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Environmental policy-making in a difficult context: motorized two-wheeled vehicle emissions in India

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Abstract

Motor vehicle activity is growing rapidly in India and other less-industrialized countries in Asia. This growth is contributing to serious health and welfare effects due to vehicle emissions, and energy insecurity, acidification and climate change. This paper applies the problem-structuring tools of "value-focused thinking" to inform policy-making and implementation related to this complex problem in a difficult context, with specific reference to motorized two-wheeled vehicles, which play an important role in transport air pollution but also provide affordable mobility to millions with few other attractive options. The paper describes the process used to elicit and structure objectives and measures, based on interviews conducted by the author, and demonstrates how the objectives and measures can be used to more effectively characterize policy impacts, and create policy packages that have a better chance of long-term success.

Keywords: Transport air pollution; Policy-making and implementation; Multiple objectives

1. Transport air pollution in India

Global motor vehicle numbers and activity are growing rapidly. The OECD accounts for the bulk of global motor vehicle activity, but much of the growth will likely be concentrated in the less-industrialized countries (LICs), including in Asia. An important characteristic of motor vehicle activity in Asian LICs is the predominance of motorized two-wheeled (M2W) vehicles. Because of the concentration of motor vehicular and other energy-intensive activities in LIC megacities, air quality in these cities is poor. Further, because of the large populations of urban poor, who suffer from inadequate nutrition and limited medical care, significant health impacts ensue (Brandon and Ramankutty, 1993; Faiz et al., 1992; Romieu et al., 1991; Sathaye et al., 1994; Walsh, 1994; 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 around 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, around 2.6 million motor vehicles were registered in 1996. Of these, about 1.7 million were M2W vehicles. The motor vehicle fleet presently stands at around four millions. 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, 1995; ASRTU/CIRT, 1997; Mohan et al., 1997).

Air quality in Delhi has been poor since the late 1980s. Surveys in the mid-1990s showed daily average suspended particulate (SPM) levels, which are strongly correlated with respiratory and cardiovascular diseases, exceeding WHO limits almost daily, 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 exceeded WHO limits on several days annually, at several sites. Ozone appears to be a major problem, especially in winter. The contribution of transport to air pollution is growing in Delhi and other Indian and LIC cities. 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

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a passenger-kilometre basis. Though vehicle emission standards have been progressively tightened in the 1990s, and those relating to M2W vehicles for 2000 are one of the most stringent globally, many in-use M2W and other Indian motor vehicles pollute heavily (CPCB, 1996, 1997; CSE, 1996; MoST, 1996; Shah and Nagpal, 1997; WHO/UNEP, 1992).

Motor vehicle activity in Delhi and other LIC cities has important implications for road safety, land use, access and mobility, and other transport impacts, in addition to air pollution. This growth also has implications for energy security, acidification and climate change. While the OECD accounts for about two-thirds of global commercial energy consumption due to transport, its demand growth is expected to be flat or growing slowly. LIC transport energy demand, currently only around one-third that in the OECD, could increase 2–3 times in three decades (Brandon and Ramankutty, 1993; Grübler, 1994; 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 Indian and other Asian LIC cities, but they also provide mobility to millions who have few other attractive options. Thus, the public policy challenge in terms of emissions from M2W and other vehicles is to address the problem while minimizing adverse policy impacts for vehicle users. It is this challenge that provides the rationale for this paper, which aims to inform policy-making and implementation related to transport air pollution in India. While the paper focuses on India, it is hoped that it will be of relevance to other Asian LICs, since many of these countries share features such as rapid growth in motor vehicle activity, particularly in terms of M2W vehicles, and deteriorating air quality, with Indian cities.

2. The policy challenge

Environmental problems involve complexity, uncertainty, and technological, institutional and human factors that are often resistant to change. Further, environmental problems, and policies to address them, involve multiple stakeholders with multiple, conflicting interests and concerns, and a range of implications for the public and for future generations. Therefore, environmental problems call for hard policy decisions with high decision stakes, involving complex trade-offs (Funtowicz and Ravetz, 1993). This challenge is made more daunting in the case of transport air pollution by the fact that this problem is harder to control than stationary source emissions, because it is more complex in its causes and effects, and involves a variety of pollutants and motor vehicles (Faiz et al., 1992). Transport air pollution, and the effectiveness of prevention and control policies, are strongly influenced by the daily choices of millions of vehicle users, and by how users are affected by and respond to policies. Additionally, there is a large number of actors, such as vehicle and fuel manufacturers, and government agencies, with conflicting agendas. Finally, policies can have transport impacts other than those related to air pollution, and a range of cost and welfare impacts for different actors and groups. Effective policy-making and implementation would entail reconciling these diverse interests, concerns and trade-offs.

The transport air pollution problem is rendered even more difficult by the realities of the Indian context. The various agencies and actors face constrained resources for the provision and maintenance of clean vehicles, fuels and transport infrastructure, and for effective information generation and policy analysis, policy-making and implementation, and enforcement and monitoring. Actors' interactions have been characterized by lack of co-ordination and conflict. The institutional setting has not only exacerbated transport emissions, it has also hampered the ability to understand and address the problem effectively (Badami, 2001). Given the conflicting interests, concerns and agendas of various actors, and given that for each of them, taking action involves spending considerable amounts of money and effort, it is hardly surprising that their interactions are marked by conflict, and that they prefer policies that minimize implementation costs for themselves. Each of the principal actors has stressed the importance of action on those aspects of this multidimensional problem for which they are not responsible. Government and the state-owned fuel industry have stressed the need to tighten emission standards, improve vehicle technologies, and scrap aging vehicles. Meanwhile, the vehicle industry has stressed the need to improve fuel quality and traffic management, enforce vehicle scrappage, and implement effective inspection and maintenance (I&M) (AIAM, 1996a, b; CSE, 1996, 1997).

Long-term policy cost-effectiveness is important in any context, but particularly so in India. A significant proportion of vehicle users in Indian cities have low incomes. Further, transport air pollution and other transport impacts are by no means the only serious urban problems that demand attention in Delhi and other Indian cities. Finally, Indian cities are characterized by meagre resources for even current basic urban infrastructure needs. While there is a particular need for cost-effectiveness in this context, little attention has been paid to implementation issues or long-term consequences, and many policies, while conveying the illusion of action, have been costly and burdensome, yet not particularly effective.

Examples of such policies abound. Inspection of in-use emissions, which combines a decentralized test-repair system and no-load testing, is technically flawed, open to corruption, burdensome for users, who circumvent or subvert the testing process, and largely ineffective. Anil Agarwal (CSE, 1996) noted that the system was merely an attempt to shield government and industry from blame, and to shift the onus on to vehicle users. Old vehicles, including two-stroke M2W vehicles, have been proposed to be scrapped in a phased manner in Delhi (NCTD, 1997). Mandated vehicle scrappage would be popular with the vehicle industry. It remains to be seen, however, how effective implementation will be. There is likely to be strong vehicle user resistance, given the absence of viable alternatives. M2W vehicles are likely to be used for as long as 10–15 years or longer, and users expect to get a reasonable re-sale value when they do dispose of them (Badami, 2001; Bose, 1998).

The Supreme Court ordered, in July 1998, that all eight-year old buses in Delhi be converted to compressed natural gas (CNG) by April 2000. The indigenous bus manufacturers were unable to supply the required numbers of conversion kits in time. The Delhi Transport Corporation, the government-owned public transit provider, and the private parties who run the majority of Delhi's buses, are critically cash-strapped, and face severe constraints in replacing their fleets with new CNG vehicles (ASRTU/CIRT, 1997). As a result of pleas from various actors, the Court extended the deadline for implementation of its order several times. Over the last couple of years, millions of commuters have been stranded on several occasions, as buses in non-compliance have been forced to cease operating, and operators have gone on strike, to protest the costs of implementing the order, and difficulties such as the lack of widespread availability of CNG. Commuter frustration has led to riots (Agarwal, 2000; Badami, 2001; BBC, 2002; CSE, 2001). Apart from reliable fuel supply, technology reliability, performance, and serviceability remain important concerns.

These few examples hopefully convey a sense of the trade-offs and conflicts, differential policy impacts, and implementation issues that need to be considered for effective policy-making and implementation. Understanding these issues, and exploring collaborative approaches for integrating the multiplicity of interests and concerns, and reconciling trade-offs and conflicts in a manner that is sensitive to contextual realities, would be useful in designing policies that address the problem effectively and equitably. This is particularly important since, just as motor vehicle activity creates costs and benefits that are unevenly distributed between groups (including vehicle users and the vehicle and fuel industries), so can policies to address its impacts. Further, in addition to a significant proportion of M2W vehicle users having low incomes, many non-users are poor and enjoy none of the benefits of motor vehicles, while involuntarily bearing the brunt of their impacts.

Formal co-ordinating mechanisms are being developed, but there are no mechanisms for eliciting and integrating the concerns of vehicle users and the public in decision-making. Further, 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, particularly for affected groups with no influence over the decision-making process. Linkages between decision makers and the policy-analytic community are weak. Finally, the diversity of possible policy alternatives, and the wide range of policy impacts for different actors and affected groups, only serves to make a difficult enterprise even more difficult (Badami, 2001; Iyer and Balaraman, 1997; Kandlikar, 1998).

3. Value-focused thinking

One of the challenges of policy analysis is the reconciliation of multiple incommensurable values that invariably characterize public policy decisions. Conventionally, this challenge has been met by monetizing all values, and integrating them into a cost-benefit analysis (CBA); indeed, CBA has been suggested as an ideal analytical framework for policy evaluation (Carbajo, 1993). Environmental values, which are intangible and not traded on markets, have often been monetized by relying on contingent valuation (CV), in which large numbers of randomly selected individuals are asked to assume a hypothetical market for environmental quality and then to state how much they would be willing to pay to either secure an improvement (or to prevent a loss), or be willing to accept compensation to either forego an improvement or tolerate a loss (Pearce and Turner, 1990).

CV has been criticized for its various methodological difficulties: elicitation of a holistic response, in terms of willingness to pay (WTP), represents an unrealistic cognitive demand, given that environmental values are not represented numerically, and much less so in money terms, in people's minds; expressions of value are strongly influenced by the manner in which CV questions are ordered and framed, and the amount and nature of information that is provided; and CV elicitations force respondents to assess both facts as well as values (Gregory et al., 1993). Quite apart from these methodological difficulties, there are ethical problems involved in monetizing health, welfare and environmental values (O'Neill, 2001).

Value-focused thinking, based on multiple criteria or multiple-objectives decision approaches and in turn on multi-attribute utility theory, is an useful alternative for integrating diverse values. The purpose of policy analysis is to illuminate the complexity of public policy issues, help achieve objectives that reflect important public values, and provide a basis for defending and communicating decisions in public (Keeney, 1982, 1988a; Morgan and Henrion, 1990). In recognition of these requirements, and also given that public policy problems are characterized by a wide range of impacts for different groups, and multiple stakeholders with multiple conflicting objectives, value-focused thinking directly involves decision makers and other stakeholder groups to identify a broad range of societal values on which policy objectives should be based, and elicit trade-offs between those objectives. Further, recognizing that people's values are multi-dimensional, that they are typically constructed rather than merely reported, and that they are strongly affected by context—as opposed to CV, which assumes that monetary values for non-market goods exist in peoples' minds, and can be discovered and measured reliably and in a valid manner—value-focused thinking focuses on helping people reflect upon, articulate and structure values and value trade-offs. This careful thinking about fundamental policy objectives and trade-offs occurs early in the planning process, rather than basing decisions on already obvious alternatives, thereby turning decision problems into decision opportunities, and enabling selection of alternatives that better serve these values (Gregory et al., 1993; Hobbs and Horn, 1997; Keeney, 1982, 1988a, b, 1992; Keeney et al., 1990; Keeney and McDaniels, 1992; McDaniels, 1996).

Value-focused thinking consists first of all in interacting with affected and interested groups relevant to the decision situation, eliciting the value dimensions on which the various groups would like to see policy alternatives evaluated, and representing the values in the form of objectives, for each group separately. Values are clearly specified and structured, instead of merely listing them. Double counting is avoided by ensuring that fundamental objectives, which are important in and of themselves, and on the basis of which alternatives will be evaluated, are separated from means objectives, which are merely ways of achieving the fundamental objectives. Next, the fundamental objectives are clearly specified, so that alternatives can be compared in terms of all important consequences. In the case of the fundamental objective "minimize environmental impacts", for example, the precise environmental impacts to be minimized are elaborated. At the same time, it is ensured that objectives are mutually exclusive, again to avoid double counting. The multiple objectives are then structured into a hierarchy for each group, and integrated into a common objectives hierarchy for all groups. Next, measures or attributes are developed 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. Structuring objectives and developing measures is an intertwined process, in which clarifying objectives sharpens selection of measures, and thinking about measures helps clarify objectives. Finally, trade-offs between objectives are assessed from decision makers and other stakeholder groups, by having them assign weights to the objectives. The weights, which represent value judgments regarding the relative importance of the objectives, are combined with expert assessments or modelled estimates of the impacts of alternatives in terms of each of the objectives, to generate an overall multiple objective evaluation of alternatives from each group's perspective (Keeney, 1988b, 1992; Keeney et al., 1990).

Whereas in CBA, WTP a market price is the only measure of value and non-market values are monetized to integrate them with economic values, the multiple-objectives framework integrates multiple values by measuring economic values in monetary terms, and non-market values in terms appropriate to them, rather than in monetary proxies, recognizing that monetizing them may be difficult and inappropriate. Whereas CBA would involve asking WTP questions of large numbers of people, the multiple-objectives approach would involve detailed interviews with representatives of a handful of groups representing a wide range of views. Thus, the multiple-objectives framework would accommodate multi-dimensionality of values and substitute depth for the CBA's breadth. The multiple-objectives framework would accommodate trade-offs between objectives by, and allow alternatives to be evaluated from the perspective of, different groups. Thus, the vitally important equity issue would be able to be addressed explicitly. Instead of merely measuring preferences of individuals as consumers, in terms of WTP, it would be possible to determine objectives that they as citizens believe would be good for society. Whereas critical value judgments concerning (for example) the worth of a human life are made by analysts and may be hidden in CBA, values are directly obtained from stakeholders, and value judgments are made explicitly and are therefore open to scrutiny, in the multiple-objectives approach. Finally, directly involving actors and affected groups, and explicitly accounting for their diverse interests and concerns, can serve as an effective means of enhancing involvement, facilitating mutual learning and appreciation of problem complexity and trade-offs, identifying and resolving conflicts, and fostering compromise and consensus. Policy packages that represent a win–win condition for all can be developed, thus enhancing the chances of long-term policy success (Hobbs and Horn, 1997; Keeney, 1982, 1988a, b, 1992; Keeney and McDaniels, 1992; Keeney et al., 1990; McDaniels, 1996).

The tools of value-focused thinking have been applied to many policy situations in Western settings, and to a few cases in the LICs (Gregory and Keeney, 1994; McDaniels and Trousdale, 1999), but not, to the author's knowledge, to complex situations such as the present case, in the LIC context. This paper applies these tools to develop multiple objectives, and demonstrates their usefulness for informing policy-making and implementation related to M2W vehicle emissions, and more generally, transport air pollution, in India. The remainder of the paper describes the process used to elicit, clarify, structure and specify multiple objectives and measures, and shows how the objectives and measures can be used to systematically think about and characterize policy alternatives in terms of environmental, health and welfare, economic and other policy objectives representing the interests and concerns of various relevant actors and affected groups in society, in order to help reconcile conflicts and trade-offs, and develop attractive and effective policy packages.

4. Structuring objectives and measures related to M2W vehicle emissions in India

The multiple objectives and measures presented in this paper in relation to policies to prevent and control M2W vehicle emissions in India were developed based on in-depth interviews conducted by the author in that country in late 1997. These interviews were held with various individuals interested in 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 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 petroleum refiner and marketer in the country, and academics and researchers in environmental policy and urban transport.

The process of developing policy objectives and measures typically involves interacting with representatives of various groups separately, jointly, and iteratively, and can be time and resource intensive. The interviewees in the present case were geographically dispersed, and had busy schedules. The author was able to meet with each individual only once or twice. During these meetings, several issues relevant to M2W vehicle emissions were discussed, apart from policy objectives. Further, many of the interviewees felt uncomfortable when requested to suggest policy objectives and evaluation criteria on the spot. Nevertheless, the interviews were extremely useful in developing objectives and measures. 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, 1992) and Keeney et al. (1990) recommend for value elicitation. The discussions suggested various means objectives, which were used to develop fundamental objectives. The multiple objectives and measures were also based on insights gained from a questionnaire survey of, and in-depth interviews with, M2W vehicle users in Delhi. In the survey and interviews, the author elicited vehicle user perspectives on how they would be affected by and respond to various technological and regulatory policy alternatives, issues and trade-offs they would consider in making choices regarding vehicle technologies, measures that would make policy alternatives more attractive to them, and desirable characteristics of emissions prevention and control policies from their viewpoint.

Trade-offs representing relative priorities among objectives were not elicited from the various actors and affected groups. Neither were expert assessments of policy alternatives in terms of the measures developed. However, this paper discusses how the objectives and measures can help in systematically characterizing the policy impacts of and discriminating between a wide range of policy alternatives, as already indicated.

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, the M2W vehicle, fuel and vehicle servicing industries, and M2W vehicle users, and then integrated into the overall fundamental objectives hierarchy (Table 1). The objectives and measures were designed to accommodate a wide range of policies to address both the per-vehicle emissions as well as the vehicle activity components of the transport air pollution problem. Policies targeted at M2W vehicle emissions can have a wide range of impacts over the long term for various actors and affected groups. 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. 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 the major cities will inevitably have implications for vehicle users in other parts of the country. The objectives and measures were therefore designed to be capable of discriminating among policy alternatives broadly

Table 1
Objectives hierarchy and measures

Fundamental objectives	Measures
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 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	Annual system-wide implementation cost, INR (Indian rupees)
Government	
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	
Minimize loss of M2W vehicle characteristics due to policies	
Reliability	Annual fleet-wide M2W vehicle service disruptions
Vehicle performance	M2W vehicle acceleration (m/s/s) and top speed (km/h)
Service life	Number of years until major overhaul
Maintainability and serviceability	Annual fleet-wide visits to mechanics for non-routine M2W vehicle servicing
Passenger and luggage carrying capacity	Number of passengers and quantity of luggage, in kilograms, that can be carried, per trip
Re-sale value	Median M2W vehicle re-sale value, INR
Minimize injuries to M2W vehicle users due to policies	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	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	Number of trips foregone annually by users of non-motorized modes, and associated change in door-to-door travel time annually, in hours

Table 1 (*continued*)

Fundamental objectives	Measures
Land use	Number of hectares lost annually due to infrastructure to implement policy under consideration
Population Displacement	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

conceived, in terms of impacts that are just as broadly conceived.

Three points deserve mention, before proceeding to a discussion of the multiple objectives and measures. Although this work is based on interviews that were conducted in late 1997, the author believes that it remains at least as relevant for the effective resolution of transport air pollution in India as it was then. Motor vehicle activity grows apace in Delhi and other Indian cities. While significant improvements have been and continue to be made in terms of vehicle emission and fuel quality standards, many of the trade-offs, conflicts and concerns over equity discussed earlier remain, and are likely to intensify with time. So are the technological and institutional constraints discussed earlier. Some of these continuing inadequacies are borne out by the recent experience with CNG in Delhi, discussed earlier. The second point is that the order in which the objectives are presented implies nothing whatsoever about their relative importance. Finally, the purpose of this paper is not to review or discuss policy and technology options for mitigating M2W vehicle emissions. These policies, and policies to address transport air pollution generally, have been discussed elsewhere—for example in Faiz et al. (1992, 1996) and Carbajo (1993). Various policies are used as examples throughout the paper, to explain the rationale for the objectives and measures, and to demonstrate their usefulness for characterizing the impacts and trade-offs associated with, and sensitively discriminating between, different kinds of policies.

5. Discussion of objectives

The first objective in Table 1 specifies the local, regional and global health, welfare and environmental impacts of system-wide air pollutant emissions that policies should attempt to minimize. This objective reflects the need to consider the emissions of critical air pollutants from all transport system sources due to M2W *vehicle activity* rather than from merely vehicle exhaust, for each policy alternative. This is important because different policies would likely target different emission sources and pollutants. On pre-control vehicles, a significant proportion of vehicular volatile organic emissions occurs from sources other than the exhaust, such as the engine crankcase (Faiz et al., 1992; Hare et al., 1974), and this source can be controlled very cost effectively. Specifying the objective in this manner would allow such policies to be shown to be attractive. The objective would also account for emission increases or reductions that might occur in other modes, due, for example, to M2W vehicle trips being transferred to these modes as a result of certain policies targeted at M2W vehicle emissions. In this connection, note that policies such as fuel quality improvements would likely positively affect emissions from gasoline-powered modes other than M2W vehicles as well.

While the importance of accounting for the range of impacts specified in the objective will be self-evident, it is worth discussing the impacts due to acidification and ground-level ozone, because of their importance, but also to demonstrate the difficulties involved in dealing with such impacts. Crop damage is an impact of particular concern, given the large population and the marginal nutrition levels in the region. Even low ozone levels can seriously diminish crop yields, but ozone appears to affect tropical crops more severely than US and European ones (Faiz et al., 1992; Roy Chowdhury, 1997). The potential effect of this crop yield reduction for millions of already poorly fed people is serious. Thus, it would be necessary to consider the indirect health effects related to poor nutrition, which may occur as a result of crop damage, in addition to the respiratory, cardiovascular and carcinogenic effects commonly associated with air pollution. The health effects specified in Table 1 should be taken to include both of these sets of effects. One other point deserves to be made. The spatial extent over which emissions impacts are considered is important because emissions can spread, and produce impacts, well beyond the area where they are produced. Indeed, the worst affected people may be outside this area. For example, while ozone levels exceed WHO limits by up to 9% within Delhi, they typically do so by 20% outside (Faiz et al., 1992; Roy Chowdhury, 1997). The specification of "system-wide air pollutant emissions" is intended to account for emissions from all transport system sources, as already discussed, but also emissions spreading beyond the area in which they are produced.

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. Finally, considering emissions over the long term would help account for improved emission standards as old vehicles are scrapped, as well as travel activity growth, vehicle emissions performance deterioration, and growing congestion over time. After all, the overall policy objective is to minimize in-use emissions over the life of the vehicle fleet, under real-life conditions, rather than only new vehicle emissions, under conditions that are assumed to be friction-free. For this reason, emissions estimates must reflect in-use realities, such as maintenance quality, and I&M regimes. Considering emissions over the long term would also help account for vicious circles that typically manifest themselves over the long term. Infrastructure investment to relieve congestion, for example, would likely lower per-vehicle running emissions, but over time, as vehicle activity increased due to suppressed demand, congestion would likely revert to its original level, with increased emissions. Thus, this specification would help discriminate between technological-curative policies that tend to become neutralized over time, and demand-reduction policies.

The second objective reflects the desirability of minimizing the long-term costs of implementing policies. From the decision makers' perspective, the objective specifies the costs of the various kinds of institutional support needed for policy effectiveness. In the case of M2W and other vehicles, these tasks would include implementing an I&M regime, which, if it involved centralized, loaded dynamometer testing, a computerized system linking vehicle registrations and I&M, and institutional structures to oversee repair centres and penalize non-compliant users, would likely be expensive but also effective in terms of long-term emissions reductions. In this regard, it is worth pointing out that maintenance quality is particularly important for new and often complex technologies which are being introduced or are being contemplated in response to increasingly stringent emission standards. Such technologies tend to be prone to failure and are very sensitive to maintenance quality, particularly in the harsh operating conditions typifying M2W vehicle use in India.

In the case of fuel and oil, these tasks would include monitoring and enforcement related to adulteration, which has significant implications for transport energy consumption and emissions, and engine life. 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). For M2W vehicle and fuel and oil manufacturers, costs would include those related to emissions control technologies, dispensing stations to accommodate different grades and types of fuels and oils, evaporative controls on various components of the fuel distribution system, and refinery technologies, which, like some vehicle technologies, may have to be imported, at considerable cost. Vehicle servicing quality is just as crucial as maintenance for the long-term effectiveness of new technologies. Ensuring good maintenance and servicing quality in turn would call for training of service personnel and new equipment, 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 emission control technologies. Re-call and liability provisions currently do not exist, but if they were introduced and enforced, this would be a major concern for M2W vehicle manufacturers, particularly in the case of advanced technologies, given their cost, the harsh operating conditions and the poor quality of maintenance, and the sensitivity of these technologies, as already discussed. 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 to minimize the long-term costs of policies for them. Based on the perspectives elicited from vehicle users, the objective is specified in terms of costs related to vehicle purchase, fuel and oil consumption, maintenance and servicing, and I&M. In this connection, note that users would prefer that I&M testing be less frequent and burdensome.

The next three fundamental objectives, along with their sub-objectives, reflect key M2W vehicle user concerns other than the need to minimize long-term policy costs. The vehicle users interviewed said that they 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. The attractiveness of policies may be enhanced from their perspective, if in addition to the foregoing characteristics not being compromised, they offered benefits such as improved driveability and fuel economy. There is a potential trade-off here, since, according to the vehicle manufacturers, engines might become "very sensitive" as a result of increasingly stringent emission standards, and be prone to poor startability and driveability. Also, their view was that vehicle power could not be compromised, since M2W vehicles are used not only for personal transport but also to carry goods (AIAM, 1996b). These objectives would allow such trade-offs to be considered.

The next objective in the hierarchy reflects the likelihood of some policies imposing welfare costs for users, in terms of travel opportunities foregone, reduced travel comfort and convenience, and increased travel times, particularly among lower income groups. In this regard, consider the impacts of a policy such as fuel taxation that dramatically raises 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. Similarly, policies that transfer trips to less polluting modes, and restrict M2W vehicle ownership and usage, while desirable from the standpoint of emissions reductions, could involve inconvenience and loss of time for M2W vehicle users. This objective does not imply that such mode transfers be limited, or that efforts not be made to restrict M2W vehicle ownership and usage. Rather, it would suggest that viable alternatives such as enhanced public transit service be provided, to make up for the inconvenience and loss of time. By the same token, the objectives "minimize loss of M2W vehicle characteristics", and "minimize other transport system impacts", do not mean that deterioration with respect to the status quo is merely to be minimized. 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 and other policy impacts (for example, by effecting trip transfers to rail or express buses, to reduce door-to-door journey times).

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 Indian vehicle users to maintain their vehicles themselves. 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).

The next objective, "minimize other transport system impacts" reflects the fact that 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 transport system impacts are important to consider in the Indian context, given the multiple demands on scarce resources, and the desirability of emissions prevention and control policies to generate transport synergies as far as possible. In this regard, note that policies directed at transport emissions can generate impacts in sectors other than transport as well. For example, removing kerosene subsidies to prevent transport fuel adulteration will likely cause kerosene to become unaffordable for the large number of low-income households that use it as a cooking fuel, even in cities (TERI, 1997). Thus, in the absence of alternatives, removing kerosene subsidies may have socio-economic and environmental impacts (deforestation and indoor air pollution), as the poor are forced to spend more on fuel, or revert to firewood and other traditional fuels.

Loss of access and time delays for users of non-motorized modes, land use, and population displacement are specified as sub-objectives, because these would likely be important impacts of infrastructure policies such as highway capacity addition, to alleviate congestion, or mass rapid transit, to effect mode transfers. These impacts are important, given the large proportion of urban poor and non-motorized mode users, and the severe land shortages, in the Indian context. Another important transport system impact is energy consumption. Minimizing energy consumption is an important objective in itself, given the growing dependence on petroleum. Additionally, it is an important consideration in evaluating policies and 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", and is therefore not repeated here, in order to avoid double counting.

The next objective in the hierarchy, which relates to 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. 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 in this paper.

The last fundamental objective in Table 1 relates to equity and fairness in applying policies. Vehicle users expressed the view that policy attractiveness (and therefore effectiveness) may be enhanced by policies being applied uniformly and fairly to all. While the first sub-objective relates to equity between M2W vehicle users and users of other motorized modes, the second stresses the importance of policies not affecting users of one M2W vehicle type disproportionately compared to users of other types. The first sub-objective would account for the effects of congestion pricing, which could force 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). The second sub-objective is particularly relevant in the case of mopeds, which are small, low-power vehicles catering for low-income users, and for which the percentage increase in purchase price due to new technologies would be greater than for other M2W vehicle types.

Policies targeted at transport emissions in India have been motivated by rapidly deteriorating air quality in Delhi and other major cities. These policies might be unnecessarily stringent in other areas of the country, yet will have cost impacts for vehicle users in those areas. Note in this regard that the proportion of mopeds in the M2W vehicle fleet is far higher in the regional centres than in the major cities (AIAM, 1995). It is in light of this consideration that the objective relating to geographical equity is included. Applying this criterion might lead to flexible policies that are differentiated geographically and by M2W vehicle type, for example. Fuel and oil quality improvements could be (and in fact, have been) implemented nation-wide, with expensive vehicle technologies restricted to the major cities. Incidentally, this highlights the importance of the choice of a spatial system boundary for analysis, an issue that was discussed earlier.

6. Means-ends objectives network

Next, the various means objectives that need to be achieved to attain the fundamental objectives developed in the previous section with respect to policies targeted at M2W vehicle emissions, are presented in Fig. 1. Whereas fundamental objective hierarchies comprise objectives over which measures should be defined, means-ends objectives networks indicate how higher level objectives can be achieved, and are thus valuable in identifying the range of technological and institutional policy levers that need to be applied to successfully address public policy problems, and in thinking about the factors and relationships that need to be considered in developing models to relate alternatives to their

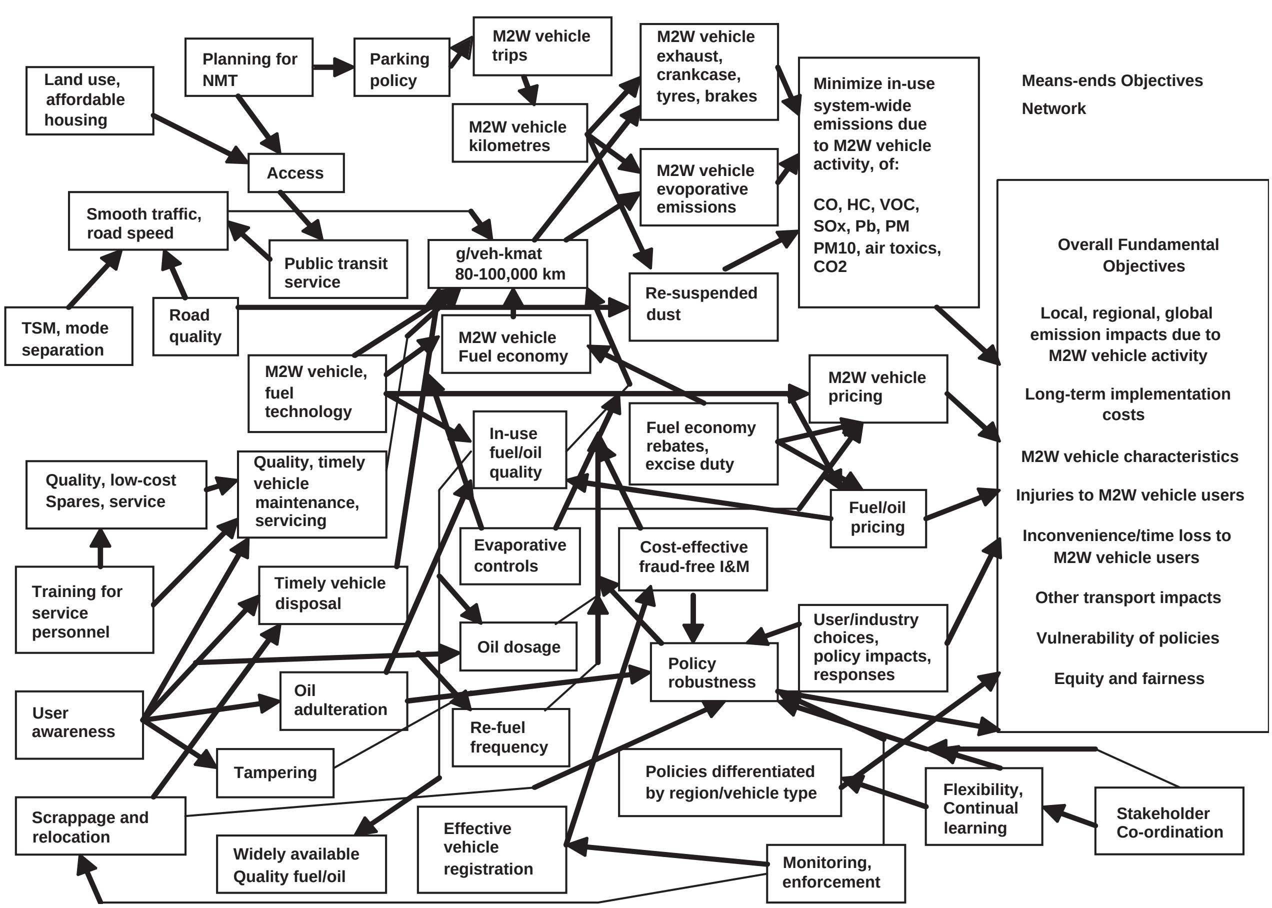

Fig. 1. Means-ends objectives network.

impacts (Keeney, 1992; Keeney and McDaniels, 1999). This is particularly so for complex and multi-dimensional problems such as transport air pollution. The means objectives in Fig. 1 are presented in the form of strategies rather than as specific policies and technologies. Some means objectives of lesser importance have been excluded, and the fundamental and means objectives have been condensed, to conserve space. The preference orientation and sub-objectives in the case of the fundamental objectives have been omitted, for the same reason.

First of all, Fig. 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, 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 are specified. In identifying the pollutants to be targeted, it is important to focus on critical pollutant components most closely associated with the impacts of concern. Also, it would be desirable to include pollutants not originally considered in the analysis that might be generated as a result of certain policies, such as in the case of policies that transfer M2W vehicle trips to other motorized modes. Thus, volatile organic compounds (VOCs) have been specified in addition to total hydrocarbons, 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. Although benzene in Indian gasoline has recently been controlled (BIS, 1995), it will still be emitted via evaporation and through the exhaust, particularly in engines without catalytic converters. The addition of MTBE (methyl tertiary butyl ether) to gasoline from 2000 (BIS, 1995) is likely to increase aldehyde emissions in vehicles without catalytic converters, thus aggravating the ozone problem (Humberto Bravo et al., 1991). It is for these reasons that air toxics such as benzene and aldehydes have been included. In this regard, note that many Indian vehicles will likely not be catalytically controlled, for sometime.

Next, the means-ends objectives network reflects the need to minimize in-use emissions system-wide due to M2W vehicle activity. It does so by specifying the various vehicle and transport system sources to be targeted. Both technological strategies targeting emissions from these sources, as well as preventive strategies targeting vehicle-trips and vehicle-kilometres, are included, along with various supporting infrastructural and institutional measures. In the case of M2W vehicle exhaust emissions, the need to control emission factors at 80–100,000 km is included, to ensure emissions reduction over the long term. In-use realities and implementation issues are reflected by including key user behavioural factors, 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, spare parts and vehicle servicing facilities, and training of service personnel, effective monitoring and enforcement, and fuel economy rebates.

Lastly, the means-ends objectives network 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 vehicle scrappage and relocation schemes (discussed in Section 8).

7. Measures

While fundamental objectives specify the important policy impacts to be considered, measures are necessary to evaluate, select and monitor policies. The measures to allow characterization of policy impacts in terms of the fundamental objectives are included in Table 1. These measures were developed based on careful consideration of the objectives elicited, and of the information gathering and policy analytic constraints in the Indian context. As Keeney (1992) points out, in addition to the desirability of measures precisely capturing the meaning of the related objectives, it is important that data necessary to operationalize them be easily obtainable, given available resources.

Some of the measures 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. But some comments are in order, with regard to specific measures. First, 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 for various policy alternatives, including the business-as-usual (BAU) scenario. Finally, the need to take a long-term perspective in policy analysis is accounted for by having the measures account for policy impacts annually, so that it would be possible to study how various policies perform on the multiple objectives over, say, a 10-year period.

Measures were not constructed for the emissions impacts specified under the first fundamental objective. This is because of the considerable difficulties involved in measuring and valuing, and in identifying the contribution of transport policies to, those impacts. These difficulties are particularly formidable in the Indian context, given its data collection and policy-analytic constraints. The measure proposed is an overall emissions impact which weights emissions of various pollutants specified in the means-ends objectives network, due to policies, 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 and for the specific geographic focus of the analysis. Weighting emissions of pollutants in a flexible manner, based on local conditions and needs, reflects the importance of continual learning, and flexible and adaptive policy-making. This approach would enable changes to such weightings as policy implementation progressed over time, and mid-course corrections to policies, to better ensure long-term 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 1 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. 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.

8. Applications

The multiple objectives developed in this study may be seen as defining the characteristics of the ideal policy. However, different policies would likely perform differently on the various multiple objectives, and no one policy is likely to be dominant on all objectives. The multiple-objective framework can therefore in fact help us think through the trade-offs posed by, and sensitively discriminate between, different policies. In order to show how the framework is useful for this purpose, I will now discuss how three different approaches for addressing M2W vehicle emissions—catalytic conversion, vehicle engine technologies, and fuel and oil quality improvements—would likely perform on the multiple objectives in Table 1.

As far as emission impacts are concerned, oxidation catalytic converters would significantly reduce CO and HC emissions in new vehicles, but these reductions might not be capable of being sustained over the long term (a key aspect of the first objective in Table 1), owing to the possibility of rapid decline in converter effectiveness or even damage resulting from, for example, lubricating oil deposition (especially on crankcase-scavenged two-strokes), malfunctioning spark ignition because of dirty operating conditions, and the heavy vibration characteristic of M2W vehicle operation. Even in Taiwan, arguably the country with the most experience with catalytic converters on M2W vehicles, an enhanced emissions durability requirement of only 20,000 km has come into force recently (Faiz et al., 1996). Catalytic converters would likely not affect fuel efficiency positively, and would therefore produce little or no CO_2 benefits. Benzene and other reactive hydrocarbon emissions are likely to be reduced, thus contributing to ground-level ozone mitigation, but sulphate PM emissions are likely to be increased, on account of the high (albeit reduced) sulphur levels in Indian gasoline.

For the vehicle and servicing industries, and relative to engine technologies, catalytic converters could potentially increase costs related to warranty, vehicle recalls and liability, if these were introduced, given the susceptibility of converters to fail in service, and to improved training and equipment for service personnel to detect and repair failures. Concomitantly, monitoring and enforcement costs are likely to be higher for government. In order to be effective over the long term, catalytic converters would likely be more dependent on quality of maintenance and servicing, I&M, and in-use fuel/oil quality, than engine technologies such as four-strokes, but perhaps no more than fuel injected M2W vehicles. From the point of view of vehicle users, percentage vehicle purchase price increase would not be as much as for four-strokes or other advanced engine technologies, compared with existing two-strokes. Percentage purchase price increase would be higher for mopeds than for other M2W vehicle types. While fuel and oil costs are likely to be only marginally affected, if at all, due to catalytic converters, maintenance and servicing, and I&M costs would likely increase, as would costs associated with periodic replacement of converters (even a 20,000 km life would likely mean replacement every 2–3 years). All of these costs are of course critically important from the vehicle user standpoint. Also, service life, and maintainability and serviceability, are likely to be negatively affected. Catalytic converters can run as hot as 500°C (Faiz et al., 1996), but because scooters have an enclosed body, safety and passenger capacity are not likely to be affected on scooters. However, both safety and passenger capacity could be adversely affected on motorcycles, and particularly on mopeds, because pillion riders on both types would be exposed to the converter. In terms of equity and fairness, moped and scooter users are likely to be the most and least adversely affected, respectively, due to the implementation of catalytic converters.

In terms of engine technologies, four-strokes would likely reduce HC and CO to a lesser extent than catalytic converters, compared to two-strokes, and PM would be practically eliminated, but NO_x could increase significantly. Benzene and other reactive hydrocarbons would likely not be controlled to the same extent as with catalytic converters. Unlike catalytic converters, however, fuel economy improvement (and CO_2 reduction) are likely to be of the order of 25–40%. Advanced two-strokes with timed fuel injection would deliver similar emissions, and comparable, if not better, fuel economy (Faiz et al., 1992, 1996; Iyer and Balaraman, 1997). However, crankcase HC emissions can be as high as 20% of exhaust HC emissions on four-stroke M2W vehicles (Hare et al., 1974), and must be considered, in view of the stress in the analytic framework on emissions from all sources system-wide. Even so, HC from exhaust as well as crankcase on four-strokes would be considerably lower than exhaust HC from two-strokes. Although HC and CO would likely not be controlled to the same extent as with catalytic converters, four-strokes and other engine technologies would likely sustain emissions reductions over considerably longer periods of time (a key aspect of the first objective in Table 1, as already discussed), compared to catalytic converters, given adequate maintenance.

For vehicle users, four-strokes and other advanced engine technologies would increase purchase price even more than catalytic converters would. The cost increase on mopeds would be considerably higher in percentage terms than on other M2W vehicle types. However, fuel and oil costs would be lower than on two-strokes because of the fuel economy improvement, thus offering the potential for a quick payback. Because of increased complexity, four-strokes and other vehicle technologies could increase maintenance and servicing costs, and adversely affect reliability, vehicle performance, service life, maintainability and serviceability. Four-strokes are typically larger for the same power output than two-strokes. They can be easily accommodated on motorcycles, which have no space constraint. Yet, scooters, rather than motorcycles, have tended to be preferred by users with families, and have formed the bulk of M2W vehicle production, because of their higher passenger and luggage carrying capacity. Accommodating four-strokes on mopeds would be more problematic than on scooters, because of even more severe space constraints. For industry, implementation costs are likely to be considerable, both because of technology development, but also because, on scooters, extensive and expensive design and tooling changes are required to accommodate four-strokes. Long-term effectiveness of advanced technologies such as fuel injection would depend strongly on reliable electronics, and maintenance and fuel/oil quality (Badami, 2001; Iyer and Balaraman, 1997). In terms of equity and fairness, the observation in the case of catalytic converters applies here also; moped users would be particularly affected by, for example, emission standards that would require four-stroke engines, because of the significantly higher proportional cost increase on mopeds than on other M2W vehicle types.

Fuel quality improvements would contribute to reductions in health effects due to lead, sulphur and benzene, all of which have either been eliminated or reduced (BIS, 1995; MoEF, 1997), and would indirectly contribute to greater reductions in HC, CO and NO_x in catalytically controlled vehicles, on account of reduction in sulphur levels, which strongly affect catalytic performance. Technologies such as low-dosage synthetic polyisobutylene base lubricating oils (which can halve lubrication oil required in two-stroke M2W vehicles and can be implemented on existing vehicles, and would therefore become effective straightaway) and line-mixing and oil injection, which provide improved oil control, have the potential to significantly reduce PM emissions from two-strokes. In addition to reducing PM, low-dosage oils would also help conserve oil, and slow the deterioration of catalytic converter performance on two-strokes (Faiz et al., 1996; Raje and Malhotra, 1997). Fuel and oil technology improvements might not be as effective as vehicle technologies in reducing per-vehicle emissions, but can, unlike the latter, start reducing emissions from all in-use vehicles (and the fuel distribution system), immediately upon introduction (Faiz et al., 1992, 1996), and can also be sustained over the long term. Further, fuel quality improvements would reduce evaporative emissions due to volatility control, from other vehicle sources, and indeed, other gasoline-powered vehicles and the fuel distribution system, thus contributing to ground-level ozone mitigation.

The costs of developing and implementing fuel and oil quality improvements, from the point of view of industry, would be high, but these costs could potentially be recovered more quickly than investments in vehicle technologies. For government, implementation costs would relate to controlling adulteration, but these would likely be no different than for existing fuels and oils. Indeed, technologies such as in-line-mixing and oil injection would reduce the possibility of oil adulteration, since oil would not need to be pre-mixed with fuel. Further, and importantly, fuel and oil quality improvements would not be susceptible, unlike vehicle technologies, to lack of quality maintenance and servicing, and monitoring and enforcement. Although fuel/oil improvements might increase operating costs for users, service life, maintainability and serviceability, and maintenance and servicing costs, all of which are important objectives from the vehicle user perspective, would likely be positively affected.

Finally, fuel and oil quality improvements would likely be more fair and equitable, for M2W vehicle users, and moped users particularly, compared to policies that required improved vehicle technologies. But fuel and oil quality improvements are not without problems. In vehicles without catalytic converters, which constitute the bulk of gasoline-powered vehicles in India, MTBE can cause increased reactive HCs, formaldehyde (a possible carcinogen), and NO_x, thus aggravating the ozone problem. While fuel volatility control would reduce evaporative emissions, low volatility levels in oxygenated gasoline (as in India) can increase exhaust VOCs, with implications for ground-level ozone, and impaired cold start and driveability, particularly at low temperatures on non-fuel injected vehicles (Faiz et al., 1992, 1996; Humberto Bravo et al., 1991), which will account for a large proportion of the fleet for a while. Finally, there is the possibility of polyisobutylene combustion increasing emissions of air toxics such as 1,3-butadiene (Faiz et al., 1996).

The multiple objectives can help think through the trade-offs posed by, and sensitively discriminate between, different policies, as discussed above; along with a consideration of vehicle user perspectives and contextual constraints, they can also help to develop creative solutions for mitigating policy impacts, and to design attractive policy packages and strategies that are likely to enhance the chance of long-term success.

As discussed, moped users would be particularly affected by policies that would, for example, require four-stroke engines, because of the significantly higher proportional cost increase on mopeds than on other M2W vehicle types. To mitigate such impacts, vehicle taxation based on efficiency rather than on engine size, as has been the case in India (AIAM, 1994), would allow manufacturers to offer (unavoidably larger) four-stroke engines on mopeds, without imposing an excessive price penalty on lower income users who own these vehicles. Further, 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 (Duleep, 1994). Also, life-cycle cost impacts due to the introduction of expensive advanced engine and vehicle technologies may be mitigated for low-income moped users, by means of policies differentiated geographically and by M2W vehicle type, as discussed under the means-ends network.

Given the complexity of new vehicle technologies and contextual realities, it would be important to design technologies to withstand poor maintenance, but also to ensure easy spare parts availability, low spare parts taxes, and training of vehicle servicing staff well in advance of introduction of new technologies. 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.

If mandated vehicle scrappage is ever contemplated, it would be desirable, recognizing the likely vehicle user resistance, that it be based on emissions performance, rather than on a fixed number of years, to serve as an incentive to quality maintenance, while preserving vehicle value, thus minimizing life-cycle costs. 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. This scheme would of course require an effective in-use emissions and sales monitoring and control regime. Offering credits to vehicle manufacturers would serve as an incentive to implement such a scheme. Improved performance and fuel economy on new vehicles would also encourage timely disposal and replacement.

Given contextual realities and constraints, it would of course be best to develop and implement 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. Fuel–oil quality improvements and low-dosage oils on two-strokes are examples of such policies. They would target critical and neglected factors such as evaporative emissions and excessive oil–fuel ratios, and would help minimize pollutants of concern such as particulates, volatile organics and air toxics. Finally, they would require minimum effort on the part of vehicle users, be insusceptible to the "free rider" problem, and produce fleet-wide results rapidly and cost effectively, all of which would enhance public acceptability.

9. Conclusions

The multiple objectives and measures presented in this paper, with reference to the transport air pollution problem in India, incorporate a wide range of environmental, health and welfare, and socio-economic impacts over the long term. Because the objectives and measures integrate these impacts, and other interests and concerns of a wide range of actors and affected groups, they may be considered to represent a broad, long-term societal perspective. In addition to illuminating the complexity of the problem, the objectives and measures can be used to systematically characterize the impacts of and discriminate between a range of policy alternatives, since different policies would perform differently in terms of the multiple objectives, as demonstrated in Section 8. The objectives and measures explicitly consider implementation issues and in-use realities. Robust policy packages may thus be developed that help mitigate policy impacts, resolve conflicts and trade-offs, and enhance the chances of effectively and equitably addressing the problem over the long term. Lastly, by explicitly considering the linkages between transport pollution and other transport impacts, the multiple objectives and measures would allow policies targeted at vehicle emissions to achieve transport synergies, which is of crucial importance, given resource constraints in the context.

The measures, which have been developed with the express purpose of making them operationalizable given contextual constraints, will enable data collection for evaluating policy alternatives, and help decision makers develop and implement effective policy monitoring programmes. The means-ends objectives network will aid in modelling emissions and other policy impacts, and 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, the objectives and measures presented in this paper are open to modification and refinement in the light of experience gained over time, to better measure policy impacts, and create better policy alternatives. It would be possible to monitor and modify regulatory, economic and demand-reduction policies, and to a lesser extent, policies involving improvements in fuel/oil and vehicle technologies, in order to respond to changing needs and circumstances.

The *process* of value-focused thinking, by directly involving and accounting for the interests and concerns of various actors and affected groups, can facilitate compromise among decision makers in government and industry and other actors, can help them work together to develop, implement and monitor effective policy alternatives, while minimizing adverse policy impacts for all, and finally, can provide a basis for better defending and communicating decisions in public. This is particularly important, given the nature of actors' interactions, the lack of institutional mechanisms to consider society-wide policy impacts, and the lack of public understanding of and support for policies.

The multiple objectives and measures discussed in this paper were developed with particular reference 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. Also, while the paper focuses on India, it is hoped that it will be of relevance to other Asian LICs, since many of these countries have similar urban transport characteristics, challenges, capabilities and constraints as does India.

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 paper has hopefully 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.

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References

Agarwal, A., 2000. Hammer of Thor. Posting on Sustran, an Electronic Sustainable Transport Discussion Group, 30 May 2000.

AIAM, 1994. The Automobile Industry—Statistical Profile 1994. Association of Indian Automobile Manufacturers, Mumbai.

AIAM, 1995. The Automobile Industry—Statistical Profile 1995 Update. Association of Indian Automotive Manufacturers, Mumbai.

AIAM, 1996a. AIAM perspectives on emission norms for the year 2000. Presentation to the Standing Committee on Emissions Legislation, Association of Indian Automobile Manufacturers, New Delhi, 10 June 1996.

AIAM, 1996b. Submission on the proposed 2000 norms to the standing committee on implementation of emission legislation. Association of Indian Automobile Manufacturers, New Delhi, 15 November 1996.

ASRTU/CIRT, 1997. State transport undertakings—profile and performance 1994–95 and 1995–96. Central Institute of Road Transport, Pune.

Badami, M.G., 2001. A multiple-objectives approach to address motorized two-wheeled vehicle emissions in Delhi, India. Unpublished Ph.D. Dissertation, The University of British Columbia, Vancouver.

BBC, 2002. Delhi's commuter agony. News Item on BBC web-site, British Broadcasting Corporation, London.

BIS, 1995. Motor Gasolines—Specification IS 2796: 1995, 2nd Revision. Bureau of Indian Standards, New Delhi.

Brandon, C., Ramankutty, R., 1993. Toward an environmental strategy for Asia. World Bank Discussion Paper No. 224, The World Bank, Washington, DC.

Bose, R.K., 1998. Automotive energy use and emissions control: a simulation model to analyze transport strategies for Indian metropolises. Energy Policy 26 (13), 1001–1016.

Carbajo, J.C., 1993. Regulations and economic incentives to reduce automotive air pollution. The Science of the Total Environment 134, 383–393.

CPCB, 1996. Ambient Air Quality—Status and Statistics (1993–1994). Central Pollution Control Board, New Delhi.

CPCB, 1997. Status and Options for Vehicular Pollution Control in Delhi. Central Pollution Control Board, New Delhi.

CSE, 1996. Slow Murder—the Deadly Story of Vehicular Pollution in India. Centre for Science and Environment, New Delhi.

CSE, 1997. Slow murder and since. Transcript of a Presentation by Anil Agarwal, Director, Centre for Science and Environment, New Delhi.

CSE, 2001. Special report on CNG in Delhi. Down to Earth 9 (23), 32.

Duleep, K.G., 1994. Reducing the energy and emissions impacts of personal transportation: simple first steps for India. Paper presented at the Workshop on the Energy Environment Nexus—Indian Issues and Global Impacts, Philadelphia, PA, 22–23 April 1994.

Faiz, A., Weaver, C., Sinha, K., Walsh, M., Carbajo, J., 1992. Air Pollution from Motor Vehicles: Issues and Options for Developing Countries. The World Bank, Washington, DC.

Faiz, A., Weaver, C.S., Walsh, M.P., Gautam, S., Chan, L.-M., 1996. Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions. The World Bank, Washington, DC.

Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25 (7), 739–755.

Gregory, R., Keeney, R.L., 1994. Creating policy alternatives using stakeholder values. Management Science 40 (8), 1035–1048.

Gregory, R., Lichtenstein, S., Slovic, P., 1993. Valuing environmental resources: a constructive approach. Journal of Risk Uncertainty 7, 177–197.

Grübler, A., 1994. The transportation sector: growing demand and emissions. In: Krishnan, R. (Ed.), Growing Numbers and Dwindling Resources. Tata Energy Research Institute, New Delhi.

Hare, C.T., Springer, K.J., Oliver, W.R., Houtman, W.H., Huls, T.A., 1974. Motorcycle Emissions, Their Impact, and Possible Control Techniques. SAE 740627, Society of Automotive Engineers, Warrenburg, PA.

Hau, T.D., 1992. Congestion charging mechanisms for roads: an evaluation of current practice. World Bank Policy Research Working Paper Series WPS 1071, The World Bank, Washington, DC.

Hobbs, B.F., Horn, G.T.F., 1997. Building public confidence in energy planning: a multimethod approach to demand-side planning at BC gas. Energy Policy 25 (3), 357–375.

Humberto Bravo, A., Ricardo Torres, J., Rodolfo Sosa, E., 1991. Motor vehicle pollution control in: Mexico City. Technical Paper No. 912426, Society of Automotive Engineers, Warrendale, PA.

Iyer, N.V., Balaraman, T.M., 1997. Personal communication, Bajaj Auto Limited, Pune.

Kandlikar, M., 1998. White paper on proposed issues for collaborative research focused on South Asia. Carnegie Mellon University, Department of Engineering and Public Policy, Pittsburgh.

Keeney, R.L., 1982. Decision analysis: an overview. Operations Research 30 (5), 803–838.

Keeney, R.L., 1988a. Value-focused thinking and the study of values. In: Bell, D., Raiffa, H., Tversky, A., (Eds.), Decision Making: Descriptive, Normative and Prescriptive Interactions. Harvard University Press, Cambridge, MA.

Keeney, R.L., 1988b. Structuring objectives for problems of public interest. Operations Research 34 (3), 396–405.

Keeney, R.L., 1992. Value-Focused Thinking. Boston, Harvard University Press.

Keeney, R.L., McDaniels, T.L., 1992. Value-focused thinking about strategic decisions at BC hydro. Interfaces 22 (6), 94–109.

Keeney, R.L., McDaniels, T.L., 1999. Identifying and structuring values to guide integrated resource planning at BC Gas. Operations Research 47 (5), 651–662.

Keeney, R.L., von Winterfeldt, D., Eppel, T., 1990. Eliciting public values for complex policy decisions. Management Science 36 (9), 1011–1030.

McDaniels, T.L., 1996. A multiattribute index for evaluating environmental impacts of electric utilities. Journal of Environmental Management 46, 57–66.

McDaniels, T., Trousdale, W., 1999. Value-focused thinking in a difficult context: planning tourism for Guimaras, Philippines. Interfaces 29 (4), 58–70.

Mohan, D., Tiwari, G., Saraf, R., Deshmukh, S.G., Kale, S.R., Wadhwa, S., Soumitri, G.V., 1997. Delhi on the move 2005: future traffic management scenarios. Report prepared for CPCB, Indian Institute of Technology, New Delhi.

Morgan, M.G., Henrion, M., 1990. Uncertainty: a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Press Syndicate of the University of Cambridge, Cambridge.

MoEF, 1997. White paper on pollution in Delhi with an action plan. Ministry of Environment and Forests, Government of India, New Delhi.

MoST, 1996. Notification of 1996 motor vehicle emission standards. Ministry of Surface Transport, Government of India, New Delhi.

NCTD, 1997. Instructions on vehicle scrappage. Department of Transport, Government of the National Capital Territory of Delhi, New Delhi.

Neale, A., 1995. How green are congestion charges? Economic instruments and sustainable transport. International Journal of Urban and Regional Research 19 (3), 447–455.

O'Neill, J., 2001. Markets and the environment: the solution is the problem. Economic and Political Weekly 36 (21), 1865–1873.

Pearce, D.W., Turner, R.K., 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf, Brighton.

Raje, N.R., Malhotra, R.K., 1997. Gasoline fuel and lubricants quality for cleaner environment. Paper presented at the Conference on Clean Air through Technology Advancement, Association of Indian Automobile Manufacturers, New Delhi, 7–8 March 1997.

Romieu, I., Weitzenfeld, H., Finkelman, J., 1991. Urban air pollution in Latin America and the Caribbean. Journal of the Air Waste Management Association 41 (9), 1166–1171.

Roy Chowdhury, A., 1997. Ozone: the other angle. Down to Earth, Centre for Science and Environment, New Delhi, 15 December 20–23.

Sathaye, J., Tyler, S., Goldman, N., 1994. Transportation, fuel use and air quality in Asian cities. Energy 19 (5), 573–586.

Shah, J.J., Nagpal, T., 1997. Urban air quality management strategy in Asia—greater Mumbai report. World Bank Technical Paper No. 381, The World Bank, Washington, DC.

TERI, 1997. TERI Energy Data Directory and Yearbook. Tata Energy Research Institute, New Delhi.

Walsh, M.P., 1994. Trends in automotive transport: implications for environmental protection, energy efficiency and sustainable development. Paper presented at the International Conference toward Clean Transport: Fuel Efficient and Clean Motor Vehicles, Mexico City, 28–30 March 1994.

WHO/UNEP, 1992. Urban Air Pollution in Megacities of the World. Blackwell Publishers, Oxford.