The Role of Transport Control Measures in Jointly Reducing Congestion and Air Pollution

By Jane V. Hall*

1. Introduction
Almost all urban regions in the US face the challenge of inducing substantial changes in current transport choices in order to meet the dual objectives of reducing congestion and improving air quality. As it has become clear that increasingly sophisticated emissions control technologies might not be sufficient to achieve air quality goals, interest in the potential of policies that could change how people use transport has increased. California now requires, for example, that measures to increase vehicle occupancy must be implemented in parts of the state that cannot otherwise achieve state air quality standards by 1997 (California Air Resources Board, 1994). The appeal of approaches that change the use of private passenger vehicles is enhanced by the apparent opportunity to kill two birds with one stone. Policies that would not be politically acceptable to meet a single objective might become possible if they are demonstrated to yield the joint benefits of reducing emissions and congestion.

One such class of policies is generally referred to as transport control measures (TCMs). This is a broad grouping of diverse alternatives that seeks to alter light-duty vehicle (LDV) use either by increasing the cost (in money or time), or by providing improved (lower cost, more convenient) alternatives.

Until the last decade or so, relatively little effort was made to evaluate rigorously how effective TCMs are in changing the choice of transport mode, or what the emissions consequences really are of such changes. The conventional wisdom can be summarised simply: reduced vehicle miles travelled and/or improved traffic flow means less congestion and cleaner air. Better understanding of actual behaviour coupled with new scientific and technical observations of how emissions really relate to patterns of vehicle use has challenged this conventional wisdom. It is now generally recognised that any impact on emissions is strongly dependent on what aspect of vehicle use is changed by TCMs. This includes reducing miles driven and number of trips made, but extends to driving speed, fleet composition and other variables. The three pollutants of most concern are hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx). How much a TCM might

* Department of Economics, California State University, Fullerton.
reduce emissions depends on the degree to which each aspect of vehicle operation is affected. The fundamental issue is whether TCMs can serve a purpose as part of effective control; the answer is a function of the interaction between the fuel/vehicle technology and human behaviour. This conjunction of technical and behavioural factors makes accurate assessment of how TCMs might affect emissions more complex than assessing their impact on congestion, where the behavioural factors alone determine effectiveness.

This paper will describe a set of commonly prescribed TCMs, discuss the emerging literature on actual (contrasted to modelled) vehicle emissions and the relationship to congestion, delineate the calculations and data necessary to quantify the expected gains from TCMs reliably, summarise some recent efforts to quantify the impact of TCMs, and discuss the emerging challenges in research and implementation.

2. Identification and Taxonomy of Transport Control Measures

Recent US federal legislation has intensified efforts to identify and evaluate TCMs that will effectively reduce emissions and improve traffic flow. Programmes to improve air quality are now explicitly linked to transport policies directed at reducing congestion or improving public transport.

The 1990 US Clean Air Act Amendments (CAA) explicitly require that states with severe or extreme ozone non-attainment regions include TCMs in their State Implementation Plans (SIPs) to ensure that growth in vehicle miles travelled (VMT) does not lead to increased emissions. The TCMs that are acceptable, a priori, for inclusion in a SIP are shown in Table 1.

From an economic point of view, the usefulness of any policy must be addressed in the context of what one is trying to accomplish. Accordingly, a simple taxonomy is presented here that places TCMs into three basic groupings: (a) those that provide alternatives to single occupancy vehicles (SOVs); (b) those that actively discourage LDV use; and (c) those that reduce the need for travel. The first group includes only measures that provide alternatives — a purely supply-side approach. The second group is aimed at demand variables. The third group could encourage supply or demand-based TCMs. The logic for this grouping is based primarily on one factor: whether a measure addresses both congestion and air quality effectively. A secondary consideration is whether a measure is supply or demand based. In any case, the effectiveness of any TCM in jointly reducing congestion and emissions will rest on the extent to which it reduces travel demand.1

The sixteen TCMs listed in Table 1 are categorised in Table 2, according to which of the three groups they fall into. Using the 1990 US CAA-specified measures as a representative set of TCMs demonstrates the difficulty in separating the objectives and mechanisms of any single TCM. In particular, this is the case for TCMs that are directed at improving fleet emissions by changing in-use operating conditions or altering the

---

1 For example, reducing congestion does not unambiguously reduce emissions, so load-shifting TCMs would not meet both needs. Reduced LDV use may improve air quality (if VMT and trips are both reduced, and the fleet mix is not adversely altered), but will only improve traffic flow if peak trips are reduced.
Table 1

Transport Control Measures Specified by the 1990 US Clean Air Act Amendments

1. Programmes to improve public transport.
2. Provision of reserved lanes or roads for high-occupancy vehicles (HOVs) and buses.
3. Trip reduction ordinances.
5. Improvements in traffic flow that reduce emissions.
6. Programmes to facilitate ridesharing/HOV use.
7. Provision of bicycle and pedestrian paths.
8. Parking facilities to support HOV and public transport use.
9. Restriction of roads or urban areas to pedestrian or non-motorised vehicle use.
10. Storage, restricted lanes and other bicycle facilities.
11. Employer-sponsored flexible work schedules.
12. Restrictions on vehicle use in areas of high emissions, especially during peak periods.
13. Programmes and ordinances to reduce event- and activity-related SOV trips, as part of local transport planning and development.
15. Programmes to reduce extended vehicle idling.
16. Programmes to reduce emissions from extreme cold-start conditions.

Table 2

Taxonomic Groupings of Transport Control Measures

<table>
<thead>
<tr>
<th>Discourage LDV Use</th>
<th>Alternatives to SOVs</th>
<th>Reduce Travel Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip Reduction Ordinances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employer-Based Transport Demand Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road or Area Restrictions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced Event-Related SOVs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved Public Transport</td>
<td>Employer-Based Transport</td>
<td></td>
</tr>
<tr>
<td>Reserved HOV/Bus Lanes</td>
<td>Demand Management</td>
<td></td>
</tr>
<tr>
<td>Ride-sharing Facilitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle/Pedestrian Paths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOV and Public Transport Parking</td>
<td>Bicycle Facilities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flexible Work Scheduling</td>
<td></td>
</tr>
</tbody>
</table>
composition of the fleet (for example, improving traffic flows, retiring pre-1980 LDVs, reducing extended idling, or reducing cold-start emissions); whereas it is not necessarily the case for those aimed at reducing travel demand or the use of LDVs or SOVs. The impact of the CAA-specified category of measures can, then, only be estimated if the multiple ways in which in-use behaviour is changed by TCMs is quantified, and not just by reductions in VMT or the number of trips.

3. Linking Travel Choice, Air Quality and Congestion
Calculating the effects of a TCM on congestion is a two-step process of using a travel model to determine travel choice and then predicting travel demand with respect to the variable of interest. Evaluating air quality changes adds the requirement of an emissions model to calculate how changes in travel behaviour predicted by a travel model will translate into quantities of emissions. The fact that assessment can be represented by two models should not be taken to mean that the process is simple, or even possible. The exposition of an idealised assessment, discussed in this section, is intended to indicate the extensiveness of data requirements, the degree of uncertainty with regard to behaviour and technology, and the importance of the interaction of behaviour and technology in determining the outcome. The next section briefly summarises recent quantitative estimates of the impacts of different TCMs on congestion and air pollution.

Behaviour
Various models are used to assess choice of travel mode and the degree of responsiveness this choice shows to variables such as time, monetary cost or availability of alternatives. From such models we know, for example, that “very significant” time savings — from 15 to 20 minutes — are required to shift solo drivers into carpools (Giuliano, 1992). Market-related TCMs, such as parking pricing, congestion (or peak travel) pricing and gasoline taxes, which increase the relative monetary cost of LDV use, have been shown to have the strongest influence on mode choice, traffic flow and fleet composition (Apogee, 1993). Air quality-based programmes generally do not provide authority to require this group of TCMs. The daily percentage change in VMT and the number of trips predicted to result from a variety of TCMs is shown in Table 3. Of the TCMs that have been extensively evaluated, parking pricing and gasoline taxes, market-based TCMs, have the greatest estimated potential impact on both VMT and number of trips, relative to any of the measures that might represent primarily time savings, such as HOVs or compressed work weeks (Loudon and Dagang, 1992).

Emissions Patterns
Knowing how a TCM will affect travel conditions includes predictions about the length and number of trips, and time of travel. These variables are critical to assessing congestion impacts. While they are necessary to quantify emissions impacts, however, they are not sufficient in themselves. Assessing the potential for emissions reductions from any TCM
Table 3  
Impact of Transport Patterns on Vehicle Miles Travelled (VMT) and Trips  
(percentage daily reductions)

<table>
<thead>
<tr>
<th>Transport Change</th>
<th>VMT</th>
<th>Number of Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOVs</td>
<td>0.23 - 1.40</td>
<td>0.50 - 0.57</td>
</tr>
<tr>
<td>Parking Pricing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>0.52 - 4.01</td>
<td>0.39 - 4.02</td>
</tr>
<tr>
<td>Non-work</td>
<td>3.10 - 4.20</td>
<td>3.90 - 5.40</td>
</tr>
<tr>
<td>Compressed Work Week</td>
<td>0.03 - 0.64</td>
<td>0.03 - 0.50</td>
</tr>
<tr>
<td>Telecommuting</td>
<td>3.40</td>
<td>2.80</td>
</tr>
<tr>
<td>Public Transport Improvements</td>
<td>0.03 - 2.57</td>
<td>0.58 - 2.46</td>
</tr>
</tbody>
</table>

Source: These estimates are derived from Apogee Research Inc. (1993). The ranges reflect such factors as the size of urban areas, peak and off-peak travel, and new versus expanded service.

requires that the travel model output be linked to the technical parameters and emissions characteristics of each mode, including flow characteristics (St. Denis et al., 1994). Therefore, we need to know how mode choice is affected and the air quality impacts of alternative modes. As more has become known about actual emissions during normal vehicle operating conditions (contrasted to assumed vehicle behaviour in commonly used emissions models) it is apparent that change in average speed is not a good surrogate for more detailed characterisation of the factors that represent vehicle operation over the entire interval of operation (JHK et al., 1992a, 1992b).

Generalised Models
Travel choice depends on preferences, the set of alternatives available, and the relative cost of each alternative. The first step in assessing how mode choice will change in response to TCMs is to determine the probability of choosing a given mode in a particular set of circumstances. This establishes a baseline pattern of travel choice, commonly estimated from a logit model incorporating observed data. The next step is estimating the elasticity of demand for a mode relative to some variable that can be changed by implementation of a TCM. For example, how responsive is carpooling to provision of HOV lanes that are predicted to reduce travel time by some amount? From this elasticity, the number of trips and VMT reduced by HOVs can be calculated for the relevant region. These changes then become inputs to emission factor models that predict emissions changes from assumed or observed associations between driving patterns and vehicle emissions.
The driving pattern typified by the US Federal Test Procedure (FTP) has historically been used to estimate the contribution of mobile sources to the overall emissions inventory. More recently, it has been used to translate changes in VMT and number of trips into emissions reductions. The FTP implies that reducing miles is the most critical factor in reducing on-road emissions, and reducing trips is critical to reducing cold start and hot soak emissions, traffic flow characteristics were not viewed as important. Increased scrutiny of cars in actual on-road operation suggests that the FTP significantly underestimates both the amount of time vehicles operate in high-emitting modes (St. Denis et al., 1994), and on-road emissions of newer cars (Lawson, 1993).

4. Available Empirical Evidence Linking TCMs, Congestion and Air Emissions

Over the past decade, many studies have increased our understanding of travel choice, shedding light on how effective TCMs might be in reducing congestion. Less attention has been paid, until recently, to estimating more precisely the air quality impacts of TCMs. This was because an essentially linear relationship between VMT and emissions was commonly assumed to exist, and because the widespread implementation of TCMs as explicit air quality policies is relatively recent.

Two recent studies estimate both the air quality and the congestion-related impacts of different sets of TCMs using data from two different regions of California. The results are summarised in Table 4. As is apparent from the Loudon and Dagang (1992) work, market-based TCMs result in substantial reductions in both VMT and emissions, relative to TCMs such as ride-sharing. A one dollar increase (or about 80 per cent) in the price of gasoline reduces both peak and off-peak trips, as well as VMT, by 4.5 per cent, whereas ride-sharing incentives reduce VMT by a quarter of this amount, at best. Increased parking fees reduce peak VMT by over 5.0 per cent, and non-peak by 3.0 per cent. Cameron (1994) shows an 11.0 per cent reduction in VMT for a five cent increase in cost per mile driven.

Vehicular emissions of HC and NOx are calculated by Loudon and Dagang to fall by about 2.0 per cent a day, and CO by 4.0 per cent, for a one dollar increase in the price of gasoline. These reductions exceed those for all other TCMs, by a factor of two in the case of NOx. Increased parking prices result in a reduction of about 1.0 per cent in HC and NOx. Cameron (1991) also reports that market-based incentives are twice as effective as all

---

2 The FTP was developed for new car emissions certification, not to represent on-road operating conditions. It is therefore not entirely surprising that it does a relatively poor job of representing emissions from actual in-use vehicles.

3 When a vehicle is started, the pollution control system, notably the catalyst, will not perform effectively until the temperature reaches a minimum threshold, hence "cold start" emissions. Residual heat from vehicle operation produces evaporative "hot soak" emissions from the fuel system.
The Role of Transport Control Measures in Reducing Congestion and Pollution

Table 4

Joint Impacts of TCMs on Travel and Emissions

<table>
<thead>
<tr>
<th>TCM</th>
<th>Change in VMT (%)</th>
<th>Change in Trips (%)</th>
<th>Change in Emissions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/gallon price increase&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.5</td>
<td>4.5</td>
<td>2% Hydrocarbons (HC) and Nitrogen Oxides (NO&lt;sub&gt;x&lt;/sub&gt;) 4% Carbon Monoxide (CO)</td>
</tr>
<tr>
<td>Parking price&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6 - 6.2</td>
<td>3.0 - 5.1</td>
<td>1% HC and NO&lt;sub&gt;x&lt;/sub&gt; 3% CO</td>
</tr>
<tr>
<td>Ride-sharing&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.4 - 1.0</td>
<td>0.5 - 0.8</td>
<td>&lt;0.5% HC, NO&lt;sub&gt;x&lt;/sub&gt;, CO</td>
</tr>
<tr>
<td>5 cent/mile cost increase&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11</td>
<td></td>
<td>Double the impact of non-market TCMs</td>
</tr>
</tbody>
</table>

<sup>a</sup> Source: Loudon and Dagang (1992). Tons per day were converted to percentage reductions based on San Francisco Bay Area emissions inventory data from Fairley and DeMandel (1992). The low end of a range indicates off-peak impacts and the high end indicates peak impacts.

<sup>b</sup> Source: Cameron (1994).

other TCMs in reducing pollution.) Cameron (1994) does not calculate emissions directly, but shows a 40 per cent reduction in the health costs of ozone and particulate-related emissions for a five cent increase in cost per mile. The air quality measures differ between these studies, however, so results cannot be directly compared.

Interestingly, the TCMs that generate the largest decreases in peak VMT and number of trips are not associated with the largest emissions reductions. This suggests the link between congestion and air quality is not as strong as has been assumed.

5. Fundamental Uncertainties

The effectiveness of TCMs in improving traffic flow and reducing emissions depends on very many behavioural and technical variables. The relationships between these variables must be realistically incorporated in the models that are used to predict how well TCMs will perform. At the same time, confidence in the ability of existing emission factor models to estimate emissions reliably has diminished. This link is now generally viewed as one of the weakest in the process of predicting the air quality impacts of vehicle use (Calvert et al., 1993).

Behaviour

The greatest uncertainty here is how inducing reductions in some trips has an impact on overall trip activity. From an economic perspective, the cost of travel falls when
congestion is relieved, inducing a countervailing increase in trips or VMT. Giuliano (1992) notes that this perverse result may be more common in heavily congested areas where latent travel demand is greatest.

Also, little is known about how vehicle choice is affected by TCMs. The majority of emissions are from "high emitters" (Calvert et al., 1993), therefore a key issue is how this subset of LDVs is affected by TCMs.

Emissions in Principle and in Practice
Average emissions depend on a complex array of variables not fully represented by predicted changes in VMT and number of trips. In-use emissions of HC and CO are now widely believed to average twice those predicted by emission models (Calvert et al., 1993). This substantial divergence between model prediction and direct observation results from many factors, some of which are summarised in Table 5. These factors represent the multiple dimensions of human behaviour, technology and the environment that jointly determine how effective any measure can be in reducing emissions. Consider that if traffic flow improves, one of two things may occur. Off-cycle events will increase, along with emissions. Conversely, latent demand will gradually reduce flow, simultaneously reducing off-cycle events, but increasing overall VMT and the number of trips. The difficulty lies in determining how travel behaviour changes, how this changes the fleet composition, and whether traffic flow actually improves (or latent demand uses the increased capacity).

Traffic flow variables are critical determinants of overall vehicular emissions. Improved flow does not unambiguously reduce emissions, because off-cycle HC and CO emissions may increase. Because the FTP does not capture these effects accurately, our present ability to estimate the impact of a TCM is significantly limited by lack of a verified emissions model. The major unknown is the degree to which a TCM will affect the occurrence of off-cycle events. Recent research suggests that the FTP overestimates the amount of time stationary and at low speeds, while underestimating acceleration and speeds from 40-50 and above 60 miles per hour. Further, off-cycle operation is more common in free-flowing urban traffic than when roads are congested (St. Denis et al., 1994).

Implications
The uncertainties discussed here work in two directions. As we learn more about in-use emissions, TCMs that do not reduce vehicle use or travel demand appear less effective than predicted by emission models based on the FTP. As gross HC and CO emission estimates are revised upward, however, the effectiveness of changing travel patterns to minimise off-cycle operations, related rich air-to-fuel ratio conditions, and cold starts increases.

---

4 Off-cycle (or open loop) events include periods when a vehicle operates under high load conditions at rich air-to-fuel ratios. Under these circumstances, which include acceleration while merging and increased engine load on grades, CO and HC emissions can be very high (Cadle et al., 1993).
Table 5

Emissions-Determining Variables

1. Age distribution of the fleet
2. Number of miles each age cohort is driven
3. Average emissions by cohort
4. Rate of decay of emissions controls
5. Extent of tampering
6. Effectiveness of inspection and maintenance
7. Ambient temperature
8. Driving speed
9. Frequency of open-loop (off-cycle) operation
10. Number of cold starts
11. Idling time
12. Fuel

Source: This list was compiled from multiple sources, notably Calvert et al. (1993) and St. Denis et al. (1994).

High Emitters
Recent data from roadside tests indicate that older cars contribute relatively little pollution, even if they are dirtier than newer cars, because they are driven less. Further, for virtually all model years, the dirtiest 20 per cent of cars contribute most of that model year’s HC and CO emissions. In fact, the mean of emissions falls within the dirtiest 10 per cent of vehicles in a model year (Lawson, 1993). These results suggest that emissions are severely skewed within the LDV population and that it is critically important that the cohort of vehicles affected by any TCM be correctly identified (Glazer, Klein and Lave, 1995; US General Accounting Office, 1993). Otherwise, there is no possibility of reliably quantifying emissions impacts.

Combined Effects
A single TCM is unlikely to meet desired goals for either congestion relief or emissions reductions. Combinations are commonly proposed and different jurisdictions may adopt diverse TCMs that jointly influence travel behaviour across a region. To assess the potential effectiveness of a TCM, it is therefore important to define carefully the baseline upon which it will operate. If we assume that the response to a new incentive takes place at the margin, the question is how an addition to public transport, or an increase in parking fees, or increased HOV access will impact travel choice. Looking at the average historical response to similar changes in the same location can lead to erroneous conclusions and overestimation of the marginal effects.
In the same way, sequential implementation of TCMs may not produce linearly additive results. Consider an employer who offers subsidies for public transport and support for telecommuting. Each employee must make a dichotomous choice, but a selection of public transport reduces the impact of telecommuting and vice versa (Loudon and Dagang, 1992). The net impact of each TCM is what must be estimated.

The Future Fleet
Many of the difficulties in calculating emissions changes from TCMs arise from the interaction of humans and current vehicle technology. We need to know, for example, not only whether VMT will be decreased, but how many cold starts will be averted by a TCM. This is important only because the current generation of catalytic converters is ineffective at low temperatures. The introduction of pre-heated catalysts will make the number of trips relatively less important.

Vehicles are expected to become inherently cleaner, with the introduction of low-emissions vehicles, improved durability of control systems, cleaner fuels, and an enhanced ability to identify and remedy high emitters.

As these changes occur, as cars become cleaner and the fleet gradually turns over, emissions reductions attributable to TCMs will diminish and congestion will be the dominant objective. This implies that TCMs that can produce shorter-term gains may be important for air quality, but will have limited long-run impacts.

6. Future Directions
The ability of TCMs to jointly reduce congestion and pollution rests on whether travel demand and SOV use are reduced without changing fleet composition and LDV operating conditions in ways that increase average emissions.

At present, we rely on the linkage between travel choice and emission factor models to estimate emissions changes, and on travel choice alone to assess improvements in traffic flow. These models appear to be more robust in predicting congestion improvements than evaluating emissions. Even with reliable estimates from travel choice models about changes in VMT, number of trips and even traffic flow, the emission factor model relies on the FTP which significantly under represents high-emissions operating conditions. Further, the travel choice models do not tell us how TCMs differentially influence use of high emitters.

There are many gaps in our knowledge of how human behaviour and technology interact to determine the impact of transport choices on congestion and the environment. For congestion, the key unknowns appear to be whether and to what extent a TCM reduces overall travel demand during periods when capacity is exceeded. This includes the question of whether latent demand will replace those who leave the road.

Emissions reductions are more complex. Perversely, TCMs that improve traffic flow can increase emissions in some circumstances. On-road emissions in driving cycles that more realistically represent the cohort of drivers and vehicles affected by a given TCM need to be more accurately estimated.
The uncertainties noted here indicate some key areas for further research. It would clearly be useful to know how on-road emissions will change with traffic flow changes induced by TCMs. This implies more in-use testing of larger samples of vehicles along with more quantitative assessment of how latent demand has an impact on net changes in capacity. Finally, because many TCMs are aimed at work-related travel, better disaggregation of travel choices is needed to determine how such TCMs affect overall travel demand.

References

Apogee Research Inc. (1993): Costs and Effectiveness of Transportation Control Measures (TCMs): A Review and Analysis of the Literature. For the Clean Air Project, National Association of Regional Councils.


Date of receipt of final manuscript: September 1994