A Transportation/Air Quality Research Agenda for the 1990's

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INTRODUCTION:

With the passage of the California Clean Air Act (CCAA) of 1988 and the Federal Clean Air Act (CAA) amendments of 1990, there is significant interest on the part of federal, state, and local agencies in research that will provide accurate methods to evaluate the emission reduction effectiveness of transportation strategies. The results of such research would be used to design projects and packages that would reduce transportation related emissions in the most cost-effective manner.

Determining what research projects should be undertaken in a resource constrained environment is a difficult task. Regulators must determine which research projects are likely to result in the most useful information, but they face this task without knowing specifically what current methodologies and assumptions result in the greatest estimation uncertainty. General difficulties in targeting the most effective research areas is coupled with the fact that emission inventory expertise incorporates two distinctly separate areas: knowledge of vehicle activity and vehicle emissions rates.

This report describes the state of uncertainty in different transportation and air quality issues, the importance of clarifying and resolving these issues, and the general areas of research and potential projects that may be proposed during Fiscal Years 1991-1996 to address these uncertainties. We consider this paper to be a starting point for discussion, from which a full research agenda is likely to be prepared.

This paper describes the emission inventory for motor vehicles and discusses the importance and relevance of the emission modeling methodologies to the ultimate research efforts. Five analytical sections follow: vehicle emission rates; vehicle activity; transportation control measure analysis; the relationship between land use, transportation, and air quality; and advanced highway technologies. A description of the policy concerns facing regulatory agencies is then addressed. Finally, conclusions are presented and short term recommendations are provided for consideration.

1 In this paper, uncertainty, means more than precision and accuracy. Many of the current methods are uncertain at the fundamental level, i.e. basic assumptions and relationships between variables in the models can be questioned.
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THE MOBILE SOURCE EMISSION INVENTORY:

Mobile source emissions are calculated by estimating vehicle activities, and coupling estimated vehicle activities with appropriate activity-specific emission rates under given operating conditions. The calculated emissions from all of the individual mobile source activities are then summed to determine the total mobile source emission inventory (CARB, 1986; CARB, 1988).

The current CARB mobile source emission inventory is developed by linking vehicle activity estimates to an emission rate model (EMFAC7B). The EMFAC model produces a computerized multi-dimensional matrix of activity-specific emission rates for specified environmental and operating conditions.

The same models and methods used to develop the emission inventory are currently used to estimate the emission reduction potential of proposed regulatory control strategies. However, current research has raised concerns regarding the ability of existing models to accurately predict the emission impacts of motor vehicles. Controlled field studies, such as tunnel monitoring, have indicated that the emission impact models used by the USEPA and the CARB may not accurately reflect the emissions from in-use vehicles (Ingalls, et al., 1989; Lawson, et al., 1990). The South Coast Air Quality Study results indicate that emissions of hydrocarbons and carbon monoxide may be seriously underestimated (Ingalls, et al., 1989).

Although the controlled field studies have not been able to identify the specific causes of underestimated emissions, a number of potential problems have been identified: underrepresented super-emitting vehicles in the emission models, underestimated evaporative emissions, sub-optimal effectiveness of inspection and maintenance programs, etc. However, existing modeling problems may be more fundamental in nature. Significant errors appear to be associated with the application of bulk emission inventory models to specific transportation corridor analysis.

Recent review of the uncertainty in the emission inventory for heavy-duty diesel powered trucks has raised a number of issues, many of which also appear to apply to the light duty vehicle fleet, with respect to uncertainty in assumptions, data, and modeling methodologies (Guensler, et al., 1991).

Emission Control Strategies:

Over the past ten years, public agencies have come to realize that control technologies for gasoline vehicles (e.g. tailpipe, electronic, and evaporative controls) were not enough to achieve continued emission reductions (due to growth in population and vehicle activity). With the adoption of new low emitting vehicle requirements (CARB, 1990a) and an updated mobile source control plan, California should be able to maintain current progress in providing absolute emission reductions from motor vehicles. However, with California's high population growth rate, transportation control strategies are still seen as necessary for attainment and maintenance of air quality standards in many urban areas.

Because the focus of mobile source emission reductions had historically been on control technologies, detailed and reliable transportation activity data were not really necessary in determining the percentage emission reductions that strategies would achieve. Because the focus of regulatory action had not been to change individual driver behavior, or emission rates under very specific operating conditions (such as acceleration), transportation emission inventory models were highly aggregated, estimating bulk vehicle activity parameters and average emission rates on a basin-wide basis.

Regulations are beginning to focus on the implementation of transportation demand management strategies, such as transportation control measures (TCMs) and economic incentives. Changes in vehicle activity must be modelable, and the changes in emission rates that result must be estimable. Regulators are concerned with corridor-specific emission reductions. To determine which measures will result in the most significant emission reductions, and how cost effective the measures will be, better analytical methods are now needed.

VEHICLE EMISSION RATES:

The accuracy of emission rate estimates directly impacts the calculated emission inventory. Because the emission inventory estimates serve as a baseline for emission reduction calculations, it is essential that uncertainty in emission rates be minimized. Plus, because the same methods are used in before and after studies, emission rate knowledge also directly
affects the reliability of calculated emission reduction potential of transportation control efforts.

Current Emission Factors:

The existing emission rates used in emission models, i.e., Mobile 4 (USEPA) and EMPACT-E (CARB), were derived through the testing of thousands of new and in-use light-duty vehicles. The testing is conducted on laboratory dynamometers, essentially a computerized treadmill upon which the vehicle can operate dynamically. The driver runs the vehicle through a specific operating cycle (starts, stops, accelerations, and constant-speed cruises) in a set procedural pattern. The bag samples of emission collected (partially in the cold engine mode, and partially in the warm stabilized mode) are analyzed to determine the average emission effects for the vehicles operating under the test parameters.

The standardized test procedures were originally developed for the certification of new vehicles, to provide an emission benchmark. The certification testing is generally viewed as equitable because all manufacturers are required to meet the same set of emission standards. By using the same test procedure for light-duty vehicles (used cars and trucks), relative deterioration of emission control systems can be examined. However, even though the procedures serve the purpose of new vehicle certification, the emission data provided is not directly related to on-road vehicle activities. Hence, the emission data collected is not directly applicable to transportation corridor analysis.

Vehicle speeds affect the emission rates of air contaminants on an average grams per mile basis. To determine the effects of speed on emission rates, emission data is gathered from test vehicles using a number of different test cycles (USEPA, 1988). Each of the test cycles employs a different profile of stops, starts, constant speed cruises, acceleration, and each has a different overall average speed. Speed correction factors currently in use in emission models are derived statistically (regression analysis) from the relationship between cycle emission rate (grams/mile from the aggregate bag sample of emissions and cycle distance) and average cycle speed. Thus, speed corrected emission rates used

in emission models are actually related to average cycle speed and not to constant cruise or instantaneous speed.

The application of average speed correction factors to actual operating speed in specific corridors, however, is likely to lead to significant errors. The main concerns about using the current correction factors are: 1) the average speed for each cycle do not reflect the varied profiles of idling, acceleration, and constant speed cruises; 2) the speed correction factors are based upon cycles that ignore high speeds and high acceleration rates, 3) a regression analysis on the existing grams/mile data may tend to unrealistically force a statistical fit at high and low speeds (Seitz, 1989 and 1991), and 4) the average speed emission data used in the regression analysis may be correlated to test cycle acceleration activity (Guensler, et al., 1991). The extent to which these problems result in emission estimation errors is currently being investigated. Regardless of which problems create the most significant analytical error, new corridor modeling methodologies that do not rely on speed correction factors are needed.

From a public policy perspective, because much of the VMT is traveled at high speeds, the highly non-linear nature of the grams per mile emission rates may "make analysts worry excessively about low travel speeds (Seitz, 1991)." In examining VMT related emissions, the focus should logically be upon total emissions (in this case VMT times the emission rate of the average operating speed). Thus, if traffic is moving slowly (with higher emission rates), it should not be a high priority unless significant VMT is associated with the low speed.

Acceleration is believed to play a very important role in incremental emissions from vehicle operation (Groblicki, 1990; Kunselman, et al., 1974; CARB, 1991a). Acceleration rates vary widely from driver to driver and situation to situation, resulting in potentially higher or lower emissions than might be noted in the laboratory under a test cycle. Thus, the uncertainty in applying average dynamometer test results to areas with acceleration activity may be high. Comparison of chassis dynamometer results to street results (as affected by friction, grade, load, wind, etc.) will be an important component of emission factor quality assurance, perhaps through the use of instrumented on-road vehicles.

The highly aggregated nature of the emission rates for motor vehicles raises significant uncertainty questions in the evaluation of mobile source emissions. For example, remote sensing tests of on-road vehicles indicate that a relatively

8 "However, due to constraints imposed by vehicle procurement and laboratory testing procedures, unsafe vehicles, tampered vehicles, and vehicles over 5 to 7 years of age are excluded from the sampling and testing process (Horse, 1991)."

9 Even though commercial vehicles are a significant component of the emission inventory, the uncertainty in the estimates for the heavy-duty truck component is not discussed. Uncertainty in the heavy-duty truck emission inventory is discussed in detail in Guensler, et al., 1991.

10 These emission rates change, but total emissions for a given trip distance are a function of travel time for most speeds. However, changes in vehicle operating efficiency, control equipment efficiency, and temperature as a function of speed may have some impact.

11 In MOBILE4, the EPA now bases speed correction factors upon grams/hour data, using a first order regression fit (USEPA, 1988; Seitz, 1991). The CARB performs their regression analysis upon grams/mile data, using a fifth order regression fit.
small percentage of vehicles on the road ("high emitters" or "super emitters") may be responsible for a large percentage of the measured emissions (Lawson et al., 1990). Thus, highly aggregated emission inventory models, even when based upon extensive data, may tend to underestimate the variance of on-road vehicle emission rates. This may be critical, because grams/mile emission rates associated with operating speed and acceleration rate are non-linear. Increased monitoring of emissions and emission related vehicle activities in specific corridors may be explored during the next decade. Portable sensors can be used to monitor pollutant concentrations, and remote sensors can be used to examine concentrations of individual vehicle exhaust (Lawson et al., 1990).

Over the short term, to resolve some of the existing uncertainty in emission rates used to prepare the emission inventory, the CARB will be developing new in-use vehicle dynamometer cycles that are more representative of actual California driving conditions (CARB, 1991b). The new cycles will include high speed operations and acceleration profiles that are more typical of California highway and local road traffic. Thus, the emission inventory generated from bulk activity estimates is likely to be greatly improved. However, much of the same aggregation bias and uncertainty in application to individual corridor specific emission impact analysis will still remain.

As a long term solution, the CARB has begun the study of real-time emissions (CARB, 1991b; Lovelace, 1991). The new procedures, known as modal emissions monitoring, would allow second-by-second pollutant emission readouts from vehicles as they proceed through various testing modes on the dynamometer. Using new equipment and procedures, the CARB hopes to establish emission rates for specific vehicle activities, such as constant-speed cruises, idling, and specific acceleration rates (e.g. to represent on ramp acceleration or stop-and-go traffic conditions). Furthermore, if modal fuel consumption models are developed concurrently, the impacts of TCMs and infrastructure changes on greenhouse gas emissions can also be better modeled. 12

With new modal emission rate data available for all vehicle classes, it is very likely that the emission inventory for mobile sources could be further disaggregated (to a much greater extent than is currently possible). Rather than providing emission rates for average cycle speeds, emission rates would be provided for distinct modal operations. In addition, emission factors could be disaggregated to a greater extent (e.g. heavy-duty trucks by size and weight). With a modal emissions model, corridor specific analysis of transportation control measure effects could be undertaken. Plus, coupling modal emission rates with mode-specific vehicle activity would significantly improve the accuracy of the overall emission inventory.

The general problem that is encountered in modal modeling, however, is that research is difficult, time consuming, and expensive. Furthermore, detailed modal models are likely to be computer intensive. The current dynameters used to certify new light-duty vehicles may not be capable of replicating the high acceleration rates and speeds that are critical from an emissions standpoint (Sussnitz, 1991). Thus, the improvements in the emission inventory from modal modeling work are likely to be long term as new equipment and techniques are employed.

Other Aspects of Emission Rates:

The CARB is continuing research on emission control technologies. New catalyst equipment will be evaluated, as well as enhanced combustion controls, and NOx reduction technologies. The focus of the research efforts will be the identification of measures to reduce and maintain vehicle emissions within the low emission vehicle standards (CARB, 1990a; CARB, 1990b; CARB, 1990c).

With respect to fuel specifications, research will continue on volatility and aromatic specification issues. The importance of researching fuel composition effects on pollutant emissions has been illustrated by the preliminary results of the Auto/Oil Air Quality Improvement Research Program. The results appear to indicate that certification fuel appears to be much less polluting than the average fuel currently purchased by the public (Coordinating Research Council, 1990). However, because the in-use vehicles that are tested as a basis for the emission rates in EMFAC use the "as is" fuel (the marketplace fuel already in the vehicle), this issue is unlikely to play an important role in current emission factor uncertainty (Lovelace, 1991).

Because the actual components of fuel and exhaust play different roles in the formation of ozone, fuels composition is an important input to grid-based photochemical models. Research into the composition of vehicle exhaust (i.e. specification) for each fuel type, will be a high priority.

With more stringent vehicle certification standards beginning in 1994, and federal mandates for alternative fuels, alternative fueled vehicles are expected to capture a
significant market share over the long term. Research into the modal emission rates from these alternatives fueled vehicles will be very important in the evaluation of which fuels are better for air quality. Changes in vehicle emission rates over the entire lifespan under given operating conditions may be critical. Hence, determining representative lifespans for all vehicle classes as a function of fuel type is important. In-use life cycle testing will likely be conducted to ensure that vehicles such as methanol fueled vehicles, do not result in increased emission under certain operating conditions over the lifespan of the vehicle.

Remote Sensing:

In 1989 and 1990, remote sensors were used in the field to identify "super-emitting" vehicles, or vehicles that have unusually high emission rates for their model year and type. Vehicles may experience unusually pronounced emission effects when the control systems are defective or tampered with, or when the engines are malmaintained. Super emitting vehicles are suspected of being responsible for a large percentage of the emission rates from on-road vehicles. Hence, the use of field equipment to identify super emitting vehicles for possible laboratory testing and control system maintenance will be high on the research agenda. Remote sensing is also likely to yield a more representative sample of high emitting vehicles for modeling purposes than will random roadside inspection programs (Horie, 1991). Remote sensors could also be used to evaluate the emission mitigating effects of ramp metering and intersection signalization.

VEHICLE ACTIVITY:

Vehicle activity parameters that affect emission rates include numerous complex contributing factors, such as: vehicle miles traveled, actual travel speed, engine starts, cold/hot start distribution, engine shut-downs (hot soak evaporation), refueling requirements, vehicle idling, acceleration, intersection activity (stop-and-go), heavy congestion, accident occurrence, and vehicle load. Even the existence of a vehicle, driven or not, contributes to the emission inventory through fuel tank evaporative losses. Thus, to accurately estimate emissions, emission-related vehicle activities must be modeled as well as the modal emission rates.

Current Emission Inventory Methods:

Aggregate vehicle activity data currently used in the emission inventory process are essentially estimates of total VMT, average speed distributions, number of trips, hot/cold start distribution, and fleet year (to calculate accumulated mileage distributions). These data are then coupled with aggregated emission rate data for calculation of total basin-wide emissions using the CARB’s BURDEN model.

The most detailed vehicle activity data currently used in emission inventory and modeling work are outputs from Urban Transportation Planning System (UTPS) type models. In the South Coast Air Basin, vehicle activity data are estimated using a trip generation and network model. UTPS-type models are generally described by a four step process: 1) estimating trip production and attraction within small geographic zones, based upon land use and socioeconomic data; 2) assigning the generated trips from zone to zone, based upon gravity-type models; 3) assigning zone-zonal trips to specific travel modes, based upon discrete choice analysis using socioeconomic and transport characteristic data (e.g. regression, logit, or probit analysis); and 4) assigning the vehicle trips to specific links on a network model, using flow and capacity characteristics and an iterative delay minimization process. The network data on VMT, starts, etc., are then coupled to EMFAC emission factors in the Caltrans DTIM program.

In the Los Angeles and San Diego areas, current vehicle activity estimates for emission modeling are based upon trip-generation and network models (Lovelace, 1991). However, in the remainder of the state, activity estimates are based upon a Caltrans aggregate fuel consumption model (Caltrans, 1979). The accuracy of fuel consumption models is questionable (Guenther, et al., 1991). Plus, the model output (aggregated VMT) is only one minor component of the information necessary to estimate emissions, and is not very useful for estimating emission changes from future transportation control strategies. It is important that we improve the accuracy of transportation demand models for estimating emission related activities. When models are improved, better disaggregation of emission inventories can occur.

14 Recent studies indicate that methanol buses may increase emissions at low average speeds, and reduce emissions at high average speeds, when compared to diesel. Results from model emission rate studies may indicate whether the use of methanol fuel in buses and/or automobiles should be discouraged on heavily congested routes (Santini, 1991).
15 The new CALIMFAC model, which incorporates an Inspection and Maintenance benefit model, is not addressed in this paper. However, additional uncertainty related to I/M benefits in this model might also be analyzed (Horie, 1991).
16 Basinwide emissions are usually aggregated from county estimates.
17 Transportation models do not provide speed distributions. Also, seasonal variations in travel are not accounted for in many models.
18 The San Francisco Bay Area, Sacramento County, Fresno County, and San Joaquin Valley network models (UTPS or MINUTP models) will be used for emission modeling procedures in the near future (Seitz, 1991). These types of network transportation models will play very significant roles in the emerging transportation and air quality planning process.
Activity Modeling Concerns:

The importance of improving vehicle activity models for air quality analysis cannot be overemphasized. Because motor vehicle emission control strategies are now being designed to affect trip making behavior, vehicle activity models must be able to predict the changes that will occur. In actuality, all of the modeling efforts on the emission rate side of the emission calculation equation will be useless, unless changes in trip making behavior can be reliably predicted.

One of the major concerns surrounding the use of existing vehicle activity models is the verification of estimated parameters. Vehicle activity models rely upon speculative and socioeconomic relationships and aggregated data, and must be calibrated through the use of surrogate indicators. Unlike models whose outputs can be compared with "real-life" values (e.g. estimated pollutant concentrations from dispersion models can be compared to measured concentrations), trip generation and VMT estimates can only be compared to on-road traffic counts. The uncertainty encountered in determining the true relationship between number of vehicles counted at each location and number of trips or total local road and highway vehicle miles traveled in the corridor. Hence, there is currently no "reality-check" to ensure that the modeled outputs are representative of the activity they are designed to estimate.

Many transportation agencies are installing computerized systems capable of monitoring traffic speeds and flow for the purposes of altering signal and ramp meter timing. Monitoring actual changes in vehicle activity over time, in response to population or vehicle ownership growth, or in response to the implementation of a control strategy, will provide substantial information that may be used to better calibrate vehicle activity models and refine transportation control strategies.

Connectivity of Emission Rates and Vehicle Activity:

The important factor affecting the use of vehicle activity estimates is "connectivity," or the ability to link activities to their corresponding activity-specific emission rates. If data from the new modal emission testing laboratory are to be of any use, modal vehicle activity parameters must be modeled and/or monitored. If VMT cannot be disaggregated into cruise speed profiles, or if acceleration activity cannot be quantified, new modal emission factors for motor vehicles will serve little useful purpose. Hence, research into quantifying appropriate vehicle activity parameters that can be linked to modal models is likely to become an important research focus. Research that can result in changing the specific activity outputs of activity models so that they can be combined with appropriate emission factors is also an important consideration. Thus, major changes in transportation modeling software will likely be required so that emission-related activity outputs can be linked with modal emission rates.

Importance of Local Analysis:

The nature of trips differs from area to area and is dependent upon the local transportation system, land use, and socioeconomic characteristics. Control strategies that work well in one urban area may not work well in other urban areas, or even in suburban areas of the same city.

Local air pollution control districts are in a good position to propose, fund, and/or undertake local transportation demand analysis. Vehicle registration surcharges enacted by the California Legislature in 1990 (AB2766) will yield increased revenues for local districts that may be applied to local transportation/air quality research projects (Scheible, et al., 1991).

Latent Demand:

The concept of latent demand on congested routes worries many critics of traffic flow improvement strategies. Many of the TCMs designed to improve traffic flow may also result in effective capacity increases. For example, in providing high occupancy vehicle systems that involve the construction of new lanes, the roadway system can handle an increased vehicle flow. Driver trip making response to new capacity is unclear. Some analysts have argued that individuals operate with a travel time budget, and that increasing capacity and flow may not appreciably change the number of hours spent behind the wheel of a vehicle. As people make more trips and drive greater distances, in accordance with their travel time budget, demand could again exceed capacity. Thus, increases in infrastructure capacity may yield only temporary flow improvements. Plus, temporary flow improvements can serve as an incentive for new development (growth) and changes in land use at the local level.

Most transportation models account for changes in route choice, based upon travel time, in the iterative network assignment process. However, these models have the capacity to

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19 Top-down estimates could be improved through the implementation of advanced monitoring networks.

20 For example, parameters such as trip length, vehicle load, fueling frequency, and duration and frequency of vehicle non-use are important emission-related activities that should be modeled (Horie, 1991).

21 See Yakov Zahavi's work for the Federal DOT.
address much more of the latent demand phenomena (Seitz, 1991). For example, trip generation, distribution, and mode choice subroutines could be linked to congestion effects through feedback processes.

Spatial and Temporal Emission Disaggregation:

Photochemical grid models, such as CALGRID, are dependent upon specific emissions input. Photochemical models account for the mixing of pollutants in each specific area (or grid cell), and account for the presence and strength of sunlight (solar radiation drives the chemical reactions). For greatest modeling accuracy, emissions should be spatially and temporally disaggregated. Thus, mobile source emissions estimates for small area grid cells, as a function of time of day, should be provided as input to the photochemical grid model is critical. Vehicle activity models that are capable of allocating emission-related activities to the grid cells must be improved for all areas that employ photochemical grid-based models.

With more accurate and applicable emission rate and activity data, emission estimates can serve as accurate input for airshed photochemical models, allowing for spatial disaggregation and gridding.

TRANSPORTATION CONTROL MEASURE ANALYSIS:

A transportation control measure is any strategy to reduce vehicle trips, vehicle use, vehicle miles traveled, vehicle idling or traffic congestion for the purposes of reducing motor vehicle emissions (California HSC 40717(g)).

The California Health and Safety Code mandates that air districts establish the quantity of emission reductions from transportation sources necessary to attain the state or federal ambient air quality standards, when entering into an agreement to jointly develop a transportation control measure plan with a council of governments or regional transportation agency (California HSC 40717(a)). However, quantifying emission reduction ranges for TCMs is not an accurate science at this point in time.

The effects of TCMs are observed primarily in changes to vehicle activity patterns. However, while some TCMs reduce specific subsets of vehicle activity, thereby reducing emissions directly, other TCMs may reduce emissions by altering the operating environment of the individual vehicles and reducing emission rates, without affecting transportation demand. For example, a carpool measure will result in fewer single occupant vehicles on the road, reducing the number of tripped and VMT for those vehicles left at home. Whereas, signal timing acts to improve vehicle flow and reduce delays in urban areas, reducing the emission rates (by increasing operating speed) for the vehicles affected. In theory, both strategies help to reduce motor vehicle emissions.

To the extent possible, the effects of TCMs should be modeled. Analysis of many TCMs could benefit from the detailed comprehensive information available in a modeling setting (Seitz, 1991). However, the effects of TCMs on emission-related activity are so complex that current transportation models are not capable of automatically addressing the majority of these effects.

Uncertainty in TCM Effects:

Uncertainty exists in motor vehicle emission factors as well as in vehicle activity changes that will result from the implementation of TCMs. Thus, uncertainty in determining the emission reduction effects of TCMs is multiplicative.

The tradeoffs in vehicle activity and emission rates are complex. For example, the implementation of telecommuting reduces the number of work trips made. However, additional home-based trips may partially offset the emission reductions achieved. Recent studies have indicated that telecommuting does result in a net decrease in trip making (Kitamura, et al., 1991), primarily during hours of congestion which is an added benefit, but the complex effects on emissions depend greatly upon local traffic parameters (acceleration and trip speeds).

Another example of a complex emission tradeoff is illustrated when a decrease in trip making exhaust emissions is partially offset by an increase in fuel evaporative emissions. When a vehicle is left idle for multiple days (e.g. when the driver takes transit or is a a passenger in a carpool) the fuel evaporation from the idle vehicle increases as the control canister becomes oversaturated with gasoline vapors. Thus, specific percentages of the vehicle fleet undergo partial, full, and multi-day diurnal evaporation, and these percentages can vary when TCMs are implemented.

Further complicating the analysis, TCMs may have a significant effect upon emission rates in ways other than by improving traffic flow. For example, if a TCM affects a specific segment of the vehicle fleet, high or low polluting vehicles may be removed from the fleet, relatively increasing

22 The pilot telecommuting program for state employees resulted in a reduction of more than two trips per day (home-work, work-home, plus additional trips). This appears to indicate that telecommuters become more efficient in their trip making.

23 Emission rates may be strongly correlated to gas tank size, indicating that increased fuel efficiency requirements can have significant effects on evaporative emissions (Groene, 1991).
or decreasing aggregate emission rates from the remaining vehicles. TCMs also have the potential to affect the age and accrued mileage distributions of the vehicle fleet. As TCMs decrease the annual mileage accrual rates, these vehicles may remain in the fleet longer, decreasing the rate of fleet turnover to newer less polluting vehicles.

Existing emission inventory methodologies are currently being used to evaluate the potential effect of TCMs in specific corridors. However, these models were designed to produce bulk estimates of the emission inventory (i.e., crude estimates, based upon aggregate parameters). These models were never designed to provide the corridor specific effects that they are being asked to reproduce.

Defining ranges of uncertainty associated with modeling efforts is not currently possible, due to the nature of the uncertainty. While potential ranges of uncertainty can be established based upon precision and accuracy of proven test methods, it is not possible to estimate ranges of uncertainty associated with questionable assumptions or the applicability of data used in modeling efforts.

Reasonably Available Transportation Control Measures:

Of particular importance for research are those TCMs that have proven to be technically feasible and effective at decreasing mobile source activity. The CARB, based upon general studies available in the transportation literature, and based upon previous implementation experience of local air pollution control districts, identified seven "reasonably available" TCMs: 1) employer based trip reduction rules, 2) trip reduction rules for other sources that attract vehicle trips, 3) management of parking supply and pricing, 4) high occupancy vehicle system plans and implementation programs, 5) comprehensive transit improvement programs for bus and rail, 6) land development policies for motor vehicle trip reduction, 7) development policies to strengthen on-site transit access for new and existing land developments (CARB, 1990d).

The California Clean Air Act requires that reasonably available TCMs be considered for implementation in non-attainment areas in the submittal of 1991 attainment plans (California HSC Sections 40918(a)(3), 40919, and 40920).

TCM Effectiveness:

The existing literature describes the potential application of TCMs in urban areas (SAI, 1990; Cambridge Systematics, et al., 1990). However, research indicates that the applicability of TCMs is location specific and the emission impacts of TCMs can vary widely. Individual urban areas have unique travel patterns and trip characteristics. Consequently, aggregation of TCM effectiveness from the literature on a statewide basis could be a misrepresentation of the actual potential effects in individual areas.

Ongoing transportation control measure studies are currently being conducted for the EPA, CARB, and local air pollution control districts. Research contractors include: Systems Applications, Inc., Sierra Research, and Ekistics, Inc. Current TCM studies are meant to develop agreement among transportation and air quality planners on the most useful methodologies for analysis and the extent and effectiveness of TCMs. Specifically, the studies should yield methodologies that will help local districts get a better feel for what kind of emission reductions can be expected from implementing TCMs and TCM packages (Eisinger, 1991). Studies will yield methods for estimating general changes in vehicle activity parameters resulting from the implementation of TCMs, recognizing that the specific effects will vary under different local conditions and urban structures. The research will lay out specific methodologies, analogous to sketch planning measures, that analysts can walk through in estimating the vehicle activity effects of TCMs (Eisinger, 1991).

The packaging of TCMs also appears to be a critical research topic. Preliminary studies have demonstrated that a synergistic effect of multiple strategies often exists (SAI, 1990); however, few previous studies have been conducted to determine how, when, and where measures can provide synergism. Research on TCM packaging will be ongoing.

Research indicates that parking pricing may be the single greatest factor in determining commute-trip mode choice and ridesharing activity (Wilson, et al., 1989). How parking price affects other trip making behavior is not as well understood. The emission impacts from public and private parking management programs are dependent upon numerous economic, transportation infrastructure, land use, and vehicle characteristic variables. Parking policy analyses are difficult to perform, given the uncertainty in determining future effects in specific local areas. Effects will vary with demand elasticities and socioeconomic conditions, as well as the land-use patterns and traffic characteristics. Additional case studies on parking pricing should still be undertaken. Further research into consumer response to incremental increases in vehicle operating and out-of-pocket costs will prove very useful in estimating changes in travel behavior resulting from other market-based strategies, such as increased bridge tolls or congestion pricing.

A new area of uncertainty may be associated with the existence of a trip-making threshold. Given a constant demand for service, consumers may be more likely to add a chained trip to a work trip than to make a separate trip. Thus, one
home-based trip to the grocery store may be replaced by multiple trips that are linked to the work-home trip (a decrease in trip-making efficiency). Research into tripmaking thresholds, and the effects that TCMs have on overall tripmaking behavior, may indicate that demand management strategies are more effective than flow improvements.

The actual activity and emission effects of TCMs are complex and difficult to quantify. TCMs potentially yield multiple individual activity effects that each must be analyzed in relation to the others, to yield cumulative activity effects that may be linked to emission factor models. At this time, neither the emission nor the activity models are sufficiently developed to yield such fine tuned corridor specific emission reduction analyses. In the case of TCMs included in State Implementation Plans, a dilemma is encountered: achievement of the emission reductions outlined in the attainment plan cannot be easily verified (Guensler, 1989).

**LAND-USE RELATIONSHIPS:**

The relationship of land use to air quality is receiving increasing attention from both transportation and air quality planners. Determining how the location and design of land uses affect tripmaking will help identify changes in land use patterns likely to reduce vehicle activity and emissions.

The California Clean Air Act (CCAA) requires air districts to consider measures to control emissions from indirect sources (activities and facilities that attract motor vehicle activity). At the same time, the CCAA also limits indirect source control such that the district's authority shall not infringe on the land use authority of cities and counties (HSC 40716). In California, local control over land use development is intensely guarded. However, as the traffic-related emission impacts of land use become better understood, development of emission related land use and land development performance standards at the local level is likely. To accomplish this, the relationship of land use to traffic and to air quality must be well understood.

The CARB is currently in the process of evaluating proposed indirect source control programs that would require developers to implement reasonably available traffic mitigation measures (CARB, 1990e). Measures such as appropriate parking guidance, transit accessibility, pedestrian access, and availability of local services are under evaluation. The development of an appropriate analytical framework within which land-use issues can be meaningfully analyzed would be of academic interest (Greene, 1991).

Areas of interest include determining the relationship of land use density to trip making. It is clear that in densely developed cities, such as San Francisco, residents have significant activity choices without getting into their cars. For example, in San Francisco's highly dense Nob Hill district, people can conduct most of their daily activities within a few blocks of their residences. Trips to employment may be of greater distance, but even those intracity trips are usually to densely developed areas and can also be made easily without a personal vehicle. In high density cities, motor vehicles can, in fact, make tripmaking much more difficult. Other gains in urban efficiency, and a loss of consumer surplus associated with the current desirability of low density development (Greene, 1991), are issues that would need to be analyzed concurrently.

While it is clear that most of California's communities are not densely developed like San Francisco, the variation in density does appear to have some impact on VMT and trip making. There is an indication that moderately dense suburbs have lower VMT and presumably lower trips than low density suburbs and rural areas (Harvey and Deakin, 1980; Kohn, 1991). Understanding the relationship of density to trip making, though, is not yet well understood. The CARB is considering research to better define this relationship.

Mixed use development has been advocated by many for its vehicle trip reducing opportunity. By providing a mix of uses at a particular site, residents or employees can make many of their trips on foot or on bicycle. But what scale of mixed use is needed? Some have argued that mixed use developments less than 2 million square feet are not effective in this regard, and that this large size is needed in order to provide both the volume of users to attract a large enough diversity of uses so that the diverse needs of users is met at that location (Cambridge Systematics, et al., 1990).

While there has been much research into the topic of pedestrian movement this research does not appear to have been fully incorporated into land use design standards (HSC, 1980). Pedestrian travel has been given short shift, in part because of the need to understand the much more bulky relationship of vehicle travel to street design criteria. While traffic counts of motor vehicles are regularly taken, very few pedestrian traffic counts are. There is little systematic evaluation by cities of barriers that prevent or diminish pedestrian travel.

The presence or absence of pedestrian travel may be an indicator of strength or weakness of an area to be able to increase vehicle trip reduction. What is needed for air quality planners is to understand what conditions people are willing to walk to destinations rather than take a car. Most trips are short. Some only a block or less. Short trips,
involving an engine start and hot soak, are highly polluting (CARB, 1989). Developments which attract pedestrians and reduce these short trips will thus reduce air pollution.

The 1989 South Coast Air Quality Management Plan based a significant part of its transportation control strategies on achieving a "jobs-housing balance" -- that is, a better balance of jobs and housing that minimizes long distance commuting. This strategy has not received widespread community support and, in fact, is not part of the 1991 Revised Plan (draft). Nonetheless, a better understanding of the nature of jobs and housing and trip making associated with this is needed.

An area of significant interest is the relationship of transit and rail to development (i.e. what types of development do transit and rail support/generate, and what sort of development maximizes transit and rail usage). In the past, transit planners have been charged to meet demand wherever it exists and in the best way they can. This is usually after the fact and does not take advantage of development opportunities that can in fact increase transit usage. What land uses near transit maximize transit usage, and what land uses may discourage transit usage, are issues of increasing importance to air quality planners (shifting travel to transit is seen as an important trip reduction measure). Although the immediate emission reduction benefits may not be significant because of the high percentage of high-polluting diesel buses, recently approved heavy-duty bus emission standards, should bring a much cleaner transit fleet. Yet, at the same time, new motor vehicle emission standards are also bringing a cleaner automobile fleet, complicating the analysis.

Many local communities in California are including "Air Quality Elements" in their general plans. The San Francisco Bay Area Air Quality Management District has recommended that all cities and counties in the Bay Area develop such elements. However, there is no standard or criteria for these elements, nor is there an established quantified air quality benefit associated with these elements. They can vary from simple policy declarations to more specific implementation criteria which promote vehicle trip reduction. Understanding the quantitative traffic relationships between land use and circulation design criteria would be useful for developing guidelines to evaluate air quality benefits of these air quality elements. The CARB is working with the Local Government Commission to develop a handbook outlining what is known and unknown about how local officials can minimize air pollution through the land use and development process.

ADVANCED HIGHWAY AND VEHICLE TECHNOLOGIES:

Transportation agencies at the state and federal level are actively undertaking research efforts related to the feasibility of advanced highway and vehicle technologies. Advanced technology concepts range from simple measures, such as computerized signalization or driver information systems, to complex measures, such as completely automated vehicle speed and steering control.

Advanced technologies are being designed to improve vehicle flow and to provide additional freeway capacity, in an effort to increase automobile mobility. Hence, the effects that advanced technologies may have on total mobile source emissions is a critical factor in evaluating the conformity of advanced technology projects with air quality attainment plans.

To the extent that advanced systems can substitute for vehicle activity (e.g. telecommuting), or provide for alternative low emitting vehicle systems (e.g. roadway electrification), advanced systems concepts should be given a high priority. (Scheible, et al., 1990). New technologies have the capacity to affect the trip making behavior, eliminating the need for trips themselves, or the infrastructure, moving people in lesser polluting modes.

Intelligent Vehicle Highway Systems:

The potential for increasing travel mobility and capacity through advanced computerization of vehicles or infrastructure is being investigated to determine if such improvements are technologically and economically feasible. Intelligent vehicle highway systems (IVHS) are currently an area of intensive research by transportation agencies.

IVHS is the generic term for the use of advanced computerization systems to perform numerous tasks within the transportation infrastructure. The tasks performed by IVHS can range from simple informational tasks (such as alerting the driver to hazardous road conditions or to the location of traffic jams) to complex vehicle control tasks (such as controlling the spacing and steering of the vehicles to reduce the potential for accidents and to increase the efficiency of roadway operations). The basic goals of IVHS systems are to increase mobility and reduce congestion delay.

An increase in capacity and mobility through IVHS could result in significant benefits both in terms of reduced accidents, personal time savings, and increased economic productivity. In addition, improvements in traffic flow can reduce vehicle emission rates for hydrocarbons and carbon monoxide. Because motor vehicle emissions are dependent upon vehicle speed and acceleration profiles, a steady flow at an
increased speed (not above 50 mph) provides reductions in vehicle emission rates of hydrocarbons and carbon monoxide, compared to congested conditions.

To the extent that IVHS proposals will result in long term sustainable emission reductions, research should be supported. Because these systems would result in reduced congestion and accident delay, they will reduce vehicle emission rates. However, if a new technology increases mobility and subsequently increases the demand for transportation services, increased vehicle travel has the potential to defeat the emission reductions achieved IVHS programs.

Because of the inability to predict the long term relationship between improved levels of service and increased traffic demand, concern has been expressed that additional research be conducted on the latent demand phenomena before high-tech congestion management solutions are implemented (Scheible, et al., 1990).

However, the potential problems of IVHS should not lead to the conclusion that research into advanced highway technologies should be put on the back burner. The potential for IVHS to provide emission reductions is great. Plus, the spin off technology from IVHS systems will significantly improve information gathering capabilities. Instead, companion studies should be undertaken so that we can reliably predict the impact of IVHS upon future air quality.

Data Collection and Analysis Potential of IVHS:

One of the major advantages that advanced technologies can play in quantifying emission reductions is that of data collection and analysis. Methods of collecting useful and applicable data for the evaluation of before and after travel patterns would greatly improve activity forecasting. Potential data collection techniques include automatic vehicle identification systems, weigh in motion stations, and computerized automobile black boxes.

The implementation of advanced monitoring systems has the potential to provide better estimates of vehicle activity, such as vehicle speed distributions, number of trips, and VMT. If privacy concerns can be addressed, AVI systems and onboard black boxes may be capable of providing much useful travel data. The concept of the "Neilson driving family" might also be introduced in conjunction with travel monitoring systems such as AVI or computerized black boxes. In this scenario, "average" families might be selected and monitored to determine how and why typical travel patterns are undertaken.

Real-time traffic control centers are being developed and could provide feedback to emission reduction analyses. Detailed data might be provided to signal timing systems that minimize air quality impacts in urban centers. Data related to changes in speed profiles, congestion, and delay would also be very useful for future studies. For example, summary data from the "Smart Corridor" demonstration program on the Santa Monica Freeway and related arterials can be used to determine change in emissions related to speeds, trips or hours of delay once the modal emission factors are developed. Plus, these actual monitored changes in vehicle activity parameters can be used to calibrate vehicle activity effect models used in alternative scenario analysis.

Monitoring system data could be used to clarify the applicability and accuracy of emission related assumptions and to improve vehicle activity models. For example, vehicle activity estimates could be improved and trip generation estimates could be updated in UTFS systems. Actual traffic speeds could be compared to modeled vehicle speeds, and speed distributions could be provided. Data compiled from the smog check program could improve vehicle activity estimates and be used to calibrate of local demand models from the top down.

Because so many projects could benefit from improved data collection and analytical techniques, the costs and benefits of using advanced monitoring systems should be fully explored.

POLICY STUDIES:

Although only a few policy studies are discussed in this section of the report, ongoing research into the non-emission-related effects of emission control strategies must be comprehensive and ongoing. It is important to clarify and resolve policy issues so that the implementation of emission control strategies does not create unforeseen social consequences, and so that those consequences that do result can be mitigated to the extent feasible. For the purposes of this paper, the following policy issues are explored: cost effectiveness calculations, stationary and mobile source emission trades, and market-based incentives.

Cost-Effectiveness Calculations:

The California Clean Air Act requires that local districts prepare a cost-effectiveness analysis for each of the control measures that are considered for adoption. Cost-effectiveness (dollars per ton per day) is a ratio of a measure's annualized cost (dollars) and the emission reductions achieved (tons per
day of reduction). The CARB guidelines allow local districts a
great deal of flexibility in calculation methodologies (CARB,
1990f). But, additional research into the cost-effectiveness
methods is warranted. For example, the selection of
inappropriate discount rates, discounting of emission
reductions over time, or allocation of costs to non-pollution
benefits (e.g., time benefits from congestion reduction) can
significantly influence calculated cost-effectiveness. Without
additional technical guidelines, it is possible that extremely
effective long-term solutions will be heavily discounted
that they will be put aside for short term, less effective,
emission control strategies.

Further research will likely be focused on the analysis of
ranked TCMs for specific urban areas. Because the CCAA
requires that local districts rank TCMs in order of their cost-
effectiveness, although not necessarily adopted in that order,
local analyses will be paramount. Also, because local air
pollution control districts will be required to submit a new
round of air quality plans (1992 federal plans and 1994
California updated), new methodologies are probably needed
within the next 18 to 24 months.

In reality, any model will result in uncertain estimates; however, the use of these estimates should be contingent upon
their relative certainty. When adopting TCMs, the analytical
emission reduction results must be evaluated in light of
prevailing uncertainty. It is imperative that analysts inform
policy and decision makers how pervasive the uncertainty in
their analysis is.

Stationary and Mobile Source Emission Trades:

The ability to trade emission reductions in the mobile
source sector for emission increases in the stationary source
sector supported by industry in Southern California. However, there are a number of major problems that
plague the verification of mobile source emission reductions as
being permanent, surplus, quantifiable, and enforceable
(Guensler, 1990), required by the federal emission trading
policy (USEPA, 1986). These federal requirements are in place
to ensure that real reductions in emissions occur.

The new low-emitting vehicle certification requirements
adopted by the CARB in 1990 will have profound effects upon the
composition of the future California vehicle fleet. Specific
percentages of new "zero-emitting vehicle" and much lower
average emissions for all vehicles sold in California are
required by the 1990 CAA and California regulations.
Speculation that the vast majority of these vehicles will be
electric brings the policy issue of stationary versus mobile
source emission tradeoffs into focus.

Electric power, provided either by existing electrical
utilities during the off-peak hours, or by new utilities
located inside and outside the air basin during peak hours,
will result in increased stationary source emissions. However,
these emissions will be significantly, if not fully, offset
by decreases in emissions from motor vehicles (Wang, et al.,
1990). The net change in air basin emissions will depend upon:
the extent to which electric vehicles are substituted for
gasoline vehicles, the location of power generation, and the
control equipment is applied to new and existing power
generating facilities (best available and best available
retrofit control technologies). A serious investigation into
the fuel switching and interbasin pollution shifts will likely
be undertaken for the South Coast and San Diego Air Basins.

Accounting for this fuel switch in an emission reduction
attainment plan will be difficult (Guensler, 1990): 1) emission
estimates for motor vehicles are much more uncertain
that for their stationary source counterparts, 2) attainment
plans have already "consumed" (relied upon) the emission
reduction benefits from a shift toward electric vehicles,
without explicitly accounting for future power plant emission
increases and 3) specialty vehicles are likely to have
different operating characteristics (VMT, number of trips, etc)
that the vehicles they displace, making tradeoff calculations
very difficult. Aside from the technical difficulties noted
above, potential equity issues associated with stationary
source (retrofit) benefits (VMT) are also significant and may complicate the proposed South Coast
AQMD marketable emission permit program (SCAQMD, 1990).

Market-Based Incentives:

Market-based incentives directed at either vehicle buyers
or vehicle/fuel suppliers are currently being considered as
tools for reducing/eliminating the vehicle emission rates. The Drive+ program proposed in California (SB1905, Hart and
Kopp; Gordon and Levenson, 1989) would levy an emission-based
tax/surcharge upon vehicles whose pollution levels exceed
specified standards and rebates for vehicles with pollutant
levels less than the standards.\(^\text{26}\) The goal of the emission fee
system is to affect consumer purchase behavior and the
subsequent provision of clean vehicles by manufacturers. The
use of registration fees based upon vehicle emission rates and
annual mileage traveled has also been recently proposed for
California (Bay Area Economic Forum, 1990). Interestingly,
proposed California legislation (SB 1139, Killea) may require
insurance premiums to be paid at the gas pump (pay as you
drive); an out-of-pocket cost that reduces the existing
incentive to drive and to own fuel-inefficient vehicles. Even

\(^{26}\) Although the Drive+ Bill was approved by both the State Senate and Assembly in 1990, it was
vetoed by then Governor Deukmejian. The Drive+ Bill will be re-introduced to the Legislature in 1991.
the new CARB low emitting vehicle standards for 1994 will allow limited emission trading between various vehicle types between manufacturers, allowing some vehicles to emit more pollutants, provided that other vehicles more than offset the emission increase (CARB, 1990a). The potential use of congestion fees, toll charges based upon time of day, may also be a viable alternative in the long term (Bay Area Economic Forum, 1990; Cameron, 1991)

The use of market-based incentives for pollution control is not a new concept (Hahn and Hester, 1989). The USEPA currently allows emission trading and source bubbles for stationary sources under the federal emission trading policy (USEPA, 1986), and the 1990 CAA calls for increased use of market-based incentives for pollution control. Even permit fees for stationary sources in the South Coast AQMD are in part based upon emissions. Although the economic principles for market-based incentives are fairly straightforward, and increased efficiency in controlling emissions is expected from market-based strategies, numerous equity issues must be resolved before these types of programs are implemented. Effects upon low income individuals, small businesses, new facilities, recently permitted facilities, etc., must be examined. In addition, resource allocation issues within regulatory agencies must be realigned and enhanced before incentive programs can be appropriately monitored (USEPA, 1990).  

Research into both the theoretical and practical implications of market-based incentives must continue for the future. In addition, pilot programs will likely be explored.

CONCLUSIONS:

The implementation of rational TCMs hinges upon our ability to assess complex transportation and air quality relationships. Yet, making decisions as to what research projects should be undertaken to clarify the transportation and air quality linkage is difficult. Because numerous and uncertain behavioral effects are superimposed on highly aggregated data, it is difficult to sort out which projects are critical. Determining which projects should be implemented and in what order proves to be as much an art as a science.

This paper has touched upon a broad range of research topics that are needed to bring greater certainty to the transportation/air quality planning process. Current problems with vehicle emissions and activity data were reviewed to set the stage for developing a transportation air quality research agenda. However, a comprehensive agenda has not yet been discussed.

In the peer review process used to finalize this paper, numerous commentators indicated that the authors should include a detailed list of research projects (specifically designed to reduce the uncertainty in estimating TCM emission reduction effects). Using the general issues and relationships described in this paper, we believe that a detailed research framework and agenda could probably be developed. However, preparing such a detailed framework and research plan, while at the same time attempting to avoid any institutional or personal bias, is formidable. A detailed study into what specific projects should be undertaken, and into the costs and feasibility of these projects (from technical and funding perspectives), could be prepared by a Delphi panel of transportation and air quality experts. Such a panel could readily evaluate potential research projects based upon technical merit and importance toward the attainment effort.

Thus, in lieu of describing specific research efforts that should be undertaken, we have opted to simply summarize the general research issues raised, and to discuss the development of a research framework. Research in the following general areas should greatly improve our ability to estimate the current emission impacts of mobile sources, better model the emission impacts of proposed transportation control strategies, and assess the feasibility of proposed measures:

- Disaggregate Modal Emission Modeling
- Disaggregate Modal Activity Modeling
- Activity and Emission Rate Effects of Specific TCMs
- Synergistic TCM Relationships
- Modal Activity Impact Modeling (Changes Due to TCMs)
- Cost Effectiveness Analysis
- Socioeconomic Effects of TCMs and Incentives
- Land Use/Transportation Linkage
- Indirect Source Analysis
- Latent Demand Effects
- Effects of IVHS and Advanced Systems Concepts
- Monitoring & Measuring TCM Effectiveness

Disaggregate modal emission modeling techniques would be proposed so that significant uncertainty in the mobile source emission inventory can be reduced. Research related to the modeling of vehicle activity will reduce emission inventory uncertainty and provide insight into the traffic effects resulting from TCMs.

Research into the effects of specific TCMs on activity and emission rates would be used better define the general relationships between transportation activity variables. Of special importance to State and local regulatory agencies would
probably be those reasonably available TCMs already identified: employer-based trip reduction, indirect source control, HOV systems, improved transit systems, and parking management and pricing. Similarly, defining the synergistic effects of TCMs is necessary if modeling capabilities are to improve. For example, determining how parking policies affect ongoing trip reduction strategies (such as employer trip reduction) is important if workable programs are to be developed.

Tying TCMs to air quality improvement over both the short and long term is critical. Relationships defined through specific research could be used to refine activity and emission modeling frameworks. Hence, using defined relationships from previous and future research, detailed modeling frameworks can be developed to better predict changes in modal vehicle activity parameters as a result of TCM and TCM package implementation.

The socioeconomic effects of TCMs and market based incentives must be better understood. Local economies can be significantly impacted by the implementation of certain TCMs. Determining the cost effectiveness of short and long term measures is important from a perspective of economic efficiency. Thus, defining the net costs to local and regional economies (as well as internal economic transfers), is important. In addition, issues surrounding distribution of social costs and internal transfers (who bears the costs and who benefits) are of equal concern in a regulatory arena.

Land use planning and development research would likely focus on how various collections of land uses in an area contribute to trip making. Research could be both quantitative, in determining the amounts and kinds of trip making associated with various densities and adjacent land uses, and socioeconomic, in terms of costs, preferences, and values.

The focus of indirect source analysis would likely be upon defining the nature of the travel activity associated with the particular source category, and what actions can be taken by the developer or operator of the indirect source to mitigate indirect source emissions. Again, determining the relationships between TCMs and land development policies appear important from both a technical and social perspective.

Defining the relationships between existing highway capacity and total travel demand will be ongoing. The effects of proposed increases in capacity are embedded in the policy arena because so little is known about the quantitative effects of new construction. The relationship between growth in area and indirect sources along transit corridors and capacity increase are not well researched. In addition, because intelligent vehicle highway systems and advanced systems concepts have been receiving serious attention in the

California policy arena, research into the potential air quality effects should probably be expanded.

Significant research is also needed in monitoring the effectiveness of TCMs over time. Utilization of new technology such as IVHS for monitoring should be examined. Developing systematic survey and monitoring protocols for transportation air quality indicators will also benefit regionwide and corridor-specific emissions models.

There is a need for coordinated research efforts (i.e. CARB, AQMDs, Caltrans, CEC, DOE, COGs, universities, and private industry) so that studies provide data and information that is transferable between agencies for a variety of uses. Local government agencies have recently begun undertaking studies to improve analysis of TCMs. Yet, the existing research efforts are not coordinated in such a manner that findings are disseminated quickly and efficiently to all interested parties. An organization capable of serving as an information and research clearinghouse on transportation/air quality issues is needed and would support an iterative research approach. In addition, the availability of trained manpower to address TCM research and implementation must be increased (Santini, 1991) so that sensible TCMs are implemented.

Future research efforts will ideally include public/private/university partnerships, to the extent that such partnerships will increase research efficiency and reduce overall costs. Unfortunately, there are a good many legislative and institutional barriers that may interfere with efficient institutional cooperation. These barriers may need to be identified and eliminated so that research efforts can proceed successfully. Although the funding aspects of research are not discussed in this paper, cost sharing between State and local transportation, air quality, and energy agencies on coordinated research efforts might have significant efficiency benefits.

In planning for transportation and air quality balance, there is a fundamental need for better understanding the relationships between transportation demand, trip making behavior, mode and route choice, and vehicle activity-related emissions. Air quality and transportation planners need a firm foundation of knowledge upon which to lay the building blocks that constitute mobile source emission control strategies. When a detailed long-term research plan is developed, with research hierarchies and data outputs specifically identified, research efforts can be linked effectively and efficiently. A detailed research framework, prepared cooperatively by a multi-agency multi-interest task force, will provide the blueprints for our foundation.
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