle user perspectives on policies presented in this dissertation.

It would be useful to conduct an analysis of policy-making relating to transport energy and emissions in India, given the increasingly important role of the sector in terms of air pollution and energy security. The analysis should focus on the goods and public transit sectors in addition to M2W vehicles, and address technological, institutional, and human behavioural issues. As discussed in Chapter II, diesel, which powers the vast majority of goods and public transit vehicles, plays a predominant role in transport energy, and in transport-generated particulates, NO_x and SO_2. Further, diesel accounts for a significant proportion of Indian petroleum imports, which are vulnerable to price fluctuations. It is suggested that extensive and in-depth interviews be conducted with multiple stakeholders in the above sectors to elicit

their perspectives, agendas and motivations with respect to energy efficiency and air pollution control, and to gain an understanding of the barriers and constraints they face in terms of implementing various technological, economic and regulatory policies. The study could also explore the implications of the entry of foreign vehicle manufacturers and transport infrastructure investment into the Indian market.

A critical appraisal of the utility of the public interest litigation process, and how it can be made more effective, needs to be undertaken urgently, in view of its important role in decision making related to transport air pollution. In particular, the issue of how the process can access independent, competent and dispassionate technical advice, and can better address and reconcile complex technical and social issues, needs to be addressed.

Economic policies such as pricing of transport infrastructure and vehicle and fuel taxation can play an important role in the management of transport demand and in promoting the choice of clean and fuel-efficient technologies. It would be worth investigating the role such policies currently play in the Indian context, and the potential for and likely impacts of pricing and taxation reform, and of innovative economic instruments such as "feebates". In this connection, note that vehicle taxation based on efficiency rather than on engine size, as was the case in 1994 (AIAM 1994a), would allow manufacturers to offer cleaner (and unavoidably larger) four-stroke engines on mopeds, without imposing an excessive price penalty on low-income users who own these vehicles (Author's interviews 1997). Thus, while vehicle taxes based on engine size might result in sub-optimal designs, vehicle taxes based on fuel efficiency and emissions would have the potential to foster technological innovations and positively influence vehicle purchasing behaviour.

As noted in Chapter III, kerosene and diesel subsidies play an important role in fuel adulteration and excessive dependence on diesel in Indian transport. It would be useful to investigate the socio-economic, health, environmental and equity impacts of these subsidies, and of their elimination. Eliminating the subsidies would make investments in improved refining technologies more attractive, discourage inappropriate dieselization, encourage diesel efficiency, and reduce kerosene adulteration. However, deregulating diesel prices might cause inflation to rise, with regressive effects. Also, vehicle manufacturers who had invested in producing diesel cars, to take advantage of administered diesel prices, would be at a

disadvantage. If diesel was deregulated and kerosene was not, diesel adulteration would only increase. If both diesel and kerosene were deregulated, regressive effects would likely further intensify. Eliminating kerosene subsidies would likely reduce transport emissions, but could also increase indoor air pollution risks and deforestation, since a significant proportion of the urban poor, who depend on kerosene as a cooking fuel, might revert to firewood. The foregoing demonstrates the importance of considering system-wide impacts of transport policies.

Given the critical need to minimize motor vehicle trips in addition to controlling per-vehicle emissions, it would be useful to investigate the barriers to, and institutional mechanisms for, enhanced use of non-motorized modes and public transit in Indian cities. With regard to public transit, constraints in terms of fleet operational efficiency and financial viability, and investment in fleet maintenance and expansion, should be investigated. It would also be useful to study in greater detail vehicle user choices in terms of the conditions under which they would be willing (and not willing) to transfer to public transit. This information will help more effectively design public transit policy and model its impacts.

The increase in female work-force participation and incomes in Indian cities will likely have important urban transport implications, as discussed. It would be useful to explore these implications in depth, and also to study, based on a survey and interviews, the needs, concerns and priorities of women with regard to daily travel, by private as well as public transport modes. Such a study would fulfill an important need, given the paucity of gender-based urban transport data.

Lastly, given that Indian cities are faced with a multiplicity of demands, but seriously constrained resources, it would be interesting and useful to undertake a study that contrasts decision maker and public perspectives with regard to urban transport and other urban ecological and health risks, compares resources allocated to these risks, and develops a prescriptive framework for prioritizing them.

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APPENDIX I

Comparison of Indian National Ambient Air Quality Standards (NAAQS) with WHO/US/California Ambient Air Quality Standards

Indian Standard		WHO Standard	US/Calif Standard
Sulphur Dioxide (SO_2), µg/m^3	**Annual average***	**Annual average**	**Annual average**
	Industrial area 80 Residential, rural and mixed use area 60 Sensitive area 15	40-60 50 [a]	US 80 Calif
	24-hour average **	**24-hour average**	**24-hour average**
	Industrial area 120 Residential, rural and mixed use area 80 Sensitive area 30	100-150 125 [a]	US 365 Calif 143 [b]
Oxides of Nitrogen as NO_2, µg/m3	**Annual average***		**Annual average**
	Industrial area 80 Residential, rural and mixed use area 60 Sensitive area 15		US 100
	24-hour average **	**24-hour average**	**24-hour average**
	Industrial area 120 Residential, rural and mixed use area 80 Sensitive area 30	150 **1-hour average** 400	Calif 470
Suspended Particulate Matter, µg/m^3	**Annual average TSP ***	**Annual average TSP**	
	Industrial area 360 Residential, rural and mixed use area 140 Sensitive area 70	60-90	
	24-hour average TSP **	**24-hour average TSP**	
	Industrial area 500 Residential, rural and mixed use area 200 Sensitive area 100	150-230 120 [a]	

Indian Standard		WHO Standard	US/Calif Standard
Respirable Particulate Matter (< 10 μm) PM_{10}, μg/m^3	**Annual average RPM (PM_{10}) *** Industrial area 120 Residential, rural and mixed use area 60 Sensitive area 50 **24-hour average RPM (PM_{10}) **** Industrial area 150 Residential, rural and mixed use area 100 Sensitive area 75	**24-hour average Thoracic particles (as PM_{10})** 70 [a]	**24-hour average PM_{10}** US 50 Calif 30 [c] **8-hour average PM_{10}** US 150 Calif 50
Lead (Pb), μg/m^3	**Annual average *** Industrial area 1.0 Residential, rural and mixed use area 0.75 Sensitive area 0.50 **24-hour average **** Industrial area 1.5 Residential, rural and mixed use area 1.0 Sensitive area 0.75	**Annual average** 0.5-1	**Quarterly average** US 1.5 **Monthly average** Calif 1.5
Carbon Monoxide (CO), mg/m^3	**8-hour average **** Industrial area 5.0 Residential, rural and mixed use area 2.0 Sensitive area 1.0 **1-hour average** Industrial area 10.0 Residential, rural and mixed use area 4.0 Sensitive area 2.0	**8-hour average** 10 **1-hour average** 30	**8-hour average** US 10 Calif 10.3 **1-hour average** US 40 Calif 22.9
Ozone (O_3), μg/m3		**8-hour average** 100-120 **1-hour average** 150-200	**1-hour average** US 235 [d] Calif 180 [d]

Sources: WHO/UNEP (1992); CPCB (1995); CPCB (1996); Shah and Nagpal (1997).

Notes:

* Annual arithmetic mean of a minimum of 104 measurements a year taken twice a week 24 hourly at uniform interval.

** 24-hour/8-hour values should be met 98% of the time in the year. While they may be exceeded 2% of the time, they may not be exceeded on two consecutive days.

1) National Ambient Air Quality Standard: the levels of air quality necessary with an adequate margin of safety, to protect public health, vegetation and property.

2) Whenever and wherever two consecutive values exceed the limit specified above for the respective category, it would be considered adequate reason to institute regular/continuous monitoring and further investigations.

3) The State Government/State Board shall notify the sensitive and other areas in the respective states within a period of six months from the date of Notification of National Ambient Standards.

3) The above standards shall be reviewed after five years from the date of notification.

a) Guideline values for combined exposure to sulphur dioxide and suspended particulate matter (they may not apply to situations where only one of the components is present).

b) With ozone > 0.10 ppm (200 $\mu g/m^3$), one-hour mean, or TSP > 100 $\mu g/m^3$, 24-hour mean.

c) Geometric mean.

d) Value not to be exceeded more than once a year.

CRITIQUE OF INDIAN AMBIENT AIR QUALITY STANDARDS

The Indian National Ambient Air Quality Standards (NAAQS) differentiate between "industrial", "residential, rural and mixed use", and "sensitive" areas. Prior to 1994, when the above standards were established, the Indian NAAQS specified limits for "industrial", "residential and rural and other", and "sensitive" areas (WHO/UNEP 1992; CPCB 1996). Incidentally, the PM_{10} standard was also added in 1994. It is not at all clear what "mixed" means exactly, and thus is no improvement really over the earlier "other". Further, though the standard does not clearly specify what precisely is meant by a "sensitive" area, it ostensibly includes sites such as hospitals, but also tourist and historical sites. The Chinese ambient air quality standards (WHO/UNEP 1992) similarly differentiate between Class III (industrial and heavy traffic areas), Class II (residential urban areas and rural areas), and Class I (tourist, historical, and conservation areas). It is interesting that areas where tourists visit are felt to be entitled to the most stringent air quality standard, rather than where the country's masses live. In any case, any differentiation in air quality standards along these lines is pointless in the Indian (and Chinese) context, because air pollution respects no boundaries, and supposedly industrial areas are also heavily populated. As Basu (1997) observes, as many as 50% of Delhi's industrial units are located in residential areas. Finally, the standard is irrelevant to rural conditions, because in that context, the real problem is indoor, not outdoor air pollution, and the outdoor air pollution levels would seldom reach the stipulated limits.

The Indian annual average SO_2 standard, which incidentally is intended to protect against regular exposure, is less stringent than the WHO standard of 50 $\mu g/m^3$ (the applicable limit in the Indian case, since both SO_2 and SPM are present), even for industrial areas. Indeed, it is questionable whether even the WHO limit is adequate from the health standpoint in the Indian

context, given the large proportion of the population that would be highly susceptible to negative health effects of air pollution, because of the high levels of poverty, poor nutrition and marginal health, and also low-quality health care access and quality (Romieu et al 1992; Brandon and Hommann 1995). Of course, there appropriately are other considerations in setting standards. The 24-hour standard, which is intended to protect against long-term chronic effects, on the other hand, is far more stringent than the WHO standard, which itself is far more stringent than the US standard.

In terms of TSP, both the annual and 24-hour Indian standards for residential areas (let alone industrial areas) are much less stringent than the corresponding WHO standards. In terms of PM_{10}, which is considered to be the most critical pollutant from the health standpoint, the 24-hour Indian standard even for sensitive areas falls short of the corresponding WHO and US standards. It is worth noting in this context that the US and California have no limits for TSP, and only a 24-hour and 8-hour limit for PM_{10}, presumably because PM_{10} is the most health-critical component and also because, as long as 8-hour and 24-hour limits are met, so will annual limits. USEPA recently added an annual $PM_{2.5}$ standard of 15 $\mu g/m^3$ and a 24-hour standard of 50 $\mu g/m^3$, on the grounds that current PM_{10} standards do not adequately protect public health.

In terms of the other pollutants, the Indian standards for NO_2 and CO are more stringent than the corresponding WHO as well as the US and Californian standards, even for industrial areas. One is left wondering what basis if any underlies the Indian NAAQS. Finally, there is no standard for O_3.

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APPENDIX II

Air Pollutants and their Health Effects

CO is quickly absorbed by the lungs, and carried in the blood. Because the affinity of haemoglobin for it is about 240 times that for oxygen, CO forms a strong bond with haemoglobin to produce carboxyhaemoglobin (COHb), which restricts the oxygen carrying capacity of blood. While the normal COHb level is 1.2-1.5%, levels in areas of heavy traffic congestion, where CO levels can be as high as 20-30 mg/m^3, can reach 3%, the same as in cigarette smokers. Luckily, except in poorly ventilated areas, CO disperses rapidly and its effects are reversible. Chances of coma and death are heightened at very high CO concentrations, but people with heart and respiratory diseases, pregnant women, infants, and senior citizens may suffer CO poisoning at much lower levels. Indeed, CO concentrations of 9 ppm (or 10.3 mg/m^3, the WHO 8-hour limit) may increase the chance of angina attacks for those at risk, and chronic exposure at 14 ppm can cause adverse, even fatal, effects, in such people. Since CO readily crosses the placenta, exposure during pregnancy affects both the mother and fetus. Exercise hastens CO build-up, and those who work outdoors may be at elevated risk due to short-term exposure (Brandon and Hommann 1995; CSE 1996; Faiz et al 1992; Government of Canada 1991; GVRD 1996; Wijetilleke and Karunaratne 1997).

NO_x include NO and nitrous oxide (N_2O) but primarily consist of NO_2, a respiratory irritant which can either cause or aggravate respiratory diseases, such as bronchitis, pneumonia, asthma or emphysema. Long-term exposure can cause irreversible lung damage. Recurrent exposure to high concentrations (such as in heavy traffic areas) is more harmful than continuous exposure to lower concentrations. In this context, it should be noted that in Delhi, daily average NO_2 levels are high, and are likely increasing, at several sites. Asthmatics may be particularly vulnerable; even if not affected directly, they may become more sensitive to environmental factors, such as dust and pollen, that can cause asthma (Barde and Button 1990; Faiz et al 1992; Wijetilleke and Karunaratne 1997).

SO_2, which forms the bulk of sulphur emissions from motor vehicles, is a harsh irritant. Individuals who suffer from chronic respiratory diseases, such as bronchitis, emphysema, and asthma may experience coughing and breathing difficulties at high concentrations, particularly in cold weather. Brief exposures to high concentrations of SO_2 and its by-products can aggravate existing cardiac and respiratory disease, and long-term exposure may increase the risk of developing chronic respiratory disease, particularly in the young. Recent data suggests that levels below the WHO limit are independently related to mortality and to worsening asthma (Faiz et al 1992; Government of Canada 1991; GVRD 1996; Wijetilleke and Karunaratne 1997).

SPM is a component of particulate matter, which comprises solid and liquid particles suspended in air, resulting from combustive and industrial as well as natural sources. Particle sizes typically range from 0.005 to 100 μm, but particles that remain suspended are usually less than 40 μm. SPM includes this size fraction mainly. Particle types include various fumes, soil, elemental carbon and soot, organic carbon (condensed VOCs), inorganic compounds (for

example, sulphates, nitrates), trace metals (for example, lead and zinc), and biological particles such as mold and pollen. PM smaller than 10 μm (PM_{10}) and 2.5 μm ($PM_{2.5}$) diameter are referred to as suspended inhalable and fine particulates respectively. PM_{10} (and particularly $PM_{2.5}$), are dangerous because they remain suspended longer than larger particles (5-15 days for PM_1), contribute to particulate smog, and penetrate deeper into, and take longer to be cleared from, the respiratory tract. Particulates, especially sulphates and acid aerosols, may increase persistent cough and acute respiratory illness. Exposure to high PM_{10} levels can chronically and acutely affect respiratory and cardio-vascular health, and initiate or aggravate morbidity and mortality due to chronic obstructive lung disease, bronchitis, upper and lower tract infections, and lung cancer (Brandon and Hommann 1995; Faiz et al 1992; GVRD 1998; Wijetilleke and Karunaratne 1997).

Epidemiological studies in North America, Europe and China consistently show non-accidental deaths closely linked to particulates but not other pollutants, and a 1% increase in non-accidental mortality risk per 20 $\mu g/m^3$ daily TSP increase. Death risks from chronic obstructive lung disease, lung cancer, pneumonia and cardio-pulmonary disease are elevated over excess risk for all deaths. In a landmark prospective study of 8111 adults in six US cities in 1974-1991 by Dockery et al (1993), mortality data was correlated with ambient TSP, PM_{10}, $PM_{2.5}$, particulate sulphate, SO_2, and O_3. Factors including smoking, sex, age, education, occupation, body weight, blood pressure, and diabetes, were controlled for. After correcting for age and sex, the mortality risk in the city with the highest annual TSP was found to be a statistically significant 1.26 times that in the city with the lowest (reflecting a 8.6% increased mortality risk per 20 $\mu g/m^3$ annual TSP increase, more than eight times higher than the excess daily risks from short-term pollution increases). The statistical significance and risk remained largely unchanged regardless of correction for confounders. This trend is found to apply to other health end-points, including hospital admissions (Smith 1994). A recent study by Kaiser Permanente of more than 1.6 million patients in Southern California showed that for each 10 $\mu g/m^3$ increase in PM, their hospital admissions increased by 7, 3, and 3.5% for chronic respiratory, cardio-vascular and acute respiratory diseases (Fazio 1997; Smith 1994; Walsh 1994).

The only developing country study correlating mortality and particulates was conducted in Brazil in the late 1980s. It focused on infant pneumonia deaths, a specific but very important end-point, being a major component of infant mortality in the LICs. Such deaths were found to increase 20% for each 20 $\mu g/m^3$ annual TSP rise. This risk is substantially greater than that for all adult mortality in the US, because of the sensitivity of children, and the intimate link between air pollution and this end-point (Smith 1994).

Finally, a few important general points on studies correlating particulates and health. There are relatively little differences in health effects due to particulates despite differences in their chemical composition. Particulates are closely linked to various health-points even when no SO_2 is present. Levels below 100 $\mu g/m^3$ were considered harmless, but linking data from the great air pollution disasters and the new studies (below 120 $\mu g/m^3$) showed no sign of either any threshold or saturation in the dose-response relationship over a range of more than two orders of magnitude from levels in the tens of $\mu g/m^3$ (Smith 1994). PM_{10} and $PM_{2.5}$ may be far

better health indicators than TSP. Californian and Canadian studies have found that 85% of air pollution health effects (and the benefits of air quality management) were attributable to PM_{10}, not photo-chemical smog (GVRD 1996).

Lead The health hazards of lead have been known since the Romans. While most modern lead poisoning has been associated with emissions from local smelters or battery recovery plants, the widespread dissemination of lead, as evidenced by its dramatic increase in the snow strata of Greenland after 1950 (a four-fold increase in 1940-1960), may be linked to its equally widespread use as an anti-knock agent in gasoline, and its wide dispersal in air in fine particulate form, from about the same time (Bates 1994).

Nearly all lead in gasoline is released to the atmosphere, mainly as inorganic lead salts (chlorides, bromides and sulphates) and oxides in aerosol form, all in the PM_{10} range, but mostly as fine particulates (only 1% of lead in gasoline is emitted unchanged as tetra-ethyl lead or tetra-methyl lead). Not surprisingly, lead particulates remain suspended in air for long periods before being deposited in the soil or on water. About 10% of motor vehicle generated lead is deposited within 100 metres of roadsides, where children frequently play in the LICs (Faiz et al 1992; Wijetilleke and Karunaratne 1997).

There is a significant relationship between lead in gasoline, airborne lead, and blood-lead. The best evidence for this may be the 37% decline in average blood levels in the USA between 1976 and 1980, while gasoline lead was reduced 55% (to coincide with the introduction of catalytic converters). Incidentally, while only 10% of refined lead in the USA was used in gasoline, such lead was responsible for 60% of airborne lead, and for as much as 90% in cities with heavy motor vehicle traffic. A statistical study of blood-lead levels of 90 children in Mexico City, where gasoline vehicles account for the bulk of airborne lead, revealed that those who lived in low traffic areas had a significantly lower blood-lead level than those living close to main roads. Similar results were obtained in a Manila study (Driscoll et al 1992; Romieu et al 1992; Wijetilleke and Karunaratne 1997).

Because lead particulates remain suspended in air for long periods, and may be deposited in the soil or on water, the primary pathways of lead exposure are inhalation and ingestion through food and water. While ingested lead results in only 10% being absorbed by the body, inhaled lead is absorbed rapidly by the lungs, resulting in 25-50% retention. Regardless of exposure mode, the outcomes are the same. Tetra-ethyl lead is metabolized in the liver and other tissues to tri-alkyl lead, perhaps the most toxic metabolite. Normal cell function and other physiological and enzymatic processes are disrupted. Chiefly affected are peripheral and central nervous, circulatory, reproductive, and kidney systems. Diets deficient in calcium, vitamin D, iron and zinc increase lead absorption. Sufficiently high concentrations can lead to anaemia, kidney failure, massive and permanent brain damage, and death (CPCB 1992; CSE 1996; Faiz et al 1992; Wijetilleke and Karunaratne 1997).

High airborne lead levels can contribute to hypertension, and significantly increase risks of heart attacks and strokes in adults. Hypertensive adults, pregnant women and their fetuses, and children are the highest risk groups. Maternal lead can be transmitted to the fetus via the

placenta at blood lead levels as low as 10 μg/dl, thus affecting gestational age, birthweight, and mental development. Children, particularly those under five, are at high risk of excessive exposure, because they take in dust and soil through normal mouthing habits. Further, lead has more severe consequences in children than adults, and the effects occur at lower concentrations. Since children inhale a higher volume of air than adults per body weight/area, their lung deposit rate is about 2.7 times higher. While 95% of lead in adults is located in the bones and teeth, 70% in children is lodged in blood and soft tissues. Blood-lead induces neurological damage, lowered intelligence and learning ability, and behavioural dysfunctions in children. Several US and European studies have consistently found these effects after correcting for confounders such as socio-economic status, and at blood-lead levels as low as 10 μg/dl. More importantly, the effects have been found to persist irreversibly into adulthood. One study showed that infants with elevated lead levels had a seven-fold increase in reading and motor skill deficits, and failure to graduate from school *11 years later*, though their blood-lead levels as young adults were less than 10 μg/dl (Bates 1994; CPCB 1992; CSE 1996; Driscoll et al 1992; Faiz et al 1992; Romieu, Weitzenfeld and Finkelman 1991; Romieu et al 1992; Wijetilleke and Karunaratne 1997).

The economic and social costs of the health effects of lead can be very great indeed. Since exposure to even low lead levels can cause effects that persist even after exposure ends, it should be noted, in considering the health effects of gasoline lead in Delhi (and other Indian cities), that gasoline lead levels have been lowered and unleaded gasoline introduced only recently, that lead levels prior to this were high (at least 0.56 g/L since 1971), and that, in addition to a lot of human activity generally, food is cooked and eaten in the vicinity of high traffic areas. It is instructive to note that, prior to removal of lead in US gasoline, which was never higher than 0.29 g/L (in 1982), blood lead averaged 16 μg/dl,[1] and that high ambient lead levels have been observed, even as late as 1992, in areas of heavy traffic in Delhi (Agrawal 1997; CPCB 1992; Wijetilleke and Karunaratne 1997).

Ground-level O_3, the major photochemical oxidant resulting from reactions between reactive HCs and NO_x in the presence of sunlight, is an intensely irritating gas. It causes cough and eye irritation, impairs lung function, reduces resistance to colds and pneumonia, and can aggravate heart disease, asthma, bronchitis, and emphysema. While it is a special hazard to asthmatics, even short-term exposure can lead to shortness of breath, wheezing and chest pain in healthy people. Repeated exposure may retard lung development in children, accelerate lung aging, impair lung function permanently, and cause chronic lung diseases such as pulmonary fibrosis. In severe episodes, people who exert themselves heavily outdoors (as many do in the Indian context) are more at risk of respiratory irritation (Bates 1994; Faiz et al 1992; Wijetilleke and Karunaratne 1997).

O_3 has been found to be related to mortality independently of PM_{10}. Data from Ontario and the Lower Fraser Valley in Canada shows a monotonic relationship between O_3 and hospital admissions, and pulmonary function decrements in farm workers at levels below 140 μg/m^3. Studies in the USA, Europe and Japan have shown significant increases in respiratory and

[1] Of course, motor vehicle activity in the USA has always been a lot higher than in India.

asthma symptoms, medication and hospital admissions, during high O_3 periods. The Kaiser Permanente study referred to earlier showed that for each 20 $\mu g/m^3$ O_3 increase, hospitalizations for chronic respiratory, cardio-vascular, and acute respiratory diseases increased 2.7, 5.7, and 1.5% respectively. Based on health effects of short-term exposure, the USEPA has concluded that 0.12 ppm (240 $\mu g/m^3$) is the permissible level, but lung function is adversely affected in the young if they exercise for six hours at 160 $\mu g/m^3$, roughly the one-hour WHO standard (Brandon and Hommann 1995; CSE 1996; Faiz et al 1992; Roy Chowdhury 1997; Wijetilleke and Karunaratne 1997).

APPENDIX III

Indian Motor Vehicular Emission Standards since 1991

	April 1991	April 1996	April 2000 (proposed)	Remarks
M2W vehicles (g/km) **CO** **HC** **HC + NO_x**	 12-30 8-12 -	 4.5 - 3.6	 2.0 - 1.5	In 1991, Conformity of Production (CoP) margins were 25 and 33% for CO and HC. In 1996, CoP margins were limited to 20% for CO and HC + NO_x From April 1998, cold start is required.
M3W vehicles (g/km) **CO** **HC** **HC + NO_x**	 12-30 8-12 -	 6.75 - 5.4	 4.0 - 1.5	In 1991, CoP margins were 25 and 33% for CO and HC. In 1996, CoP margins were limited to 20 % for CO and HC + NO_x From April 1998, cold start is required.
Cars (g/km) **CO** **HC** **HC + NO_x**	 14.3-27.1 2-2.9 -	 8.68-12.4 - 3-4.36	 2.72 - 0.97	In 1991, CoP margins were 20 and 27% for CO and HC. In 1996, CoP margins were limited to 20% for CO and HC + NO_x. Crankcase emissions were banned, and evaporative emission limits of 2 g/test were set. From April 1998, cold start is required.

	April 1991	April 1996	April 2000 (proposed)	Remarks
Diesel vehicles > 3.5 t GVW (g/KWh)				In 1996, CoP margins were limited to 10% for CO, HC and NO_x.
CO	14	11.2	4.5	
HC	3.5	2.4	1.1	
NO_x	18	14.4	8.0	
PM	-	-	0.36	
Diesel vehicles < 3.5 t GVW (g/km)				In 1996, CoP margins were limited to 10% for CO and HC + NO_x. Cold start was made a requirement.
CO	14.3-27.1	5-9	5-9	
HC + NO_x	2.7-6.9	2-4	2-4	

Sources: Central Motor Vehicles (Amendment) Rules (1995); CSE (1996); MoST (1996).

APPENDIX IV

Indian Motor Gasoline Specifications (Current and Proposed for 2000) -- Comparison of Key Characteristics

	Motor Gasoline prior to 1995			Motor Gasoline proposed for 2000		
	87 Octane Unleaded	**87 Octane Leaded**	**93 Octane Leaded**	**Leaded Regular**	**Unleaded Regular**	**Unleaded Premium**
Anti-knock Index, min.	82	82	88	84	84	88
Lead content, g/L, max.	0.013	0.56	0.80	0.15	0.013	0.013
Sulphur, total, % by mass, max.	0.20	0.20	0.20	0.20	0.10	0.10
Benzene content, % vol.	no standard			5.0	5.0	5.0
Reid Vapour Pressure (RVP) at 38 deg C, kPa	35-70	35-70	35-70	35-60	35-60	35-60
Existent gum, g/m^3, max.	40	40	40	40	40	40

Source: BIS (1995a). Oxygenates will be permitted from 2000. Benzene will be controlled to 3% by volume in the four major cities in 2000.

Schedule of Improvements (Unleaded and Low-lead Gasoline and Low-sulpur Diesel)

	Delhi, Calcutta, Chennai, Mumbai	**Taj Trapezium**	**State/Union Territory Capitals, other major cities**	**Entire Country**
Low-lead (0.15 g/L max.) Gasoline	April 1994	Sept 1995	-	Dec 1996
Unleaded (0.013 g/L max.) Gasoline	April 1995	April 1995	end Dec 1998	end March 2000
Diesel, 0.5 % max. sulphur	April 1996	April 1996	-	-
Diesel, 0.25 % max. sulphur	-	Sept 1996	-	April 1999

Source: MoEF (1997b).

APPENDIX V

List of Interviewees in Government Agencies, Industry, and Research Institutions

Mr. Vishwanath Anand, Additional Secretary, Ministry of Environment and Forests, Government of India, New Delhi
Mr. Y. Ramachandra Babu, Member (R&D), TVS-Suzuki Limited, Hosur
Dr. Ranjan Bose, Fellow, Tata Energy Research Institute, New Delhi
Mr. T. M. Balaraman, Senior Manager (Product Engineering), Bajaj Auto Limited, Pune
Mr. Balraj Bhanot, Deputy Director General, Ministry of Industry, Government of India, New Delhi
Dr. Shripad Bhat, Assistant Director, Association of Indian Automobile Manufacturers, New Delhi
Dr. T. Chandini, Director (Technical), Ministry of Environment and Forests, Government of India, New Delhi
Mrs. Kiran Dhingra, Secretary and Commissioner, Transport Department, Government of the National Capital Territory of Delhi, New Delhi
Dr. Axel Friedrich, Director, and Head of Division, Transport and the Environment, Umwelt Bundes Amt (Federal Environmental Agency), Germany (visiting Delhi)
Dr. Prodipto Ghosh, Environment Specialist, Asian Development Bank, Manila
Mr. N. V. Iyer, General Manager (Engineering Support), Bajaj Auto Limited, Pune
Dr. T. K. Joshi, Professor, Centre for Occupational and Environmental Health, Maulana Azad Medical College, New Delhi
Dr. Ajay Mathur, Dean, Energy Engineering and Technology, Tata Energy Research Institute, New Delhi
Dr. Dinesh Mohan, Professor and Co-ordinator, Transportation Research and Injury Prevention Programme, Indian Institute of Technology, Delhi
Mr. M. N. Muralikrishna, Vice President (Technical), TVS-Suzuki Limited, Hosur
Mr. K. Pandarinath, Deputy General Manager (Research), Sundaram Brake Linings Limited, Chennai
Mr. N. R. Raje, Deputy General Manager, Indian Oil Corporation Limited, Research and Development Centre, Faridabad
Dr. N. Ramani, General Manager (R&D), TVS-Suzuki Limited, Hosur
Mr. T. S. Reddy, Chief, Traffic and Transportation Division, Central Road Research Institute, New Delhi
Mr. Dunu Roy, Peoples' Science Institute, New Delhi
Mr. Jagdish Sagar, Principal Secretary, Ministry of Urban Development, Government of the National Capital Territory of Delhi, New Delhi
Dr. Sareen, Deputy Director, Central Road Research Institute, New Delhi
Dr. B. Sengupta, Central Pollution Control Board, New Delhi
Dr Ajay Singh, Assistant Director, Central Road Research Institute, New Delhi
Mr. A. S. Subramanian, Deputy General Manager, Tata Engineering and Locomotive Company Limited, Pune
Dr. Geetam Tiwari, Assistant Professor, Transportation Research and Injury Prevention Programme, Indian Institute of Technology, Delhi

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APPENDIX VI

Informed Consent Form # 1

Project -- Multiple Objective Evaluation of Public Policies to Address Motorized Two-wheeled Vehicle Emissions in Delhi, India

Discussions with Government Decision Makers, Experts, and Vehicle and Fuel Industry Representatives

Principal Investigator

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Co-Investigator

Madhav Badami
PhD Candidate
School of Community and Regional Planning
The University of British Columbia
Vancouver, BC, V6T 1Z2, Canada
Phone: (604) 822-6081

Note: This research is for Madhav Badami's PhD (Doctor of Philosophy) degree thesis in the School of Community and Regional Planning at The University of British Columbia.

Purpose

The purpose of this PhD project is to enable systematic thinking and sound public policy with regard to motor vehicle emissions in Indian cities. The objectives of the project are: first, to develop a policy-analytic framework to enable achievement of the above purpose;

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and second, to conduct research focused on key components of the policy-analytic framework, as applied to the specific case of motorized two-wheeled vehicle emissions in Delhi, including the evaluation of some policy alternatives.

In-depth discussions are being conducted with decision makers, experts and vehicle and fuel industry representatives to take advantage of their professional expertise, and to elicit information from them in order to facilitate development of the policy-analytic framework and its application to motorized two-wheeled vehicle emissions in Delhi.

Procedure

Participation involves in-depth, face-to-face discussions with the investigator(s), on the following issues:

- multiple policy objectives and evaluation criteria for selection and evaluation of policy alternatives with regard to motor vehicular emissions in general, and motorized two-wheeled vehicle emissions in particular;
- technical and institutional factors contributing to motorized two-wheeled vehicle emissions, and the decision making framework and actors' roles;
- information and expert judgements regarding impacts of policy alternatives in terms of the multiple policy objectives.

Time Required

It is anticipated that the discussions will take no longer than three hours totally, spread over no more than three sessions.

Confidentiality

The identities of all of the participants will be kept strictly confidential. Participants will be referred to by number, with only Dr. Timothy McDaniels and Madhav Badami holding the key detailing which number refers to which participant. Participants will not be identified by name in any reports based on this study.

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Questions and Inquiries

The investigator(s) will answer any inquiries concerning the research project and the procedures, to ensure that they are fully understood.

Contact

If I have any questions or desire further information with respect to this study, I may contact Dr. Timothy McDaniels, Principal Investigator, or Madhav Badami, Co-Investigator, at the addresses and/or phone numbers indicated on Page 1.

If I have any concerns about my treatment or rights as a research subject, I may contact:

Dr. Richard Spratley
Director, Office of Research Services and Administration
The University of British Columbia
Room 323 - Woodward IRC
2194 Health Sciences Mall
Vancouver, BC, V6T 1Z3, Canada
Phone: (604) 822-8584 Fax: (604) 822-5093

Consent

I understand that my participation in this study is entirely voluntary, and that I may refuse to participate or withdraw at any time.

I have received a copy of this consent form for my own records.

I consent to participate in this study.

_____ _____
Signature of Participant Date

APPENDIX VII

Proposed Rules for Vehicle Scrappage/Phase-out in Delhi

M2W vehicles with two-stroke engines

From April 1, 2000 -- all vehicles over 15 years old.
From April 1, 2005 -- all vehicles over 10 years old.
From April 1, 2007 -- all vehicles.

M3W Vehicles

According to NCTD (1997d)

All autorickshaw permit holders are directed to dispose of their autorickshaws older than 15 years by March 31, 1998. Failure to do so would result in impoundment and/or scrapping of the vehicles by the State Transport Authority. Old autorickshaws are to be replaced with new ones with "backloaded" engines, as follows:

Scrapping of vehicles older than 15 years to be replaced by new autorickshaws, or

Sale of the old autorickshaws outside NCTD and replacement of the old vehicles with new autorickshaws on proof of registration of the old vehicles outside NCTD.

Additionally, according to MoEF:

From April 1, 1999 -- vehicles older than 12 years to be scrapped.
From April 1, 2000 -- vehicles older than 10 years to be scrapped; new vehicles only with alternative fuels.

According to NCTD (1997c)

From April 1992, no M3W goods carriage operated on either gasoline or diesel shall be registered in Delhi. Permit holders of M3W goods or passenger carriage shall be required to dispose of their vehicles by sale outside Delhi, and shall be entitled to register a new vehicle which shall be:

A M3W vehicle fitted with rear four-stroke unleaded petrol driven engine and catalytic converter that meets 1996 mass emission norms with catalytic converter that meets 1996 norms (2000 mass emission norms from April 1, 1999, or

A M3W vehicle fitted with rear two-stroke engine that meets 1996 mass emission norms (2000 mass emission norms from April 1, 1999) till a M3W vehicle fitted with rear four-stroke unleaded petrol engine is not (sic) available, or

A M3W vehicle fitted with rear engine and operated by alternate fuel or source of energy, that may be electricity, battery, CNG, LPG, propane, or solar power, or

A 6-8 seater, metered and a four-wheeled vehicle fitted with unleaded petrol driven engine and catalytic converter meeting 1996 mass emission norms (2000 norms from April 1, 1999), or operated by alternate fuel or source of energy, that may be electricity, battery, CNG, LPG, propane, or solar power.

Taxis

According to MoEF (1997b)

From March 31, 1998 -- all taxis older than 15 years to be scrapped.
From March 31, 1999 -- all taxis older than 12 years to be scrapped.
From March 31, 2000 -- all taxis older than 10 years to be scrapped.

According to NCTD (1997c)

From April 1, 1998, no vehicle older than two years old shall be registeredas a taxi, provided that:

Between April 1, 1998 and March 31, 1999, no vehicle shall be registered as a taxi unless it meets 1996 mass emission norms or is operated on alternate fuel or source of energy, that may be electricity, battery, CNG, LPG, propane, or solar power.

From April 1, 1999, no vehicle shall be registered as a taxi unless it is operated on alternate fuel or source of energy, that may be electricity, battery, CNG, LPG, propane, or solar power, or meets 2000 mass emission norms.

From April 1, 2000, no vehicle shall be registered as a taxi unless it is operated on alternate fuel or source of energy, that may be electricity, battery, CNG, LPG, propane, or solar power.

Transport (medium- and heavy-duty) Goods Vehicles and Buses

After March 31, 1998 -- all transport vehicles over 15 years old.
After March 31, 1999 -- all transport vehicles over 12 years old.
After March 31, 2000 -- all transport vehicles over 15 years old.
After March 31, 2001 -- no medium- or heavy-duty vehicle (passenger and goods) over 8 years old shall ply in Delhi.

From April 1998, only those medium- and heavy-duty vehicles (passenger and goods) manufactured after March 31, 1996, and complying with 1996 norms, and from April 1999, only those complying with 2000 norms, shall ply in Delhi.

From April 1998, replacement of engine shall be allowed only with an engine complying with the mass emission standards in force at the time of replacement, provided that the replacement engine operates on the same fuel specified in the registration certificate.

Sources: MoEF 1997b; NCTD 1997c; NCTD 1997d; Roy Paul 1997.

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APPENDIX VIII
M2W VEHICLE USER SURVEY INFORMED CONSENT FORM

Informed Consent Form

Project -- Multiple Objective Evaluation of Public Policies to Address Motorized Two-wheeler Emissions in Delhi, India

Questionnaire Survey of, and Discussions with, Motorized Two-wheeler Users

This research project is funded by the International Development Research Centre in Ottawa, Canada, and is being conducted in association with the Indian Institute of Technology, Delhi. It is for Madhav Badami's PhD (Doctor of Philosophy) degree thesis in the School of Community and Regional Planning at The University of British Columbia, Vancouver, Canada.

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Purpose

The purpose of this PhD project is to enable good public policies to address the problem of motor vehicle emissions effectively in Indian cities. Toward this end, a method is being developed by means of which such policies can be selected, and is being applied to the specific case of motorized two-wheeler emissions in Delhi.

To accomplish the above tasks, it is necessary to understand the factors that contribute to motorized two-wheeler ownership, use, and emissions. Also, it is important to obtain from users their views as to the desirable characteristics that they believe emission prevention and control policies ought to have from their point of view, and their views of various policies. The sessions being conducted with motorized two-wheeler users are designed to provide this information.

Procedure

Participation involves a) filling out a questionnaire, and/or b) engaging in a discussion, either along with other participants and the investigator(s), or face-to-face with the investigator(s).

Participants will be requested to provide information with regard to:

- their household and its vehicles;
- their travel on the previous working day, and on the previous weekend;
- the factors that influenced their choice of motorized two-wheelers as their mode for commuting, and of the particular motorized two-wheelers they use;
- their perceptions of bus service and bicycle commuting in Delhi;
- vehicle operation and maintenance;
- their views as to the causes and effects of deteriorating urban air quality in Delhi;
- their awareness and perceptions of vehicle emissions control measures currently in place in Delhi;
- desirable characteristics of emission prevention and control policies, from their point of view;
- their views of various policies, and possible incentives that would make these attractive to them.

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Time Required

It is expected that answering the questionnaire and participating in the discussion will together take no longer than 1 hour 30 minutes.

Confidentiality

The identities of all of the participants will be kept strictly confidential. Questionnaires and participants will be referred to by number, with only Dr. Timothy McDaniels and Madhav Badami holding the key detailing which number refers to which participant. Participants will not be identified by name in any reports based on this study.

Questions and Inquiries

The investigator(s) will answer any inquiries concerning the research project and the procedures, to ensure that they are fully understood.

Contact

If I have any questions or desire further information with respect to this study, I may contact Dr. Timothy McDaniels, Principal Investigator, or Madhav Badami, Co-Investigator, at the addresses and/or phone numbers indicated on Page 1.

If I have any concerns about my treatment or rights as a research subject, I may contact:

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Consent

I understand that my participation in this study is entirely voluntary, and that I may refuse to participate or withdraw at any time.

I have received a copy of this consent form for my own records.

I consent to participate in this study.

_____ _____
Signature of Participant Date

APPENDIX IX M2W VEHICLE USER SURVEY QUESTIONNAIRE

Project -- Multiple Objective Evaluation of Public Policies to Address Motorized Two-wheeler Emissions in Delhi, India

Questionnaire Survey of Motorized Two-wheeler Users

Important Note: Your responses should reflect your own views and judgements. Please feel free to express your views, and do not be concerned about whether they are right or wrong. There are no right or wrong answers. Use the margins for any comments you may wish to make.

****

Personal Information

Gender Male ☐
Female ☐

Age ..... years

Please indicate the locality and the street in which your home is (please do not indicate your residential address) .....

Household Details

For all members of your household who share the same kitchen, please provide the following information, starting with yourself:

Persons in House-hold (Please do not indicate names, only relation-ship to you)	**Age**	**Employed Full-time/ Part time** **Unemployed** **Housewife** **Student etc.)**	**Profession and Occupation, if employed**	**Approx. monthly income**	**Most common daily travel destination (Office, school, market, temple etc.)**	**Vehicle used for most common daily travel destination (bus, charter bus, car, scooter, motorcycle, bicycle, auto-rickshaw etc)**
1) Yourself						
2)						

Table Continued on Next Page

Persons in House-hold (Please do not indicate names, only relation-ship to you)	**Age**	**Employed Full-time/ Part time** **Unemployed** **Housewife** **Student etc.)**	**Profession and Occupation, if employed**	**Approx. monthly income**	**Most common daily travel destination (Office, school, market, temple etc.)**	**Vehicle used for most common daily travel destination (bus, charter bus, car, scooter, motorcycle, bicycle, auto-rickshaw etc)**
3)						
4)						
5)						
6)						

What is the approximate area of your house ? ..... square feet.

Do you own a	refrigerator	Yes ☐	No ☐
	television	Yes ☐	No ☐
	car	Yes ☐	No ☐

If you are employed, please indicate the locality and street in which your workplace is
.....

Is the organization you work for	In the public sector	☐
	In the private sector	☐
or are you	Self-employed	☐

Household Vehicle Details

In the table below, please provide information for all vehicles owned and used by members in your household who share the same kitchen. Please remember to include all vehicles owned and used by members of your household, whether motorized or non-motorized (including bicycles).

Vehicle Type, Manufacturer and Model	**Year purchased**	**Approx. purchase price**	**People in household who use it; highlight two-wheeler used the most with an asterisk**	**Approx. daily kilometres run**	**Monthly expenses**	
					Fuel + Oil	**Servicing**
1)						
2)						
3)						
4)						
5)						

Approximate total monthly expenditure on transport
for all members of your household who share the same
kitchen, including expenses on the
above vehicles used in your household .....

Your Daily Travel

In the table below, please provide information as requested about all the trips you made on the last full working day last week.

For vehicle(s) used, please specify -- scooter/motorcycle/moped DTC bus/charter bus/train/car/carpool/auto-rickshaw/cycle-rickshaw/taxi walk/bicycle/tempo-matador/government staff car/company car.
If you used more than one vehicle on a trip, indicate all vehicles used, and circle the vehicle by which the greatest portion of the trip was conducted.
For trip purposes, please specify – work/education/shopping/ social/recreation/religious/medical.

Trip origin and destination	Trip Purpose and Approx. Time of day	Vehicle used	Passenger or Driver	Total passengers/ luggage carried	Trip distance	Trip time

Similarly, please provide information as requested about all the trips you made on one day last weekend.

Trip origin and destination	Trip purpose and Approx. Time of day	Vehicle used	Passenger or Driver	Total passengers/ luggage carried	Trip distance	Trip time

Table Continued on next page

Trip origin and destination	**Trip Purpose and Approx. Time of day**	**Vehicle used**	**Passenger or Driver**	**Total passengers/ luggage carried**	**Trip distance**	**Trip time**

Motivations

Name the two most important reasons why you chose a motorized two-wheeler as your vehicle for traveling in the city .....

Please indicate the importance of the factors that influenced your choice of motorized two-wheeler as your vehicle for traveling in the city (as opposed to other vehicles):

1-- Very important 2 – Important 3 -- Of some importance
4 -- Of minor importance 5 -- Unimportant

	1	2	3	4	5
Ability to carry passengers and luggage	☐	☐	☐	☐	☐
Accessible 24 hours	☐	☐	☐	☐	☐
Door-to-door capability	☐	☐	☐	☐	☐
Increased personal income/affordability	☐	☐	☐	☐	☐
Minimizing journey time	☐	☐	☐	☐	☐
No alternatives available	☐	☐	☐	☐	☐
Not having to change vehicles	☐	☐	☐	☐	☐
Reliability, feeling confident you will get to destinations on time	☐	☐	☐	☐	☐
Status/prestige due to owning personal motor vehicle	☐	☐	☐	☐	☐
Other					

Please indicate the manufacturer and model of the motorized two-wheeler you use .....

Name the two most important reasons that influenced your (or your family's) decision to purchase the particular motorized two-wheeler referred to above

.....

Please rank the factors that influenced your (or your family's) decision to purchase the particular motorized two-wheeler referred to above:

1-- Very important 2 – Important 3 -- Of some importance
4 -- Of minor importance 5 -- Unimportant

	1	2	3	4	5
Affordability	☐	☐	☐	☐	☐
Appearance	☐	☐	☐	☐	☐
Attractive credit facilities	☐	☐	☐	☐	☐
Long life	☐	☐	☐	☐	☐
Low fuel consumption	☐	☐	☐	☐	☐
Passenger/luggage carrying capacity	☐	☐	☐	☐	☐
Performance (power, acceleration, ability to pull heavy loads easily)	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐
Trouble-free service	☐	☐	☐	☐	☐
Other					

What kind of engine does the two-wheeler you use have ?

Four-stroke ☐ Two-stroke ☐ Don't know ☐

When do you propose to dispose of the two-wheeler you currently use ? .....

When you dispose of your vehicle, which vehicle and model would you like to buy ? .....

Can you name any motorized two-wheelers currently being sold in India that have four-stroke engines ? .....

Perceptions of Bus Service In Delhi

Have you ever used a bus in Delhi ? Yes ☐ No ☐

What is your opinion of the quality of the bus service between your residence and your most common daily destination ?

Very good ☐ Good ☐ Fair ☐ Poor ☐ Very poor ☐
No basis for judgement, do not use buses enough to know ☐

How long would it take you to walk to the nearest bus stop from where you live ? ..... minutes.

From your most common daily travel destination ? ..... minutes.

How many times have you ridden in a bus in the last month ? ..... times

How many times did you ride in a bus in a month five years ago ? ..... times

Is bus service available between where you reside and your place of work ?
Yes ☐ No ☐

If so, and if you use a motorized two-wheeler to work, why ? .....

If so, and you take the bus rather than your motorized two-wheeler, why ? .....

What is the approximate journey time between your residence and your workplace:

By bus .....
By motorized two-wheeler .....

What would the bus fare be ? ..... rupees

What according to you are the main problems with bus service in Delhi ?
.....

Name the two most important improvements that you think ought to be made to bus service in Delhi that would make make you use it/use it more
.....

If you do not currently use a bus, would you do so if these and other improvements were made to the service ?
Yes ☐ No ☐

For which trip purposes ? .....

Please indicate the importance of following improvements to bus service in Delhi that would make it more attractive:

1-- Very important 2 – Important 3 -- Of some importance
4 -- Of minor importance 5 -- Unimportant

	1	2	3	4	5
Lower trip cost	☐	☐	☐	☐	☐
Less crowded buses	☐	☐	☐	☐	☐
Wider coverage	☐	☐	☐	☐	☐
More direct routes, fewer transfers	☐	☐	☐	☐	☐
Improved safety/security	☐	☐	☐	☐	☐
Lower journey times	☐	☐	☐	☐	☐
Improved reliability	☐	☐	☐	☐	☐
Higher service frequency	☐	☐	☐	☐	☐
Stops closer to home/destinations	☐	☐	☐	☐	☐
Other					

Even if bus service were improved dramatically, would you give up your motorized two-wheeler ?
Yes ☐ No ☐

Perceptions of Bicycle Commuting in Delhi

Have you ever cycled in Delhi ? Yes ☐ No ☐

What is your opinion of bicycle commuting in Delhi ?

Very good ☐ Good ☐ Fair ☐ Poor ☐ Very poor ☐
No basis for judgement, do not bicycle enough to know ☐

How many times have you cycled in the last month ? ..... times

How many times did you cycle in a month five years ago ? ..... times

What according to you are the main problems related to bicycle commuting in Delhi ?
.....

Name the two most important improvements that you think ought to be made to cycling in Delhi that would make make you use it/use it more
.....

If you do not currently use a bicycle, would you do so if these and other improvements were made to cycling facilities ?
Yes ☐ No ☐

For which trip purposes ? .....

Please indicate the importance of following improvements to cycling in Delhi that would make it more attractive:

1-- Very important 2 – Important 3 -- Of some importance
4 -- Of minor importance 5 -- Unimportant

	1	2	3	4	5
Reduction in time delays due to traffic	☐	☐	☐	☐	☐
More direct routes; fewer diversions	☐	☐	☐	☐	☐
Availability of dedicated bikelanes on roads/protection from traffic	☐	☐	☐	☐	☐
Improved security of bike storage	☐	☐	☐	☐	☐
Other					

Road Safety in Delhi

How many times have you been involved in a road accident ?
.....

Describe the most serious road accident in which you were involved:

When (approx. date and time of day)
.....

Where
.....

Vehicles involved (including your's)
.....

Damage/injuries sustained (including to yourself)
.....

How it was resolved
.....

The investigator administering this survey will pick up this questionnaire from you when you have finished, and will schedule a convenient time for a discussion. Many thanks for your co-operation and participation !

APPENDIX X M2W VEHICLE USER INTERVIEW PROTOCOL

Project -- Multiple Objective Evaluation of Public Policies to Address Motorized Two-wheeler Emissions in Delhi, India

Discussions with Motorized Two-wheeler Users

Thank you very much once again for your participation. I will raise a number of issues for discussion. Some of the issues I raise may seem to be a repetition of questions you have already answered in the survey. If so, please bear with me. I wish to make sure I have covered everything, and that I understand your views and motivations clearly. Please feel free to express your views, and do not be concerned about whether they are right or wrong. I am interested in everything you think about the issues I will be raising, and would like you to say everything you wish to express them.

VEHICLE OWNERSHIP AND MOTIVATIONS

1) What factors influenced your choice of a motorized two-wheeler ? What according to you are the main advantages of the motorized two-wheeler which influenced your using it (in comparison to other modes) ?

2) What mode(s) did you use before you purchased a motorized two-wheeler ? Have you stopped using them, now that you have a motorized two-wheeler ? What are the main drawbacks of those mode(s) ?

3) Are other modes accessible to you ? Buses ? Bicycles ? If so, but you do not use them, why not ? What according to you are the main disadvantages of these modes which prevent your using them ?

4) If you continue to use other mode(s), what purposes do you use them for and why, and for what purposes do you use your motorized two-wheeler, and why ?

5) What do you see as the main problems related to travel in Delhi, and how have these influenced your mode/model choice decisions ?

6) Would you say it is easier or more difficult now, compared to five years ago, to buy a motorized two-wheeler ? Why ?

7) What are the factors that determined your choice of residence location ? If you live far from your place of work, why do you do so ?

8) What factors influenced your choice of the particular model of motorized two-wheeler you use (as opposed to other models of motorized two-wheelers) ?

9) Was your present two-wheeler bought first-hand or second-hand ?

10) How many two-wheelers have you had before your current one ? For how many years did you use each of these before disposing of them, and how was each disposed of ?

11) If your two-wheeler has a four-stroke engine, why did you choose it ?

12) Do you know the differences between vehicles with a four-stroke and a two-stroke engine, in terms of their performance, fuel consumption, emissions and cost ?

13) Would you ever consider buying a motorcycle ? Please indicate the reasons for your answer.

VEHICLE OPERATION, MAINTENANCE AND DISPOSAL

14) How much do you spend on fuel and oil monthly for your two-wheeler ? Is this reflected in the amount shown under fuel in the questionnaire ?

15) How many kilometres per litre does your two-wheeler give ?

16) How frequently do you fill your fuel tank ? How much do you fill each time ? How much 2-T oil do you ask for along with the fuel ? Do you specify the 2-T oil to be used ? Or do you use your own 2-T oil ? If so, which one ?

17) What servicing do you have done regularly, and who does it ?

18) How many years do you expect to use your vehicle totally ? Under what circumstances will you dispose of your vehicle ?

19) When you dispose of your vehicle, what model and make will you buy and why ? What will you be looking for most of all in your replacement vehicle ?

20) If cost were no constraint, which vehicle and model would you get, and why ? Which two-wheeler model and make, and why ?

USER VIEWS REGARDING AIR QUALITY

21) What in your opinion are the two or three most serious problems relating to life in Delhi today ?

22) What do you think about urban air quality in Delhi ? What are its impacts on people ? What are its causes ? Who and what factors are responsible ?

23) Who should be responsible for improving urban air quality in Delhi ? What should they do? What should the role of government be ?

CURRENT MEASURES

24) Do you know what measures are being taken to improve urban air quality in Delhi ?

25) Do you think they will be effective ? Why or why not ? How have these measures affected you ?

POLICIES

26) How much do you think you could comfortably afford to spend on a new two-wheeler if you were buying one today ?

27) Given that motorized two-wheelers are a major contributor to air pollutant emissions from motor vehicular sources in Delhi; that air quality could be improved by more people using four-strokes or similar improved technology two-wheeler; and that two-wheelers with improved technology would likely be more expensive, how much would you be willing and able to pay for such a two-wheeler, over and above the amount you indicated in response to the previous question ?

28) How much would you be willing and able to pay for an improved technology two-wheeler over and above the amount you indicated in response to Question 18, if this improved technology two-wheeler gave 1.3-1.6 times improved fuel economy in addition to lowering emissions ?

29) What is the absolute maximum price that you would be willing and able to pay for a two-wheeler, if you were buying it today ? If the price of a two-wheeler exceeded this amount, what would you do ?

30) If government mandated that from say 2000, all new two-wheelers should be with improved technology, and these cost more than what you could afford, would you delay disposing of your existing vehicle ? Buy a second-hand two-stroke vehicle ? What if you have a moped ? How would paying this extra price affect your family's life ?

31) Improving fuel (and 2-T oil) quality is another way of reducing air pollutant emissions, but this will likely involve increased fuel cost. How much (either per month or per litre) would you be willing and able to spend on improved quality fuel and oil for your present two-wheeler over and above the current level, for improved air quality ?

32) How much would you be willing and able to spend on improved quality fuel (and oil) over and above the current level, on an improved technology two-wheeler, given that the fuel economy would be better by a factor of 1.3-1.6, and given also that such a two-wheeler would be more expensive ?

33) What is the maximum fuel plus oil cost (either per month or per litre) you think you could bear for your two-wheeler ? If fuel cost went up by more than this, how would your family's life be affected ?

34) Given that old vehicles generally tend to be more polluting than new vehicles: if government passed a law preventing vehicles older than a certain number of years from being driven in Delhi, what is the minimum service life that would be acceptable to you from your point of view ? At present, and with more expensive improved technology two-wheelers?

35) Please rank in order of acceptability (most acceptable, least acceptable etc.) the following policies: a) a government mandate requiring only improved technology two-wheelers to be manufactured, and assuming the cost of these two-wheelers is 40, 000 rupees b) a fuel plus oil cost increase (for improved quality fuel) of five rupees per litre, and c) a law preventing two-wheelers older than 10 years from being driven in Delhi ?

36) Based on our discussion, what kind of policies would you prefer, what would you be opposed to, and why ? (emission standards requiring more expensive vehicles, a ban on two-strokes, vehicle scrappage laws, higher fuel costs etc.)

37) What sort of incentives would make a) more expensive improved technology two-wheelers, b) more expensive improved quality fuel and oil, and c) a law preventing vehicles beyond a certain age from being used, more attractive to you ? When these are implemented singly, and jointly ?

38) From your point of view, what do you think ought to be the objectives for policies to control air pollution due to motorized two-wheelers in Delhi ?

39) How important is it for you and your family to have the use of the motorized two-wheeler? How would your life and that of your family be affected if you did not have or could not operate a motorized two-wheeler ?

40) Under what circumstances would you use buses/bicycles rather than your motorized two-wheeler, for which trips purposes, and why ? Under what circumstances would you give up your two-wheeler for all purposes in favour of buses/bicycles ?

41) Now that you have become used to your motorized two-wheeler, would you stay with it (or even get a car), as long as you could afford it, regardless of the improvements made to the bus service ? If fuel costs went up ? If congestion increased significantly ?

42) If vehicle operation and fuel costs increased, would it reduce your travel ? Under what circumstances would you use your motorized two-wheeler more ? (fuel cost, reduced congestion etc.)

43) If you were paying the same amount of money on fuel costs, but could travel twice as far, would you increase your commuting (for what purposes), or would you travel the same amount and save the money ?

44) Do you think transportation expenditure should be focused on increasing road capacity (to reduce congestion), or on increasing and improving public transit service ?

APPENDIX XI
M2W VEHICLE USER SURVEY SUPPLEMENTARY QUESTIONNAIRE

Project -- Multiple Objective Evaluation of Public Policies to Address Motorized Two-wheeler Emissions in Delhi, India

Supplementary Questionnaire (to be completed after finishing responding to the 9-page main questionnaire)

NOTE

Thank you very much once again for your participation. Some of the issues raised in this supplementary questionnaire may seem to be a repetition of questions you have already answered in the survey. If so, please bear with us. We wish to make sure we have covered everything, and that we understand your views and motivations clearly. Please feel free to express your views, and do not be concerned about whether they are right or wrong. We are interested in everything you think about the issues raised, and would like you to say everything you wish to express them. Please use the margins if necessary.

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VEHICLE OWNERSHIP, OPERATION, MAINTENANCE AND DISPOSAL

1) Please list all vehicle modes you use – two-wheeler, bus, auto, rickshaw, car, etc., and indicate the purposes you typically use each vehicle for.

2) What do you see as the main problems related to travel in Delhi, and how have these influenced your choice of vehicle modes and models ?

3) What are the factors that determined your choice of residence location ? If you live far from your place of work, why do you do so ?

4) Was your present two-wheeler bought first-hand or second-hand ? .....

5) How many kilometres has your present two-wheeler done to date ? .....

6) How many two-wheelers have you had before your present one ? For how many years did you use each of these before disposing of them, and how was each disposed of ?

7) If your two-wheeler has a four-stroke engine, why did you choose it ?

8) Would you ever consider buying a motorcycle ? Please indicate the reasons for your answer.

9) How many kilometres per litre does your present two-wheeler give ? .....

10) How frequently do you fill your fuel tank ? .....
How many litres do you fill each time ? .....
How much 2-T oil do you add to the fuel ? .....
In what form do you buy 2-T oil (loose, pouch etc.) ? .....

11) What servicing do you have done regularly, and who does it ?

12) How many years do you expect to use your present two-wheeler totally (from purchase to disposal) before you dispose of it ?

CURRENT MEASURES

13) Do you know what measures are being taken to improve urban air quality in Delhi ? Do you think they are effective ? Why or why not ? How have these measures affected you ? Please give an example.

POLICIES

14) How much do you think you could comfortably afford to spend on a new two-wheeler if you were buying one today ? Does this figure assume re-sale of your present two-wheeler? If so, what is the amount you think you would get for it ?

15) Given: that motorized two-wheelers are a major contributor to air pollutant emissions from motor vehicular sources in Delhi; that air quality could be improved by more people using four-strokes or similar improved technology two-wheeler; and that two-wheelers with improved technology would likely be more expensive, how much would you be willing and able to pay for such a two-wheeler, over and above the amount you indicated in response to Question 14 ?

16) How much would you be willing and able to pay for an improved technology two-wheeler over and above the amount you indicated in response to Question 14, if this improved technology two-wheeler gave 1.3-1.6 times improved fuel economy in addition to lowering emissions ?

17) What is the absolute maximum price that you would be willing and able to pay for a two-wheeler, if you were buying it today ? If the price of a two-wheeler exceeded this amount, what would you do ?

18) Improving fuel (and 2-T oil) quality is another way of reducing air pollutant emissions, but this will likely involve increased fuel cost. How much (either per month or per litre) would you be willing and able to spend on improved quality fuel and oil for your present two-wheeler over and above the current level, for improved air quality ?

19) How much would you be willing and able to spend on improved quality fuel (and oil) over and above the current level, on an improved technology two-wheeler, given that the fuel economy would be better by a factor of 1.3-1.6, and given also that such a two-wheeler would be more expensive ?

20) What is the maximum fuel plus oil cost (either per month or per litre) you think you could bear for your two-wheeler ?

21) Given that old vehicles generally tend to be more polluting than new vehicles: if government passed a law preventing vehicles older than a certain number of years from being driven in Delhi, what is the minimum service life that would be acceptable to you from your point of view ? At present, and with more expensive improved technology two-wheelers?

22) Please rank in order of acceptability (most acceptable, least acceptable etc.) the following policies: a) a government mandate requiring only improved technology two-wheelers to be manufactured, and assuming the cost of these two-wheelers is 40, 000 rupees b) a fuel plus oil cost increase (for improved quality fuel) of five rupees per litre, and c) a law preventing two-wheelers older than 10 years from being driven in Delhi ?

24) What sort of incentives would make a) more expensive improved technology two-wheelers, b) more expensive improved quality fuel and oil, and c) a law preventing vehicles beyond a certain age from being used, more attractive to you ? When these are implemented singly, and jointly ?

23) How important is it for you and your family to have the use of the motorized two-wheeler? How would your life and that of your family be affected if you did not have or could not operate a motorized two-wheeler ?

SPACE FOR ADDITIONAL COMMENTS