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16. Abstract
The objective of this investigation is to determine if there is currently an adequate organization of technical and scientific knowledge to accurately estimate the impact of mobile sources on urban air quality. Engineering problems related to vehicular emissions, transportation control measures, smog formation, and mathematical models are identified rather than solved. The relation between mobile sources and air quality is systematically evaluated by dividing the process into linkages: 1) the impact of transportation control measures on travel behavior, 2) the impact of travel behavior on vehicular emissions, and 3) the impact of vehicular emissions on air quality. The literature of each analysis stage is reviewed and research needs are prioritized based on inadequacies in the current state of knowledge. Inadequacies in data collection methods, real world experiences and scientifically validated procedures for estimating impacts are outlined.

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RESEARCH NEEDS AND EVALUATION OF AIR POLLUTION PROBLEMS ASSOCIATED WITH VEHICULAR EMISSIONS

A Multi-University Project
Louisiana State University, Baton Rouge, LA
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SUMMARY OF FINAL REPORT

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ABSTRACT

The objective of this investigation is to determine if there is currently an adequate organization of technical and scientific knowledge to accurately estimate the impact of mobile sources on urban air quality. Engineering problems related to vehicular emissions, transportation control measures, ozone formation, and mathematical models are identified rather than solved. The relation between mobile sources and air quality is systematically evaluated by dividing the process into linkages: 1) The impact of transportation control measures on travel behavior, 2) the impact of travel behavior on vehicular emissions, and 3) the impact of vehicular emissions on air quality. The literature of each analysis stage is reviewed and research needs are identified based on inadequacies in the current state of knowledge. Inadequacies in data collection methods, real world experiences, and scientifically validated procedures for estimating impacts are outlined.

IMPLEMENTATION STATEMENT

The results of this study can be used to clarify the relevant technical problems encountered in the analysis of air pollution from vehicular emissions. This report outlines research needs based on an analysis of the linkages between Transportation Control Measures, travel behavior, vehicular emissions, and urban air quality. The results are significant for planning and management problems which incorporate transportation and air quality considerations. The results are to be used to direct future research and identify where the present state of knowledge, procedures, and data are insufficient to accurately predict and monitor the impact of automotive emissions on air quality. This document will serve as a framework for discussions and decision-making among professionals from diverse disciplines.

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OBJECTIVE

The objective of this study is to identify research needs based on a systematic evaluation of urban air pollution problems associated with vehicular emissions. The goal of this investigation is to determine if there is currently an adequate organization of technical and scientific knowledge to accurately estimate the impact of mobile sources on urban air quality.

SCOPE

Technical and engineering problems related to transportation control measures, vehicular emissions, smog chemistry, and mathematical models are identified rather than solved. Although the health impacts of poor air quality are a major concern, they are beyond the scope of this investigation. The focus of the investigation is on inadequacies in technical knowledge and analysis procedures for regional ozone problems. Other urban air quality problems, such as carbon monoxide and particulate matter, are discussed but not evaluated in detail.

METHODOLOGY

The complex relation between mobile sources and urban air quality was systematically evaluated by dividing the whole process into linkages, or impacts. Literature of each analysis stage was reviewed and research needs were identified based on technical inadequacies. Each linkage was investigated with respect to the whole process and interviews were conducted with experts to clarify the relevance of problems.

INTRODUCTION

Despite two decades of air pollution control efforts, 84 million Americans continue to live in areas where the air is unhealthy. Why do almost 100 cities currently violate the ozone standard? Will the Clean Air Act Amendments of 1990 solve our urban air quality problems? During Congressional testimony the following reasons were given for the large number of nonattainment areas (1):

Understatement of pollution-emission inventories as compiled by state and local agencies and reported to the Environmental Protection Agency (EPA).

Inadequacy of mathematical models used to predict the success of various control plans.

Failure of some control measures to obtain predicted emission reductions.

Lack of political will at all levels of government to implement difficult, but necessary, control measures.

Lack of adequate resources at the federal, state, and local levels to analyze and address the problem.

Several of the above reasons indicate that inadequate technical analysis, coupled with increased automobile use, has contributed to our inability to understand and control urban air pollution. Inaccurate emission inventories, insufficient mathematical models, and failed control measures are examples of the difficulties encountered in air pollution analysis.

The severity and persistence of air quality problems prompted the initiation of this research project, which analyzes the ozone problem from a technical perspective focusing on the contribution of vehicular emissions. Very few studies have synthesized the numerous steps which link transportation and air quality analysis. This investigation is founded on a detailed literature review and systematic evaluation of air pollution problems associated with mobile sources. Recent public policies and advances in technical analysis tools are evaluated in order to direct future research.

This study is based on the three steps required to analyze the complex relationship between air pollution control measures and pollutant concentrations. This multi-stage process consists of (2):

1. Analysis of Linkages between Transportation Control Measures and Traffic Conditions.

2. Analysis of Linkages between Traffic Conditions and Vehicular Emissions.

3. Analysis of Linkages between Vehicular Emissions and Air Pollutant Concentrations.

A conceptual model of the relation between control measures and urban air quality is presented in Figure 1. Figure 2 shows a computer modeling approach to the processes depicted in Figure 1. Figures 1 and 2 give the framework of the air quality analysis for transportation planning described in this report. Many of the difficulties encountered in assessing accurately the impact of Transportation Control Measures relate to how well the components of Figure 2 represent the real world processes of Figure 1. This report outlines the current state of knowledge in analyzing the impact of vehicular emissions on urban air quality. Inadequate representations of the real world processes are outlined as research needs.

The body of this report is divided into four parts. Part I presents background TCM information. Part II demonstrates the three analysis of linkages steps enumerated above. Part III gives an example of air quality and TCM issues in Baton Rouge, Louisiana, a serious ozone non-attainment area. The report ends with recommendations listed as a prioritized summary of research needs based on inadequacies in the current state of knowledge.

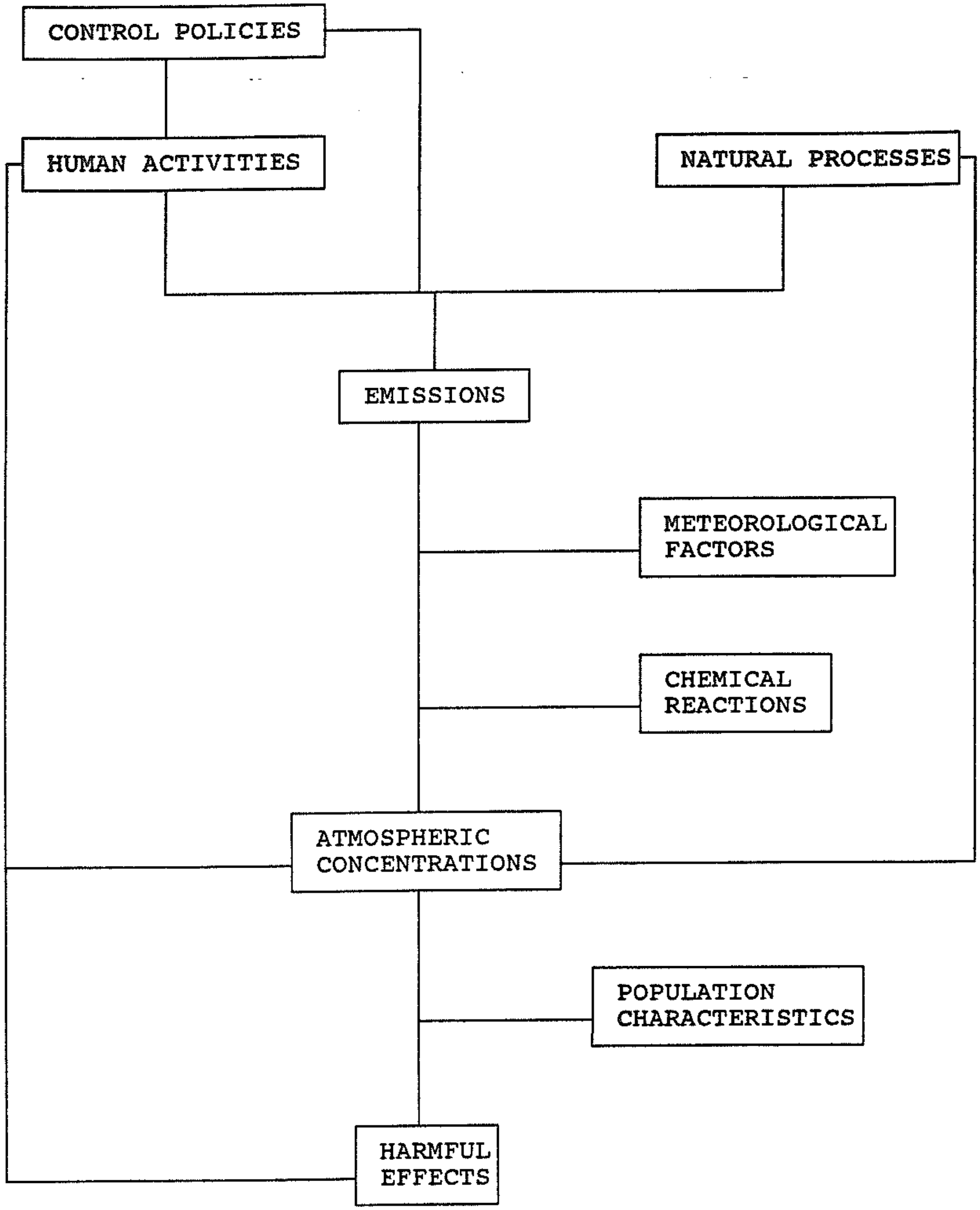

Figure 1. Conceptual framework for air quality analysis of vehicular emissions (2).

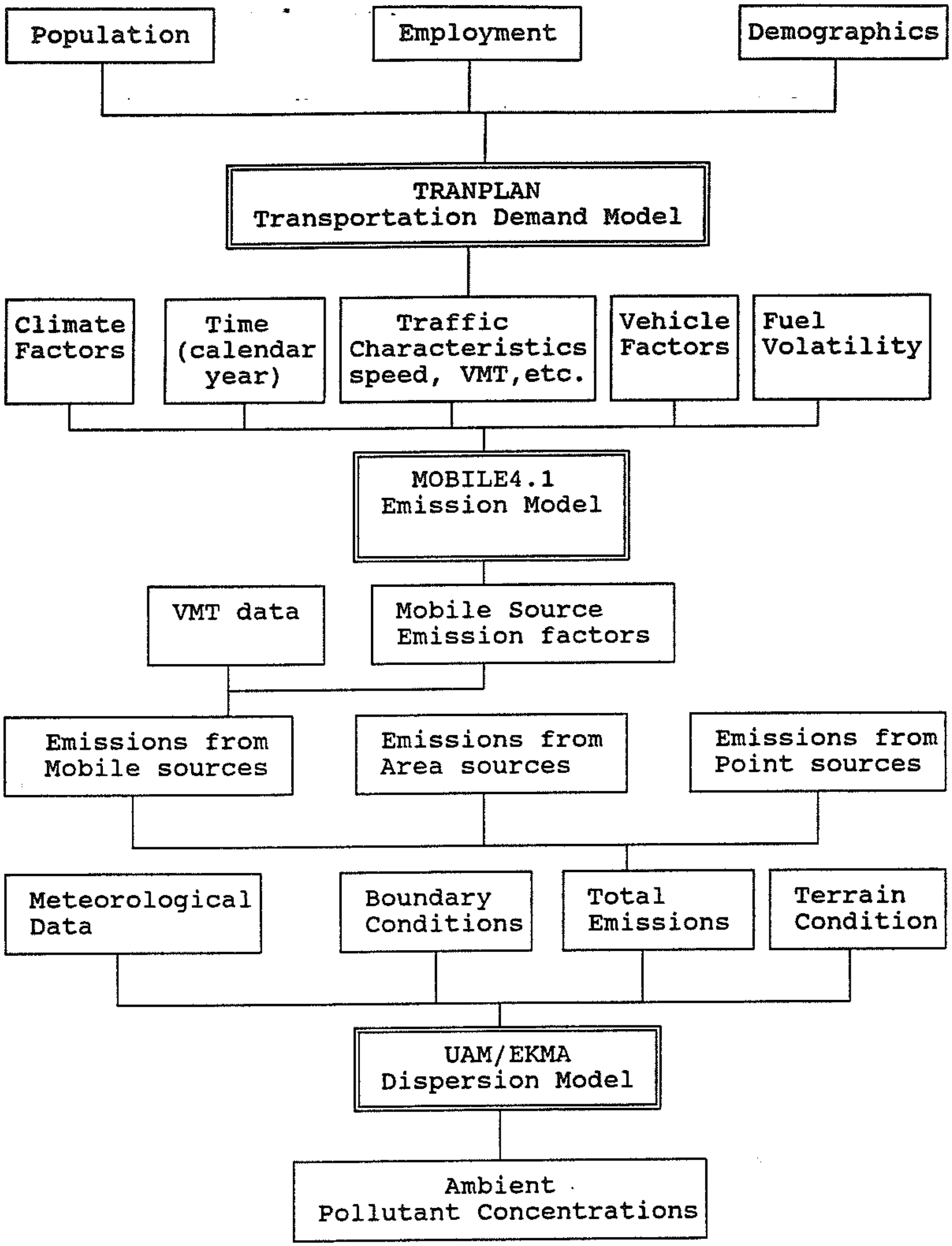

Figure 2. Modeling approach for air quality analysis of vehicular emissions (13).

PART I - BACKGROUND TCM INFORMATION

Most control measures impact the conceptual system of Figure 1 by influencing either human activities that cause emissions (i.e., programs to encourage non-motorized means of transportation) or the relation between human activities and emissions (i.e., cleaner burning fuels). The relationships depicted in Figure 1 underscore the fact that control measures affect air pollution in a very indirect, complex and even controversial way. Predicting and measuring the impact of TCMs on air quality is a multistage process with sources of error and uncertainty inherent in each step. Hence, it is currently unrealistic to expect uncontroversial, very precise and accurate predictions of the TCM effects in a given area.

TCMs Defined

Transportation Management Measures (also called Transportation System Management strategies) are "actions whose objective is to change traffic volumes or traffic flow conditions and, thereby, motor vehicle emissions" (2). Transportation System Management (TSM) strategies are short-ranged, low capital, supply side strategies for improving air quality by enhancing existing transportation systems (3). TCMs may include TSMs, but more often they involve Transportation Demand Management (TDM) strategies. TDMs attempt to lower vehicular emissions by improving traffic conditions through demand side actions. The TCMs listed in the CAAA of 1990 also include measures which lower vehicular emissions without directly affecting traffic conditions (i.e., the voluntary removal of pre-1980 cars). Under the Clean Air Act Amendments of 1990, states are required to implement TCMs based on the severity of air pollution in urban areas that have not attained National Ambient Air Quality Standards (NAAQS) for ozone (120 ppb for one hour) and carbon monoxide. The sixteen TCMs listed in the CAAA of 1990 (Table 1) are principally demand-oriented programs to stimulate the reduction of vehicle emissions by encouraging less-polluting forms of personal travel.

Definition of the Problem

Although total automobile emissions in the U.S. have consistently declined since 1970, they are expected to begin increasing around the year 2000 due to worsening congestion (4). Increases in congestion, which are the result of traffic volumes surpassing existing system

TABLE 1
TRANSPORTATION CONTROL MEASURES
OF SECTION 108(f) OF THE CAAA OF 1990, PUBLIC LAW 101-549-NOV. 15

The Administrator shall publish and make available to appropriate Federal, State, and local environmental and transportation agencies not later than one year after enactment of the Clean Air Act Amendments of 1990, and from time to time thereafter:
(A) information prepared, as appropriate, in consultation with the Secretary of Transportation, and after providing public notice and opportunity for comment, regarding the formulation and emission reduction potential of transportation control measures related to criteria pollutants and their precursors, including, but not limited to:

(i) programs for improved public transit;
(ii) restriction of certain roads or lanes to, or construction of such roads or lanes for use by, passenger buses or high occupancy vehicles;
(iii) employer-based transportation management plans, including incentives;
(iv) trip-reduction ordinances;
(v) traffic flow improvement programs that achieve emission reductions;
(vi) fringe and transportation corridor parking facilities serving multiple occupancy vehicle programs or transit service;

(vii) programs to limit or restrict vehicle use in down-town areas or other areas of emission concentration particularly during periods of peak use;

(viii) programs for the provision of all forms of high-occupancy, shared-ride services;

(ix) programs to limit portions of road surfaces or certain sections of the metropolitan area to the use of non-motorized vehicles or pedestrian use, both as to time and place;

(x) programs for secure bicycle storage facilities and other facilities, including bicycle lanes, for the convenience and protection of bicyclists, in both public and private areas;

(xi) programs to control extended idling of vehicles;

(xii) programs to reduce motor vehicle emissions, consistent with title II, which are caused by extreme cold start conditions;

(xiii) employer-sponsored programs to permit flexible work schedules;

(xiv) programs and ordinances to facilitate non-automobile travel, provision and utilization of mass transit, and to generally reduce the need for single-occupant, vehicle travel, as part of transportation planning and development efforts of a locality, including programs, and ordinances applicable to new shopping centers, special events, and other centers of vehicle activity;

(xv) programs for new construction and major reconstructions of paths, tracks or areas solely for the use by pedestrian or other non-motorized means of transportation when economically feasible and in the public interest. For purposes of this clause, the Administrator shall also consult with the Secretary of the Interior; and

(xvi) program to encourage the voluntary removal from use and the marketplace of pre-1980 model year light duty vehicles and pre-1980 model light duty trucks.

capacity, have the potential to negate the benefits of cleaner emitting vehicles, particularly in areas under one million in population (4). The slow and unsteady driving patterns associated with congestion significantly affect emission rates. For example, a California study concluded that congestion, alone, increased hydrocarbon emissions by 46 percent on Los Angeles freeways during 1988 (4).

Increased congestion has not significantly deterred growth in vehicle miles travelled (5). Estimates of annual nation-wide VMT growth in urban areas during the 1980's range from 2 - 10 percent (4). On a national basis, VMT increased an average of 4.4 percent annually during the 1980's while population increased 2.5 percent. Annual VMT of cars and trucks in the U.S. has now reached 2 trillion miles compared to 1 trillion in 1970.

Role of TCMs

The link between growth in VMT, congestion, and emissions prompted TCMs and VMT forecasting to be a centerpiece of the most recent legislation. TCMs are a key provision of the CAAA of 1990 for nonattainment areas to meet National Ambient Air Quality Standards for ozone and carbon monoxide. The principal role of TCMs in the CAAA is to reduce vehicular emissions enough to match increased emissions due to VMT growth. In the case of ozone, twenty-seven communities are mandated to utilize TCMs to offset increased emissions due to VMT growth. The time table of TCM implementation for specific areas depends on the severity of the air pollution problem.

Qualitative Considerations

The impact of implementing TCMs on urban air quality can be assessed in a quantitative manner using complicated modeling techniques or in a more qualitative manner based on past experiences. Although technical analysis is an important step in the TCM assessment process, it is just one aspect of a complex and multi-stage process to control air pollution. The effectiveness of utilizing TCMs to change people's travel habits depends on external factors which are difficult to quantify and vary substantially from region to region. These external factors include institutional requirements, administrative and technical considerations, market potential, TCM interactions, innovations, cost impacts, public acceptability, and socio-economic trends. Frequently, the most effective TCM incentives, such as pricing constraints, tend to be controversial and difficult to implement. Technical considerations must be linked with a qualitative analysis of socio-economic, ecological, health, and political issues to assess accurately the potential impact of TCMs for a specific non-attainment area. Discussions of such issues requires local and national experts from diverse disciplines to identify the information that really is essential for reaching a decision. Moreover, once a group of TCMs have been analyzed and selected, they must be implemented promptly, monitored, enforced, and modified if necessary. "To clean the air it is necessary to implement TCMs, not just study them" (6).

TCM Categories

Analysis of the potential impact of individual TCMs can be aided by first classifying TCMs based on their respective emission reducing strategy. TCMs which focus on congestion reducing strategies are designed to increase the speed and capacity of existing road networks during peak travel periods. Modal choice strategies are aimed at reducing emissions by decreasing VMT and the number of trips taken in single occupancy automobiles.

Congestion Reducing Strategies

Congestion reducing tactics will generally cause carbon monoxide (CO) and volatile hydrocarbon (HC) emissions to decline (due to higher speeds and less frequent starts and stops), but may cause nitrogen oxide (NO_x) emission rates to increase. Congestion reducing TCMs have generally been considered appropriate for local CO problems but less effective for regional ozone problems (2). Employer-sponsored flexible work schedules and traffic-flow improvements are the two TCMs of the CAAA of 1990 which focus entirely on congestion reduction. In areas where the supply of nitrogen oxides may control ozone formation, such as Baton Rouge (7), congestion reducing tactics may have a negligible or even negative impact on air quality (8).

Modal - Choice Strategies

Modal-choice strategies reduce car emissions by encouraging the use of mass transit, high-occupancy vehicle (HOV) and other less-polluting modes of travel. Hence, emissions of HC, CO, and NO_x will decline due to the reduction in VMT and car trips. Modal-choice oriented TCMs also contribute to lower emission rates by reducing congestion. Most of the 16 TCMs of the CAAA of 1990 are modal-choice tactics which emphasize peak-period trips.

Demand-Side and Supply-Side TCM Strategies

TCMs can also be classified as demand-side or supply-side strategies. Demand-oriented tactics seek to influence travel behavior in order to reduce vehicular emissions. Beneficial changes in travel behavior rely on the effectiveness of TCMs to modify public attitudes and commute decisions. In many areas supply-side strategies, which focus on network changes, are practiced at their technological limits and further improvements depend upon the rate of innovation (9).

TCM Market Potential

An important limitation to the potential impact of a TCM is the size and location of its market. Most of the 16 TCMs listed in the CAAA of 1990 focus on work trips. Encouraging the use of alternative commute modes is one of the most effective ways to reduce peak-period congestion.

Work trips generally account for 20 - 30 percent of the daily VMT (5, 6) and 20 - 25 percent of daily trips (6). In Baton Rouge, the ratio of work trips to total trips has been decreasing in recent years (down from 40 to 20 percent). The potential market is further limited by the fact that TCMs are most appropriate for work trips beginning in cities or suburbs and terminating in a central city. These types of trips, which have the greatest number of transit and HOV options, only account for 10 percent of daily VMT for a typical medium-sized urban area (5).

The limited number of trips that an individual TCM is likely to affect is an important factor in estimating the TCM's impact on emissions. In serious ozone areas where TCMs are intended to offset growth in emissions (due to annual growth in VMT and trips), the traditional focus on work-trips may need to be expanded. The small market potential of most TCMs will also limit their role in moderate ozone areas where 15 percent reductions in ozone levels are mandated in six years. Hence, in order for TCMs to be effective they often need to be combined into complementary packages.

TCM Packages

Many studies have indicated that individually, TCMs generally demonstrate very little impact on regional air-quality problems (3, 6). Limitations in air-quality data tend to make the effect of relatively small changes in emissions (relative to the total amount of regional emissions) from one TCM difficult to assess with a computer model. However, packages of well-coordinated, compatible and site-specific TCMs have exhibited noticeable improvements in air quality using regional ozone models (6). TCM interactions, which are complex and uncertain, can be supportive, neutral, or even conflictive. For example, traffic-flow improvements tend to conflict with most TCMs. The art of matching appropriate TCM packages with specific traffic, demographic, and air quality conditions is a multi-disciplinary endeavor uniting a wide range of factors.

PART II - AIR QUALITY ANALYSIS FOR TRANSPORTATION PLANNING

Evaluating the impact of implementing TCMs on air quality requires a number of analytical steps. Once a TCM, or TCM Package, has been selected its effects on traffic must be estimated (Step 1). The changes in traffic volumes and speeds will cause changes in vehicular emissions (Step 2). The resulting impact of the modified mobile emissions on air quality will differ from uncontrolled conditions (Step 3). Hence, air pollutant concentrations are a function of vehicular emissions, which are a function of traffic conditions, which are dependent on the effectiveness of TCM implementation. Therefore, effective TCM selection and implementation requires the combined efforts and knowledge of professionals from diverse disciplines. Implementation decisions require effective communication between local and national experts in order to identify the essential factors for success.

Prior to implementing TCMs, state and local agencies must select suitable TCMs for their respective air quality problems. In this step, the region's traffic and air quality problems are defined. Regional ozone problems generally call for TCMs which reduce VMT and trips over an entire urban area. Other factors influencing the matching of TCMs with air quality problems include seasonal considerations, population and demographics, economics, the role and status of existing TCMs, and institutional considerations.

Step 1 - Analysis of Linkages between Transportation Control Measures and Traffic Conditions

Once a TCM is deemed appropriate for a given nonattainment area its potential effectiveness must be assessed using computer or manual methods. An implemented TCM will impact traffic conditions which will affect emissions and air quality. The traffic effect of TCMs may include the number of trips, the locations of trips, or mode choice. The resulting traffic-flow changes will impact emissions by altering time of day of travel, mode choice, trip length, trip frequency, or travel speed (6).

Computers are often utilized for transportation demand modeling in order to simulate complex TCMs over large geographic areas. The most widely used transportation demand models are UTPS, TRANPLAN, MINUTP, QRS-II, TMODEL, EMME/II (6). These models are based consideration of engine temperature, load, start-stop driving, engine tune-up, fuel, air temperature and condition of all engine parts. Any effort to obtain an average operating condition has been unsuccessful because of the wide range over which the above parameters may function. Historically, operating conditions have been approximated based on a number of driving cycles. One of the first was the California 7-mode cycle. The CVS-1 and CVS-2 cycles are constant volume sample (CVS) cold start and constant volume sample cold start test average with a constant volume sample hot start test. Both are twenty-two minute driving cycles which try to include a series of expected driving conditions.

The automobile engine was originally designed to have theoretically complete combustion in a hot engine with an air to fuel ratio of about 15:1. With anti-pollution legislation, it was necessary to include all phases of engine operation in the initial design. The five general divisions selected to represent engine performance were: idle, cruise, acceleration, deceleration and soak (post drive). These divisions also must be evaluated under hot and cold operation and at low and high speeds. The primary pollutants studies include HC, CO, and NO_x. Table 2 was modified from several references to summarize these operating conditions.

There is still a need for significant research before any driving cycle can be effectively used to predict any local driving conditions. Typical driving cycle research has used one of the standard cycle specifications for the basis of study. Traffic congestion, vehicle type, weight loads, and local environmental conditions vary widely. Testing procedures are specified in the Federal Register (42 FR 32954 June 28, 1977) and the Code of Federal Regulations (40 CRF July 1, 1984).

Emissions from engines under simulated driving conditions are used to predict emissions from city streets. This is done in combination with data collected on car density as a function of time, average speed, and distances. This approach will give some idea about the level of pollutants to be expected during rush hours and at other times. In order for this to be a good approximation, it is always necessary to also assume an appropriate model for the engine. The mix of automobiles over the years when significant anti-pollution devices were introduced varies substantially. This issue will have to be adequately addressed in order for any model to be effective.

TABLE 2
VEHICULAR EMISSIONS AND OPERATING CONDITIONS

OPERATIONAL CONDITIONS	POLLUTANTS		
	HC	CO	NO_x
Idle:			
Cold			
Low speed	Very high	Very high	Very low
High speed	High	High	Low
Cruise:			
Cold			
Low speed	High	High	Low
High speed	Moderate	Moderate	Low
Hot			
Low speed	Low	Low	Low
High speed	Very low	Very low	Moderate
Acceleration:			
Cold	High	High	Moderate
Hot	Moderate	Moderate	Moderate
Deceleration:			
Cold	Very high	Very high	Low
Hot	Very high	Very high	Low
Soak:			
Cold	None**	None	None
Hot	Very low	None	None

** Some cars with carbon adsorbers to remove the HC are only effective for 1 to 2 days, then there is some HC evaporation.

Claims are made that vehicles made in the 1980s are 80 percent less polluting than those previous. Also some of the older vehicles are operating off of design conditions and are extremely high polluters. A fleet of cars was tested for emissions and it was concluded that 10 percent of the fleet was responsible for 55 percent of the CO emission (10). It would appear logical from this report and from the above claim that ten percent of the vehicles could easily be the source of over half of vehicular emissions. Enhanced Inspection and Maintenance Programs are being applied more stringently to regulate high level (gross) emitters.

Three Major Emission Sources

Internal combustion engines emit ozone precursors from three major sources: exhaust gas, blow by the piston, and fuel evaporation. The exhaust gas from an engine will contain a multitude of chemical components depending upon all factors which functionally affect the performance of the engine. Of specific interest here are factors such as cold state conditions, stop and go operations, idling at points of congestion, high acceleration, and operation under the standard power testing cycle. A relatively small part of the gas of combustion in the cylinder will blow past the rings and enter the engine crankcase above the motor oil. Finally, all pre 1970 vehicles had fuel evaporate from the vented gas tank and carburetor to the environment.

The automobile industry was faced with a mandate to clean up the engine performance with respect to pollution. In the beginning stage there was no technology available to handle the pollutants in the engine exhaust stream. This led to a multi-stage effort which is continuing. The stages of improvement for the internal combustion engine are directly tied to the development of technology capable of reducing emissions. For this reason, the emissions performance will depend on the year an automobile was manufactured. This is reflected in the material below.

In addition to the developments required in the design of the internal combustion engine, there is an equal effort being made to develop fuels which are less polluting. Approximately 92 percent of the emissions from vehicles is in the exhaust gas, 4 percent is blow-by gas, and 4 percent is by evaporation. While it is obvious that all pollution sources must be researched, the development of new fuel mixes to reduce evaporation will make only small improvements. However, the development of a cleaner burning fuel can make significant changes. The addition of methyl tertbutyl ether, methanol, or ethanol can increase the oxygen content of fuels and lead

1974 which did not have this equipment. There was a period from 1974-80 when a number of people removed all anti-pollution equipment from their car and continued to burn leaded gas in their car.

Any effort to establish meaningful relationships between theoretical models and actual city pollution will include a careful study of the details of why each factor influences the operational performance of an engine in a prescribed manner. However, even this knowledge can only be marginally effective since actual vehicle operations are not ideal and include timing off, idle set improperly, plug fouling, and gas not up to specifications.

The major problem with HCs in the air is their photo-chemical transformations which is addressed in the next section of this final report. One of the products of these chemical changes is the production of ozone. HCs also contribute to the production of greenhouse gases.

Motor vehicles are the source of approximately 45 percent of the HC emissions and 84 percent of the CO in cities (13). These are most dominant in the cold start portion of operation. One source indicated that the driving in their city could best be represented by an average drive of 7.5 miles. For this type of drive, the cold start condition would last for at least one-half of the driving time. It is also during this time that the catalytic converter experiences its worst performance. The cold start problem seems to offer a second best area in which to attempt to reduce pollution. Fuel and catalytic converter heaters have been suggested for possible improvement in these areas.

Problems with Nitrogen Oxides

Some of the methods used above to reduce HCs caused an increase in NO_x. The only two methods of reducing NO_x seem to be avoiding their production or the use of a catalytic converter. For this reason, the automobile industry has improved in stages. The effectiveness of current catalytic converters may decrease after 50-60 thousand miles of operation. It may be necessary to mandate some replacement policy in order to avoid a major return to pre 1980 conditions.

The photo-chemistry for NO_x is very similar to that of the HCs with essentially the same end products. Both NO_x and HCs produce an acid rain when in contact with water vapor and after photo-chemistry has occurred. Therefore, with both producing similar pollution results and methods of reducing one component causing an increase in the other, the final design decision will be a compromise.

A Connecticut vehicle inspection program used an independent contractor to evaluate all automobiles on a yearly basis. Other states have incorporated a testing program similar to this. They have found that automobiles three years old or less do meet emission standards. However, all of the predictions of future air pollution reduction often base their considerations on the continued excellent performance of anti-pollution devices. This may be a possible area which needs study. It is obvious that catalytic converters will not be effective throughout the life of an automobile. It is not unusual to see automobiles with over 150,000 miles of operation. Since catalytic converters of today have dramatic reductions in performance after 60,000 miles, some consideration for replacing these components when they become ineffective should be included in this study. It is recommended that the typical lifetime of the catalytic converter and the cost of replacement be determined. This information will be necessary if a model of pollution from traffic is to be accurate.

MOBILE 4.1, Emission Factor Model

MOBILE 4.1 is a personal computer program which estimates hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) emission factors (grams/mile) for gasoline-fueled and diesel highway motor vehicles for any calendar year between 1960 and 2020. The 25 most recent model years are considered to be in operation in a given calendar year. MOBILE 4.1 contains numerous improvements over MOBILE 4. For example, MOBILE 4.1 considers the benefits of enhanced Inspection and Maintenance programs. The updated program also permits the option of calculating HC emission factors as total hydrocarbons (THC), non-methane hydrocarbons (NMHC), volatile organic compounds (VOC), total organic gasses (TOG), and non-methane organic gasses (NMOG). MOBILE 4.1 can be used to provide hourly emission factors based on ambient temperature, average speed, and mileage accrual rates.

Emissions Analysis Approach

The procedure for conducting the emissions analysis differs depending on the scale at which it is to be conducted (i.e., either regional or intersection scale). A typical approach to evaluating the emissions for a State Implementation Plan (SIP) involves the following steps:

1. Definition of a road network for a given year.
2. Network subdivision into traffic analysis zones.

3. Transportation demand model forecasts of inter- and intrazonal trips.
4. Assignment of trips to links in the network.
5. Validation of model results i.e., verifying travel patterns against traffic counts and known link capacities.
6. Transportation demand-model output of vehicle trips on each link; and
7. Use of emissions model(s) to calculate emissions by link.

The EPA in its latest update of the Mobile Sources Emissions Inventory Preparation Guidance has published the emissions requirements for post-1987 carbon monoxide and ozone SIPs. The following are the major steps involved in the completion of the emission inventory (6):

1. Identify the transportation model used, transportation agency that developed the model, travel information used to estimate inventory, and contact at the transportation agency.
2. Comply with various other requirements pertaining to the year the run was generated; data used to "grow" VMT to 1987 - 1988, road classifications, etc.
3. Derive VMT using VMT base year of 1987 or 1988 and the transportation model.
4. Run MOBILE 4.1 to obtain emissions factors.
5. Derive highway emissions by multiplying VMT by MOBILE 4.1 emission factors.
6. Include local traffic emissions, as well as major highway emissions, in the highway vehicle emissions inventory; include such off-highway vehicles as aircraft, railroads, vessels, industrial equipment, construction equipment, and other sources unique to an area.

For the determination of emission factors, the EPA requires all states other than California to use MOBILE 4.1. For California, EMFAC is prescribed. For the translation of emission factors and activities into air quality modelling inventories, two types of tools are available - tools that grid emissions or tools that provide emissions at the county or regional scale (6). There are two types of inventories : regional or county level and gridded.

Step 3 - Analysis of Linkages between Vehicular Emissions and Air Pollutant Concentrations

The resulting vehicular emissions of Step 2 will contribute to ozone concentrations in a very complex and indefinite manner. The exact impact is not clearly understood due to the complex nature of the meteorology, chemistry, and emission inputs. The response of ozone production mechanisms to fractional changes in concentrations of precursors is not yet fully understood. This section discusses ozone formation processes in simple terms and reviews regional modeling efforts with respect to vehicular emissions. The goal of Step 3 is to estimate the concentration of a pollutant at any given location and time as a function of the rates and locations of emissions, meteorological factors, and rates of chemical reactions. The temporal and spatial output from the emissions model is used as input to model ozone formation.

TCMs and Regional Air Quality Models

The two regional ozone models recommended by EPA (6) are the Urban Airshed Model (UAM) and the Empirical Kinetic Modeling Approach (EKMA). UAM is preferred due to its spatial and temporal features and theoretically sound treatment of chemistry, transport, diffusion, emissions and reactivity, and transport from outside to the urban area (6). EKMA, on the other hand, is a simpler model which resolves emissions from an entire urban area into one air parcel.

UAM is generally more attractive than EKMA for TCM studies due to its ability to predict downwind impacts of specific TCMs and congestion. According to EPA (6), UAM is "useful for regional or corridor-specific analyses, and accounting for changes in population distribution, traffic patterns, etc.; however, TCMs must result in significant emissions reductions individually or in packages to obtain meaningful results," whereas, EKMA is "useful for evaluating TCMs' region-wide air quality effects; EKMA cannot distinguish corridor-specific effects; significant emissions changes are necessary to observe meaningful model results." The ability of the two models to obtain meaningful results is limited by the typically small ratio of emission changes of TCMs to the total emissions in an airshed.

Regional ozone models can generally be classified as Eulerian, Lagrangian, or statistical. Eulerian models, such as UAM or EKMA, use a mathematical statement of the mass conservation equation. This equation attempts to define and account for all the mass entering, produced within, and leaving an elemental volume. The goal of the equation is to account for all the transitions and transformations of mass within the volume element. This is the most complete type of equation because it can account for deposition, chemical reactions, emissions, and transportation.

The EKMA model is used to generate ozone isopleths (equal concentration lines) for various NO_x and HC levels. This kind of output is very useful to planners who wish to see if reductions of NO_x or HC or both, through TCM implementation, will have the desired effect on ozone concentrations. The EKMA model does not predict spatial distribution of ozone or the regional maximum, and its use is restricted to areas with a well defined urban core. The input requirements for the EKMA model are limited and they are the normally-measured parameters

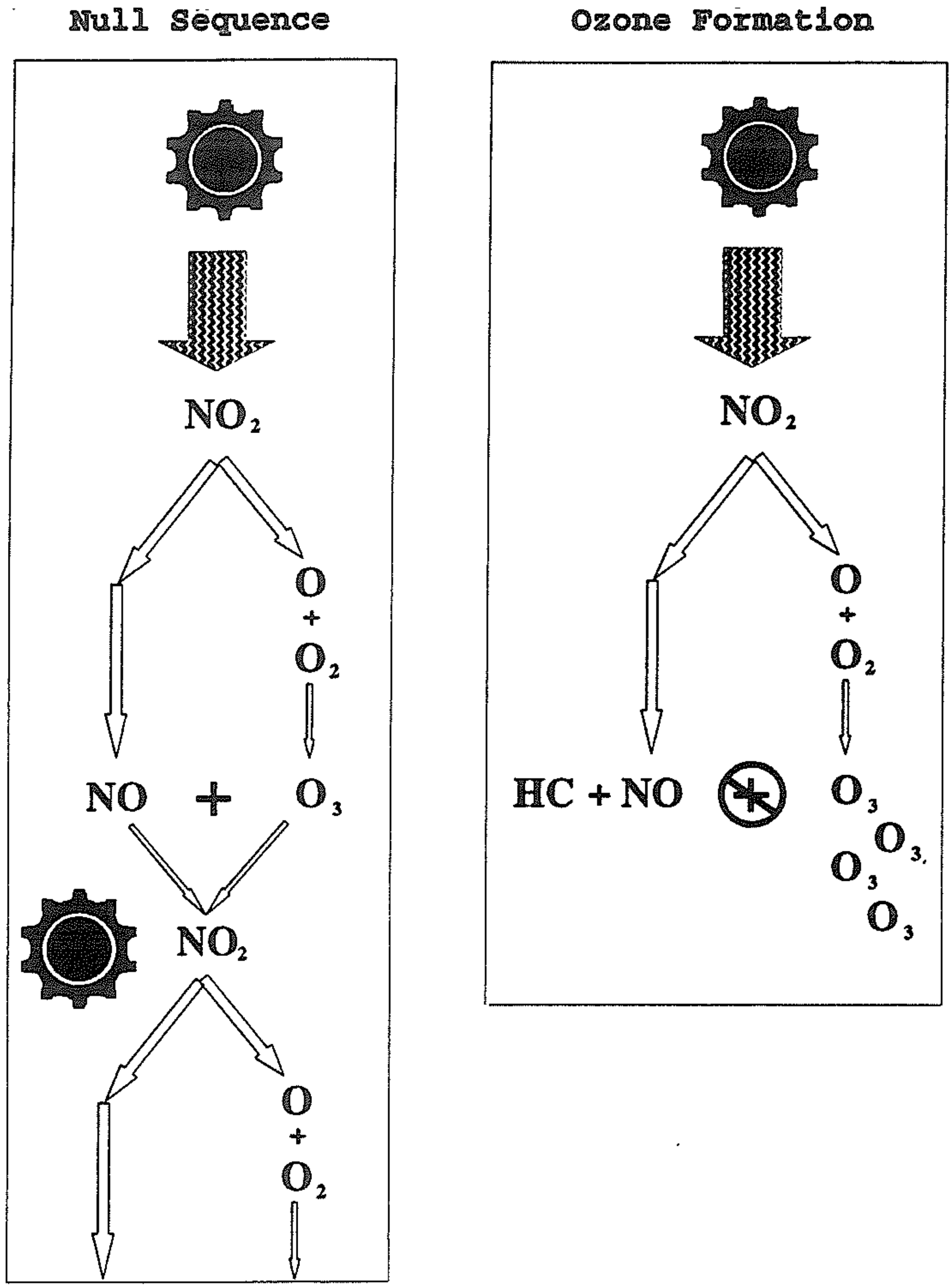

Figure 3. Simplified model of ozone formation (7)

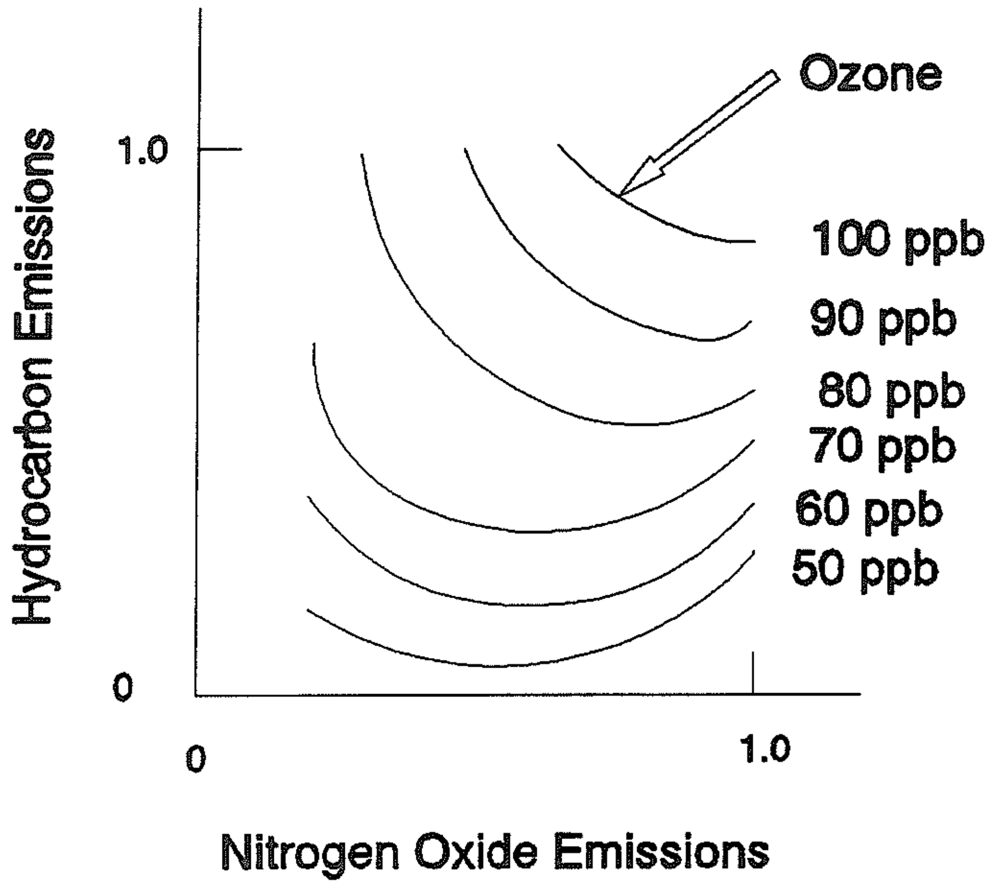

Figure 4. Nonlinearities of the precursor-ozone system (33).

PART III - POTENTIAL IMPACT OF TCMs IN A SERIOUS OZONE AREA

The Baton Rouge metropolitan area exceeds the NAAQS Standard for ozone an average of 10-15 times a year and is classified as a Serious Ozone area by EPA. Baton Rouge is located along the east bank of the Mississippi River and is intersected by Interstate 10. During the summer, when high temperatures average 91 °F, the region has four of the ideal conditions for ozone formation (7): 1) It is hot, 2) there is sufficient sun, particularly in the morning, 3) the air is stagnant and 4) there are several sources of ozone precursors. Table 3 shows that nature and industry are significant sources of precursors. Numerous petrochemical industries are located along the River and Baton Rouge's semi-tropical climate results in a thick green canopy of vegetation between May and October.

During the 1970's and 1980's, hydrocarbons were considered to be the controlling factor contributing to ozone formation in Baton Rouge. Despite an 82 percent reduction in industrial hydrocarbon emissions between 1972 and 1987, the area continued to exceed the ozone standard of 120 ppb. In order to understand better the ozone problem, the Department of Environmental Quality combined efforts with industry to form the Baton Rouge Ozone Task Force (OTF) in October 1988. The Task Force made several additions and improvements to air-monitoring stations in the area and gathered other relevant data. Based on results from the Urban Airshed Model, it was found that vehicular emissions of nitrogen oxides contribute significantly to the smog problem in Baton Rouge. These findings were not anticipated and current efforts are focusing on NO_x sources as well as volatile hydrocarbons. Although mobile sources only account for 16 percent of the NO_x emissions in Baton Rouge, cars are a major part of the regional air pollution because (7; p. 12):

1. Auto exhaust emissions are released at ground level where ozone pollution occurs. The NO_x goes directly into the reactive zone. Most industrial NO_x is released from tall smokestacks that extend high above the reactive area.

2. Automotive NO_x comes hot from the car's engine. It is pre-heated and ready to react in sunlight. Industrial NO_x emissions are cooler by comparison after they disperse to ground level.

TABLE 3
SOURCES OF HYDROCARBONS AND NITROGEN OXIDES IN BATON ROUGE

(For a typical hot, summer day)

	HYDROCARBONS (TONS/DAY)	NITROGEN OXIDES (TONS/DAY)
Industry	88	316
Mobile *	134	65
Biogenic	821	0
Miscellaneous	18	21
Total	1061	402

* Railroad emissions in Baton Rouge account for 2 tons/day of HC and 7 tons/day of NO_x.
1 ton = 2000 lbs.

Source: (7; p. 9)

DISCUSSION OF RESULTS

This final report has presented the current state of technical understanding of the impact of vehicular emissions on urban air quality. The entire analysis process was divided into four steps: the effectiveness of TCMs on improving air quality, the role of emission factors, an evaluation of mathematical models, and a presentation of smog formation theory. A number of analysis problems were identified related to insufficient data bases and the lack of uniform, impact assessment procedures. Evaluation of TCM impacts on travel behavior is also complicated by the influence of qualitative factors.

The effectiveness of TCMs on changing travel behavior varies greatly depending on location and many external factors. Often, data are only available for the most ideal circumstances. Hence, impact evaluations which appear in the literature tend to overestimate potential success. Very few proven and uniform technical procedures exist for assessing the impact of TCMs for a given urban area.

Although great progress has been made in estimating emissions from mobile sources, a number of problems remain to be resolved: What is the relative role of NO_x, HC, and CO emissions from hot car engines at ground level in smog formation? How are the magnitudes of the impacts due to mobile sources to be estimated and measured? Is there a lack of traffic data to implement assessment procedures?

Mathematical models currently used to analyze urban air pollution problems are quite complex. The increased sophistication of models has led to the concern that uncertainties in emissions and biogenic data may limit the accuracy of predictions. The relatively small impact of TCMs on regional air quality is currently very difficult to model accurately.

CONCLUSIONS

This report has evaluated the numerous steps and analytical tools currently available to evaluate air pollution problems associated with vehicular emissions. The ability to predict travel behavior changes due to TCMs is often limited by uncertainties encountered in the implementation process. Due to the site specific nature of these uncertainties, technical analyses must be linked to qualitative considerations in order to assess TCM effectiveness accurately. Hence, expert judgement continues to play a major role in estimating the impact of TCMs due to an absence of proven procedures and a lack of data. Impact evaluations based on judgement tend to be controversial.

Emission reductions due to individual TCMs are estimated to be 1-2 percent for a typical nonattainment area. Packages of TCMs are expected to reduce mobile emissions by up to 7 percent. Hence, the potential for TCMs to offset emission increases due to future VMT growth rates of 2 - 4 percent is debatable, especially over the long term. Emission changes due to TCMs are often difficult to quantify due to insufficient traffic data before, during, and after implementation. The impact of the relatively small TCM-induced emission reductions are currently difficult to quantify using regional air quality models. Until the roles of HCs, NO_x, and other precursors are better understood, TCMs which reduce all potential precursors simultaneously offer the greatest potential for reducing ozone formation.

Most of the research needs identified in this report are founded on the following weakness:

<u>Linkages between TCMs and Traffic Conditions</u>
Improved understanding of this linkage will require quantifying factors of success for TCMs in a transferable and organized manner.

<u>Linkages between Traffic Conditions and Vehicular Emissions</u>
This relationship appears to contain less uncertainty than the other two linkages. The quantifiable nature of this linkage is fairly well defined although the role of gross emitters and non-ideal operations is often debated.

<u>Linkages between Vehicular Emissions and Air Pollutant Concentrations</u>
The extremely complex nature of the physics and photochemistry of this relationship continues to be difficult to quantify in a useful way for transportation planners. The poorly defined relationship between vehicular emissions and ozone formation limits our ability to predict air quality improvements due to TCMs in urban areas.

Hence, uncertainties remain due to the qualitative and site-specific relationship between demand oriented TCMs and human behavior in the first linkage and the nebulous and inherently complex relationship between vehicular emissions and ozone concentrations in the third linkage. Moreover, the implementation of TCMs to limit ozone formation is a unique, multi-disciplinary endeavor requiring a holistic approach. TCMs are not a panacea, but rather an integral part of coordinated efforts to reduce urban air pollution.

RECOMMENDATIONS

A number of research needs have been identified based on the analysis problems evaluated during this investigation. Many of these problems are associated with the qualitative relationship between TCMs and human behavior, insufficient traffic and emission data, and the lack of uniform and proven analysis procedures. The following research needs are proposed to strengthen the weak linkages in technical analyses of the relationships between transportation control measures, vehicular emissions, and urban air quality.

Research Needs

Based on the preceding evaluation of the most recent literature available on the impact of implementing TCMs on urban air quality, the following research needs have been identified:

High Priority

Linkages between TCMs and Traffic Conditions

- Quantification of the important parameters required to assess the net impact of Trip Reduction Ordinances (and other coordinated TCM Packages) in order to develop optimal combinations of TCMs. Most of the studies on TCM Packages were conducted in the late 1970's and early 1980's. Trip Reduction Ordinances are viewed by EPA as the most effective and enforceable TCM.

- Development of a standard method to estimate TCM cost effectiveness in order to synthesize experiences from various areas (15). TCM effectiveness varies greatly from region to region. The important technical and qualitative factors determining TCM success need further clarification. Knowledge-based Expert Systems and Geographic Information Systems offer potential applications at both the national and local level.

- Development of innovative methods which enable effective TCMs to be implemented on days when the NAAQS will most likely be exceeded.

Linkages between Traffic Conditions and Vehicular Emissions

- Verification of emission changes due to TCMs and development of an emissions modeling process. Emission model outputs (emission estimates) are seldom compared with measured emission values (12).

Linkages between Vehicular Emissions and Air Pollutant Concentrations

- An improved methodology for locating monitoring networks to distinguish ambient conditions and TCM impacts on air quality.

- Better understanding of ozone; persistence, long range transport, seasonal variation and effects, and latitude and temperature correlations.
(29, 30, 31).

- Studies on the theoretical and observed relation between TCMs and the physical and chemical processes producing ozone at ground level and resulting from the combined, hot emissions of concentrated nitrogen oxides and volatile hydrocarbons from automobiles (7).

Medium Priority

Linkages between TCMs and Traffic Conditions

- The long-term effectiveness of TCMs should be analyzed. Very few studies have looked at TCM effectiveness as a function of time.

- The impact of work schedule changes on non-work trips and VMT during days off requires clarification (11). Development and impact assessment of non-work trip TCMs needs further study.

- The impact of TCMs on factors other than emissions need to be addressed. For example, what is the impact of traffic flow improvements on land use and planning?

Linkages between Traffic Conditions and Vehicular Emissions

- Identification and analysis of TCMs which are most appropriate for smart cars and highways need to be explored from an air quality point of view. The results of such studies need to be incorporated into the design of the smart systems.

- Evaluation of TCMs and innovative approaches not listed in the CAAA of 1990, including consideration of noon-time vehicular use, and other non-work trips.

- Development of national data base for detailed traffic data used in emission models (13). Traffic data are often insufficient, resulting in the use of assumed and approximate data.

Linkages between Vehicular Emissions and Air Pollutant Concentrations

- Total emissions of nitrogen oxides in the U.S. rose 7% between 1970 and 1988. All other conventional air pollutants have declined since 1970. During the 1980's the impact of TCMs focused on reducing hydrocarbons. In the nonattainment areas where nitrogen oxides are suspected of being the controlling factor in smog formation, TCM analysis should also focus on their reduction. In addition, the potential increase in local ozone levels due to nitrogen oxide reductions needs to be evaluated.

- Evaluation of the uncertainties in data and models for each step of TCM impact analysis in order to identify the step with the greatest degree of uncertainty.

- The role of mobile emissions in clean air sheds (those that meet the standard, i.e., New Orleans) needs to be analyzed and applied to non-attainment areas, i.e., Baton Rouge.

- Refinement of the vertical and horizontal concentration and turbulence distribution patterns. (14, 15, 16, 17,18,19).

- Boundary layer representation and plume interaction (14,20,21).

Low Priority

Linkages between TCMs and Traffic Conditions

- The quantification and empirical verification of the relation between congestion and VMT growth rates. VMT growth rates have appeared to be independent of the degree of congestion (5).

- Study of the significant parameters which determine the relation between the status of existing transit use and new mode choice strategies. In some areas, new mode-choice oriented TCMs have been successful despite high transit use prior to the introduction of the TCMs.

- The relative effectiveness of incentives versus disincentives needs to be identified (11).

- Traffic forecasts within 20 percent accuracy are considered good (6). This relatively high degree of uncertainty needs to be evaluated with respect to the impact analysis of TCMs.

- Impact of TCM implementation needs to distinguish between local and regional effects in greater detail.

- A greater emphasis must be placed on reporting and studying failures and shortcomings of TCMs. The underlying reasons for these failures must be incorporated into future control strategies.

- Flexible TCMs which can be modified to account for long-term, external trends need to be developed in order to offset future growth in VMT and non-work trips.

Linkages between Traffic Conditions and Vehicular Emissions

- Methods and tools for improved transfer of knowledge between various local and national professionals (Air Quality staff, Transportation Planners and MPOs, Modelers, Scientists, Politicians...) are needed in order to implement, monitor, compare and enforce cost effective TCMs. Effective communication will require determination of the essential factors which determine success.

- Better emissions spectrum representation: hot and cold starts, new reformulated fuels, high emitters, driving modes, etc.
(22, 23, 24, 25, 26).

Linkages between Vehicular Emissions and Air Pollutant Concentrations

- Transportation management involving the public has been relatively successful. Often times, the people impacted the most by air pollution associated with automotive emissions are low income households along congested routes. High ozone concentrations are particularly harmful for people with breathing problems, specifically children and the elderly. The incorporation of members of these households into the technological innovation process is seldom done and might be considered in the future.

- The interaction between vegetation and car emissions along congested roadways is not well understood. Optimal combinations of vegetation and TCMs need to be identified to limit ground level smog formation.

- Refinement of the biogenics; inventories, chemistry, and effect on urban areas
(17, 18, 27, 28).

- Refinement of vehicle and building wake-dispersion parameters and the effects of atmospheric stability on this dispersion
(32, 16).

- Better understanding of low chemical concentration and night-time chemistry
(19, 17, 18).

- Refinement of aerosol chemistry and processes, and depositional rates and effects
(32, 19).

- Assessment of the impact of TCMs on indoor air pollution in buildings near congested arteries.

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