TSM

An Assessment of Impacts

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In cooperation with:	Environmental Protection Agency

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Fred A. Wagner, Keith Gilbert

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Alan M. Voorhees, Inc.
7798 Old Springhouse Lane
McLean, Virginia 22101

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Contributing Team Members: Steven Shapiro, James E. Watt,
William S. Herald, William A. Stimson

16. Abstract

This report provides an assessment of the impact of areawide applications of various classes of TSM actions. Individual Transportation System Management actions are grouped into four classes, according to their impact on transportation supply and travel demand. For each of these classes, computations are performed to determine how a major multi-year program applying these actions would affect the area's vehicle miles traveled and vehicle hours traveled. The results will serve to help local areas in developing appropriate transportation measures for use in local TSM plans as required by DOT regulations and SIPs as mandated, by the Environmental Protection Agency.

The second portion of the document contains six working papers describing experience with and impacts of some of the major TSM actions. The appendix explains the development of the methodology that led to the findings in this report.

TSM actions include a wide range of transportation improvements from basis traffic engineering to a variety of transit improvements, parking stragegies, and pricing proposals. Under DOT regulations, urban areas with population greater than 50,000 are required to develop TSM plans that document their strategy for improving air quality, conserving energy, and increasing the efficiency of the overall transportation system.

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EXECUTIVE SUMMARY

This report summarizes interim results of research designed to quantify the impacts that the many TSM actions have on the transportation system. Through the research methodology, all TSM actions are divided into four action classes; areawide impact assessments and cost-effectiveness analysis are then performed for each action class and for strategies consisting of combinations of classes. The ultimate aim of this research is to assist local areas to develop TSM programs relating to their specific goals and objectives.

CLASSES OF TSM ACTIONS

The conceptual approach of this research is grounded in transportation supply-demand theory, and is used to assess the effects of different actions in producing "shifts" in transportation system equilibrium. For example, a ridesharing program would reduce demand for vehicle travel, while truck restrictions would enhance highway supply. The use of this concept as a methodology resulted in the discovery that all TSM actions could be split into four categories of actions as a means of understanding their impacts and interrelationships. These four classes and their component TSM actions are as follows:

Class A	Demand reduced	Ridesharing, Transit improvement, Bicycle facilities, Paratransit, Pricing incentives
Class B	Supply increased	Traffic engineering, Freeway management, Truck restrictions, Flexitime
Class C	Demand reduced and Supply reduced	Preferential treatment of HOV (take-a-lane), Auto restricted zones, Parking management
Class D	Demand reduced and Supply increased	Preferential treatment of HOV (add-a-lane)

This conceptual approach is used as a framework for quantifying the order of magnitude of areawide impacts of TSM action classes and multi-action strategies, based on two variables: vehicle miles traveled (VMT) and vehicle hours traveled (VHT). While collapsing of major impacts into two key indicators of supply and demand is a rather radical simplification of traveler response to TSM, it is nonetheless believed to provide a highly useful global view of consequences of multi-action TSM programs which can be of significant value in policy-level strategic TSM planning.

IMPACTS OF TSM ACTIONS

Detailed analyses were performed of the impacts, costs, and cost effectiveness of six generic types of TSM action. These analyses appear in Part Two of the report. Additional generic types of TSM action were analyzed in a more cursory manner, relying on the results of recent theoretical and empirical evaluations carried out by others.

All of these impact assessments are aimed at estimating upper limit potential of areawide impacts of different TSM actions which are possible to achieve through comprehensive programs of action implemented over a five-year period. This implementation scenario implies major expansions of the level of TSM effort expended by urban area transportation agencies, compared with prevailing TSM programs.

Figure E-1 shows calculations of work-trip supply-demand equilibrium changes for each major class of action. The impacts of three different combined TSM strategies are also computed. These are:

1. A mobility dominant strategy, comprised of TSM action classes A, B, and D.

2. An energy conservation/emissions reduction strategy, comprised of TSM action classes A, C, and D.

3. All TSM actions combined.

One can see from Figure E-1 that actions within Class C have the greatest potential for reducing VMTs. These include introduction of diamond lanes onto freeways, auto restricted areas within center cities, and the wide variety of parking management strategies. The action class providing the most effective means of reducing vehicle hours traveled was Class B, consisting of traffic engineering, ramp metering, truck restrictions, and flexitime. These types of actions, however, had the side effect of increasing VMTs to some extent.

While sizeable work-trip VMT reductions are possible through fairly massive introduction of TSM actions throughout a metropolitan area, one finds that non-work off-peak trip impacts are dramatically different. One of the reasons for this is that it is inherently more difficult to effect shifts to ridesharing and transit for these trips. Also, one finds that the home-based auto availability that results from commute-shifts to high-occupancy modes can cause a sizeable increase in VMT from use by other members of the household. The non-work-trip areawide supply-demand equilibrium calculations for each major class of TSM action, plus the combined strategies, are shown in Figure E-2.

TSM Strategy	Work Trip Changes After Equilibrium is Reached (in percent) VMT	Travel Time
Class A, Exclusive of Pricing Actions Which Reduce Travel Demand	-5.3	-5.3
Pricing Actions Alone	-2.4	-2.4
Class B Actions Which Enhance Highway Supply	+0.6	-9.4
Class C Actions Which Reduce Demand and Degrade Supply	-6.0	-4.9
Class D Actions Which Reduce Demand and Enhance Supply	-0.6	-1.4
Combined Strategies		
Class A, B, & D	-5.4	-16.1
Class A, C, & D	-11.9	-11.6
Class A, B, C, & D	-11.4	-21.0

Note: These numbers are derived from Figure 9 of the report, which contains estimates for both low and medium elasticities of demand with respect to travel time. The numbers in this chart are an average of the results for these two levels.

FIGURE E-1

IMPACT OF TSM ACTION CLASSES ON WORK TRIP VMT AND TRAVEL TIME FOR PROTOTYPICAL URBAN AREA OF ONE MILLION PEOPLE

TSM Strategy	Non-Work-Trip Changes After Equilibrium is Reached (in percent) VMT	Travel Time
Class A, Exclusive of Pricing Actions Which Reduce Travel Demand	+1.2	+0.2
Pricing Actions Alone	-6.1	-1.2
Class B Actions Which Enhance Highway Supply	+2.2	-7.1
Class C Actions Which Reduce Demand and Degrade Supply	+2.0	+0.4
Class D Actions Which Reduce Demand and Enhance Supply	+0.2	Negl.
Combined Strategies		
Class A, B, & D	+3.6	-6.9
Class A, C, & D	+3.3	+0.6
Class A, B, C, & D	+5.5	-6.7

Note: These numbers are derived from Figure 10 of the report, which contains estimates for both low and medium elasticities of demand with respect to travel time. The numbers in this chart are an average of the results for these two levels.

FIGURE E-2

IMPACT OF TSM ACTION CLASSES ON NON-WORK TRIP VMT AND TRAVEL TIME FOR PROTOTYPICAL URBAN AREA OF ONE MILLION PEOPLE

COST-EFFECTIVENESS ANALYSIS

The research calculated order-of-magnitude estimates of annual public agency costs of implementation and continuing operation of each TSM action for a hypothetical urban area of 1 million population. Using this information, cost-effectiveness figures can be determined, showing the cost of various TSM actions by VMT reduced and VHT reduced. These figures appear in Figure E-3. They show that:

- With respect to the objective of reducing VMT: Ridesharing stands out as the most cost-effective demand reduction strategy with a cost of only 1 cent to 2 cents per VMT reduced.

- Both express bus and local bus service expansions cost approximately 40 cents per VMT reduced, while comprehensive preferential treatments for HOV's cost an estimated 16 cents per VMT reduced.

- With respect to the objective of time savings through reduced VHT: Signal timing optimization is the most effective strategy--at 2 cents per VHT saved.

- Work rescheduling and computerized traffic control systems have approximately equal cost-effectiveness, at 25 cents per VHT saved. Freeway surveillance and control have higher costs, at approximately $1.00 per VHT saved.

TSM Action	Cost Per VMT Reduced	Cost Per VHT Reduced
Ridesharing	2¢	
Current Programs	1¢	
Major Expansion of Programs	40¢	
Express Bus	43¢	
Local Bus (50% increase)		
Work Rescheduling		25¢
Signal Timing Optimization		2¢
Computerized Traffic Control		27¢
Freeway Surveillance and Control		$1.00
Truck Restrictions/Enhancements		50¢
Comprehensive Preferential Treatment	16¢	
Exclusive HOV Lanes	$1.30	$8.00

FIGURE E-3

COST-EFFECTIVENESS OF SELECTED TSM PROGRAMS

PREFACE

UMTA, FHWA, and EPA have underway a research project designed to advance the state-of-the-art of Transportation System Management (TSM) by assessing the impact of areawide applications of various classes of TSM actions. Results of this research will help in identifying appropriate transportation measures for use in local TSM plans, as required by DOT regulations, and the State Implementation Plans (SIPs), as mandated by the Environmental Protection Agency pursuant to the Clean Air Act. The research is an ongoing effort, but in the interest of getting information to local areas to assist in the initial submission of the SIPs, this report has been prepared as an interim summary of the research findings.

TSM actions include a wide range of transportation improvements from basic traffic engineering to a variety of transit improvements, parking strategies, and pricing policies. The analysis also provides an assessment of the relative cost-effectiveness of the actions in each class and identifies prototypical programs of TSM actions for a number of generic types of cities or problems. The analysis found that these actions could be brought into clearer focus by classifying them according to their impacts on transportation supply and travel demand. For each of the resulting four classes, computations were performed to determine how an areawide application of these actions would affect the area's vehicle miles traveled (VMTs) and vehicle hours traveled (VHTs).

The first chapter describes the research methodology and explains how the many TSM actions were divided into four distinct action classes. Chapter 2 contains the major findings of the report, including detailed impact assessments for the many types of TSM actions. Chapter 3 describes the development and results of the cost-effectiveness analysis of the individual action classes, and Chapter 4 summarizes the prototypical programs developed for a variety of goal mixes and city types. These improvements can accomplish a number of goals--increases in mobility, reduced travel time, reduction of VMT, energy conservation, and improved air quality.

Part Two of the report consists of working papers on six TSM action categories, providing more detail as to national experience in using these actions and their effectiveness in achieving specific goals. The ongoing research effort will result in the preparation of similar papers on actions not covered in this report. The appendix is an integral part of the analysis, but was taken out of the body of the report due to its technical nature. It describes the analysis which led to the division of TSM actions into the four classes of impacts.

This project was jointly funded by the Urban Mass Transportation Administration and the Federal Highway Administration. Close cooperation was also maintained throughout the project with the Environmental Protection Agency, as TSM measures can be a key element in the development of areawide plans to improve air quality.

PART ONE

Summary Report

CHAPTER 1

THE FOUR TSM ACTION CLASSES

Much emphasis in the past has been devoted to "project-level" impact assessment of diverse individual types of TSM actions, with less attention directed at "areawide" consequences of major groupings of actions and their interactions with respect to policy-oriented goals and objectives. In this work, a conceptual framework for overall TSM program assessment is devised within which areawide impacts and interactions can be quantified.

RESEARCH METHODOLOGY

The principal methodology used for analyzing TSM impacts and interactions in this research is based on the fundamental concept of transportation supply and demand equilibrium. The existing transportation situation in an urban area can be characterized by two fundamental curves:

1. The transportation <u>supply</u> curve which depicts the level of service provided by the transportation system as a function of the demand for personal travel.

2. The transportation <u>demand</u> curve which depicts the quantity of travel demand which the public will generate at different levels of service experienced in traveling.

Plotting supply and demand curves together on the same graph results in definition of the current <u>equilibrium</u> point, where the two curves intersect. TSM actions, indeed any event affecting transportation, may change either the supply curve, the demand curve, or both the supply and demand curves. In turn, the equilibrium point where the two curves cross is shifted from the initialpoint to a new point. This fundamental concept of economics has been applied in this research as a tool for clarifying and estimating the impacts of TSM actions. A full description of the methodology appears in the Appendix.

The primary result from application of this methodology is that the large number of TSM actions can be grouped into four major classes depending on how each action affects the supply and/or demand curves (and the resultant shift in equilibrium). TSM actions have been so grouped, as explained subsequently, and the shift in supply-demand equilibrium for each is explained.

After describing how the TSM actions were classified, this chapter reports quantified, order-of-magnitude estimates of the areawide impacts of each class of action on vehicle miles traveled (VMTs) and vehicle hours traveled (VHTs). The calculations, performed for both work and non-work trips, are derived principally from the materials contained in Part Two (the supporting papers) of this report. For actions not covered in these papers, similar information was obtained from recent theoretical and empirical evaluations carried out by others. The final section of this chapter reports conclusions relating to the potential usefulness of TSM actions to achieve specific goals of local areas.

GROUPING OF TSM ACTIONS INTO MAJOR CLASSES

The four TSM action classes are as follows:

Class A: Actions Which Reduce Demand for Vehicle Travel

This class includes actions which induce travelers to shift from lower occupancy vehicles into higher occupancy vehicles (transit and ridesharing) or non-motorized travel modes, or reduce trip frequency or trip length, thereby lowering VMT demand, but without altering highway supply. TSM actions included are:

- Encourage ridesharing (carpooling and vanpooling)
- Transit marketing
- Express bus/park-ride
- Local transit route and schedule improvements
- Paratransit systems
- Bicycle and pedestrian facility improvements
- Pricing (reducing taxes, tolls, fees, or fares for HOVs or increases for autos)

The impact of Class A actions on supply and demand is illustrated in Figure 1A. When demand is reduced, the demand curve is shifted to the left while the highway supply curve is unchanged. The demand reduction results in decreased travel time for the remaining vehicles, and the supply-demand equilibrium point is shifted downward and to the left.

A special action in this class is:

- Work rescheduling (four-day work week), which reduces travel demand during commuting hours.

Class B: Actions Which Enhance Highway Supply (i.e., Improve Traffic Flow)

This class includes a wide range of traffic engineering and control measures which reduce the travel time experienced at given levels of VMT demand. Actions in this class include:

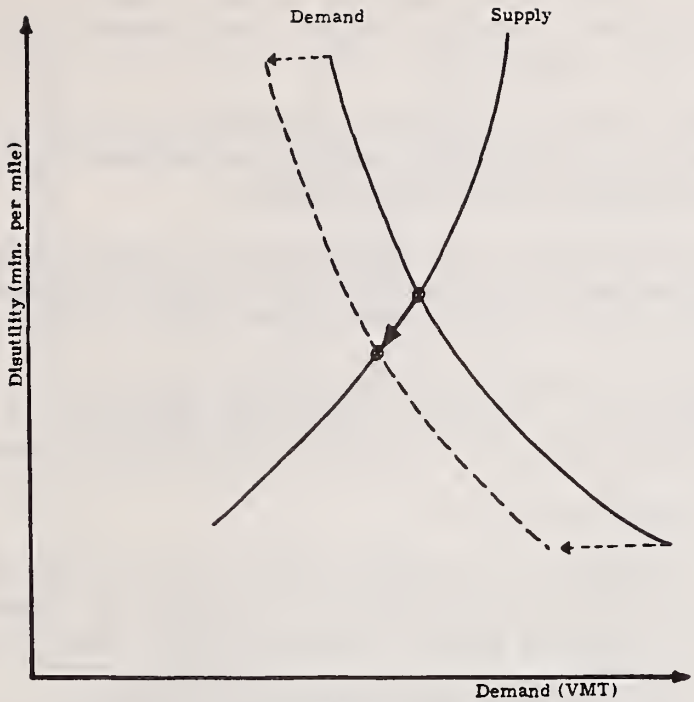

FIGURE 1-A

CLASS A, ACTIONS WHICH REDUCE DEMAND FOR VEHICLE TRAVEL

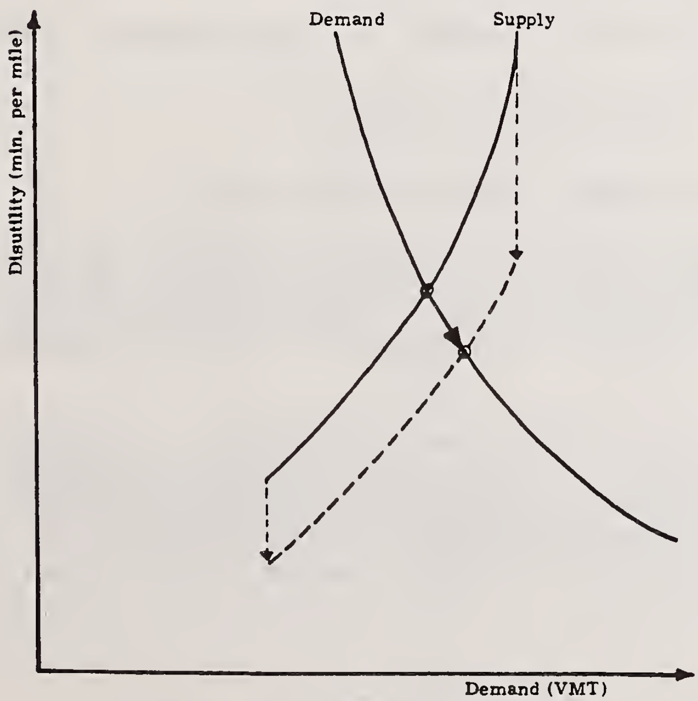

FIGURE 1-B

CLASS B, ACTIONS WHICH ENHANCE HIGHWAY SUPPLY

- General Traffic Engineering (a whole host of traffic regulation, control, and minor design improvements aimed primarily at reducing travel time).

- Freeway Traffic Management (including incident surveillance and response, ramp control, and driver advisory information aimed at upgrading freeway performance).

- Truck Restrictions and Enhancements (aimed at reducing the conflict between truck and automobile operations and facilitating curbside pickup and delivery operations of trucks).

The impact of Class B actions is illustrated in Figure 1B. The supply curve is shifted downward (i.e., improved) while the demand curve is unchanged. The initial decrease in travel time results in subsequent increases in VMT.

A special action in this class is:

- Work rescheduling (staggered hours and flexitime) shifts some work trip VMT from periods of higher to lower congestion, thereby reducing overall average travel time per vehicle mile.

<u>Class C: Actions Which Reduce Demand and Degrade Supply</u>

These are actions primarily aimed at inducing travelers to shift from lower occupancy vehicles to higher occupancy vehicles or non-motorized travel modes but do so by increasing general vehicular travel time while reducing travel time for high-occupancy vehicles (HOVs) or for non-motorized modes. Actions in this class include:

- Preferential treatment for high-occupancy vehicles (take-a-lane)

- Auto restricted zones (ARZs)

- Parking supply reduction (off-street)

It should be noted that off-street parking supply reduction, and in some cases ARZs, do reduce travel time along the highway, per se, but often increase the portal-to-portal time of auto users who select an available and/or less costly parking place further from their destination than previously used.

The impacts of Class C actions are illustrated in Figure 2A. The supply curve is shifted upward (i.e., degraded), and the demand curve is shifted to the left (i.e., reduced). The equilibrium point is shifted to the left and either upward or downward depending on the slopes of the supply-demand curves and the magnitudes of changes from the initial curves.

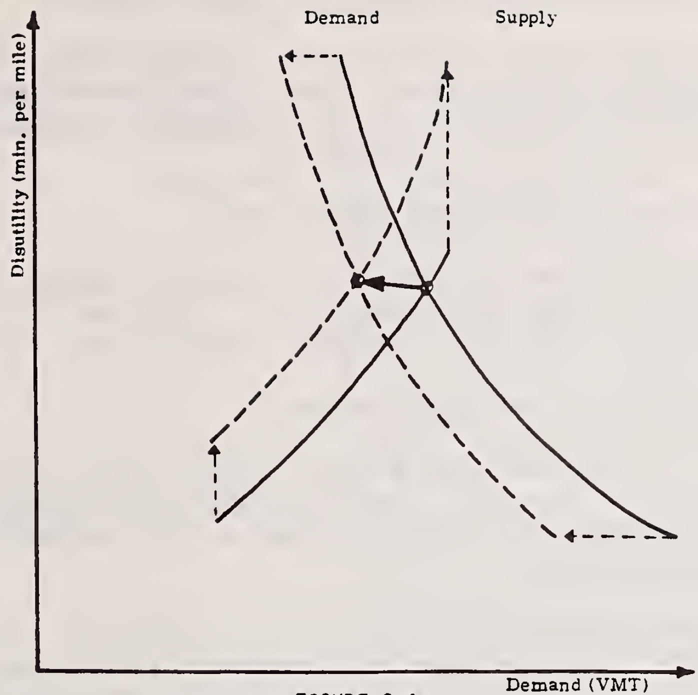

FIGURE 2-A

CLASS C, ACTIONS WHICH REDUCE DEMAND AND DEGRADE SUPPLY

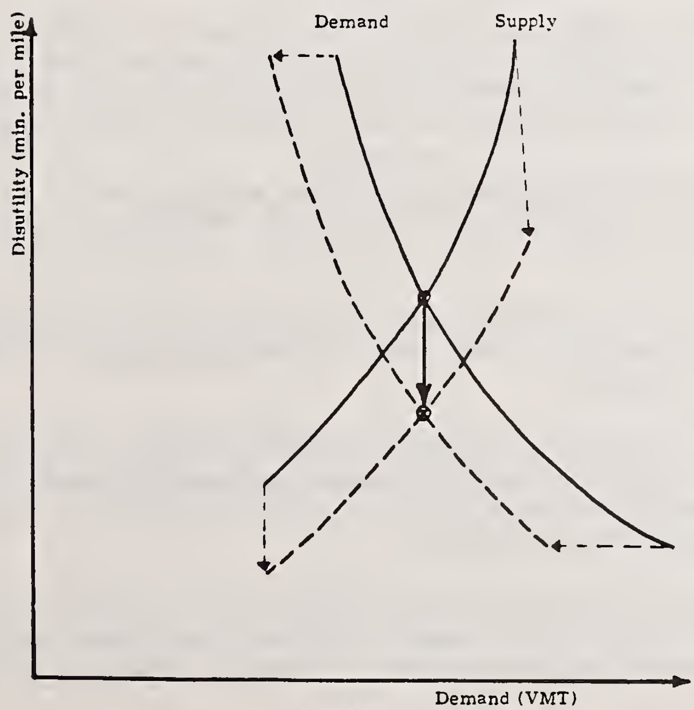

FIGURE 2-B

CLASS D, ACTIONS WHICH ENHANCE SUPPLY AND REDUCE DEMAND

Class D: Actions Which Enhance Supply and Reduce Demand

Such actions simultaneously decrease the general travel time for given levels of VMT and decrease HOV travel time by even greater amounts to induce travelers to shift from lower to higher occupancy vehicles. The most striking example of this type of action is:

- Preferential treatment (add-a-lane)

such as the construction of added exclusive lanes for buses and carpools on the Shirley Highway in the Washington, D.C., area and the San Bernardino Freeway in Los Angeles. Another possible action in this category is:

- On-street parking restrictions

which decreases the disutility of highway travel while simultaneously reducing the supply of parking thereby possibly discouraging automobile trips. Any VMT reduction may be offset, however, by increasing circulating travel in search for parking.

The impacts of such actions are illustrated in Figure 2B. The supply curve is shifted downward (i.e., enhanced), since additional capacity is added, and the demand curve is shifted to the left (i.e., reduced) as a result of the preference given to high-occupancy vehicles or reduced trips by auto. The equilibrium point is shifted downward and either to the left or right, depending on the slopes of the supply-demand curves and the magnitudes of shifts of the initial curves.

SUMMARY OF ACTION CLASSES AND IMPACTS

Figure 3 presents a summary listing of the grouping of TSM actions into four major classes--A through D. Figure 4 illustrates the likely general directions of shifts in supply-demand equilibrium resulting from each of the four major TSM action classes, based on the concepts in the preceding sections.

Several inferences may be drawn concerning which types of actions are most desirable to pursue depending on the goal mix promulgated for a given urban area.

If energy conservations and emissions reduction are the predominant goal, then conceptually (without reference to the magnitudes of impacts of the four TSM action classes):

- Class A actions should receive highest priority since these tend to both reduce VMT demand and reduce travel time, and shift the equilibrium point in a nearly optimum direction for energy and emissions benefits.

- Class C actions should receive next highest priority since these also produce nearly optimum directional shifts for energy and emissions reductions. Class C actions can be expected to

TSM Action Class	Impact On: Highway Supply	Impact On: Automobile Demand	Examples of TSM Actions
A	—	Reduce	Encourage Ridesharing Transit Marketing Express Bus/Park-Ride Transit Route and Schedule Improvements Paratransit Systems Bicycle and Pedestrian Facilities Pricing (transit fare reductions) Pricing (reduced taxes, tolls, fees, and fares for HOV's, or increases for autos) Work Rescheduling (4-day week)
B	Enhance	—	General Traffic Engineering Freeway Traffic Management Truck Restrictions and Enhancements Work Rescheduling (staggered hours and flexitime)
C	Degrade	Reduce	Preferential Treatment for HOV's (Take-a-Lane) Auto Restricted Zones Parking Supply Reduction
D	Enhance	Reduce	Preferential Treatment for HOV's (Add-a-Lane)

FIGURE 3

SUMMARY OF TSM ACTION CLASSES

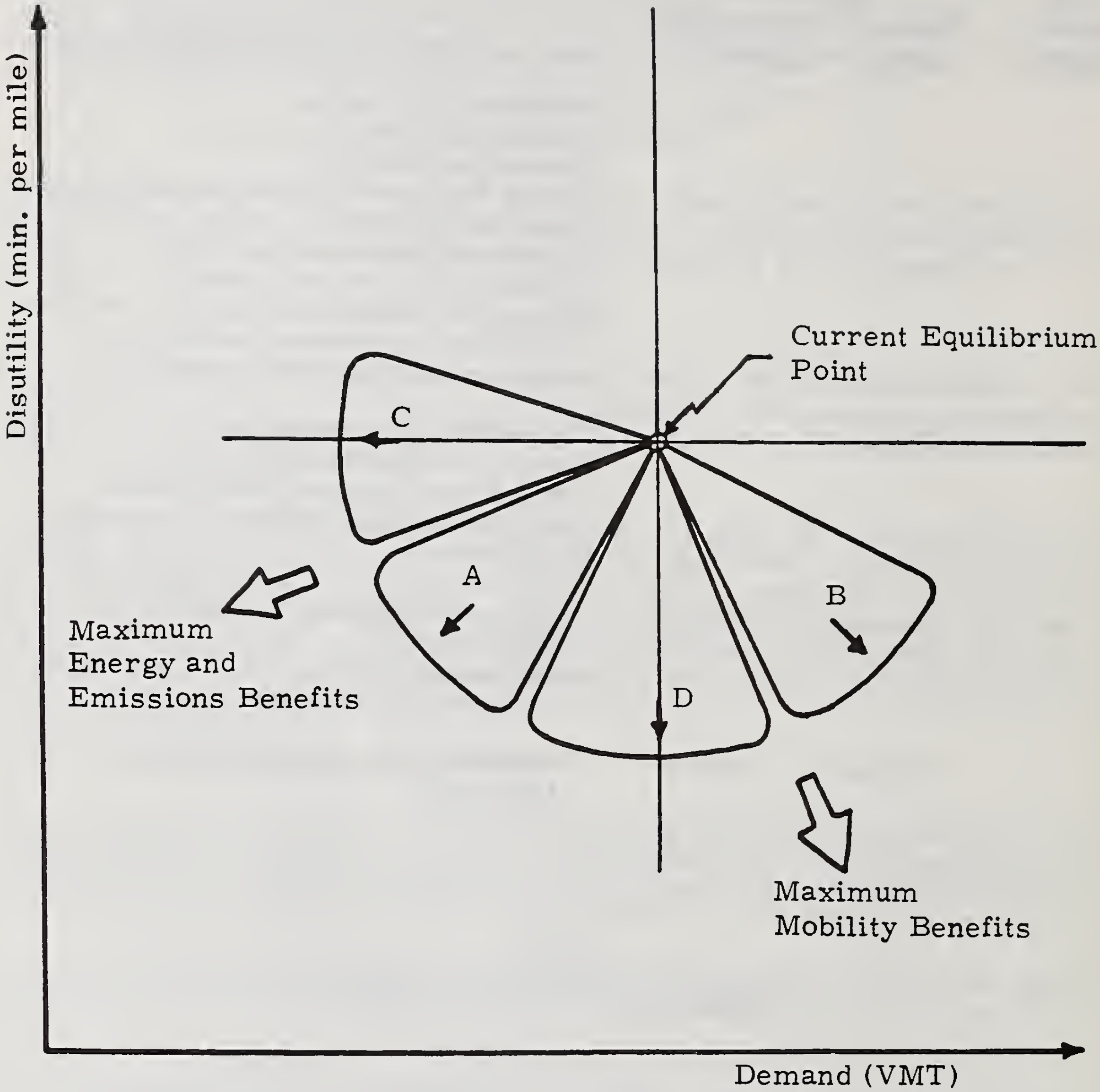

FIGURE 4

SHIFTS IN SUPPLY-DEMAND EQUILIBRIUM RESULTS FROM DIFFERENT CLASSES OF TSM ACTION reduce VMT by the largest proportions; however, this is gained at the possible degradation of travel time, user cost, and possible reduction in freedom of choice of desired travel behavior.

- Class D actions are less desirable, although they are fairly certain to save energy and emissions by reducing travel time and affecting VMT by marginally small amounts--either upward or downward.

- Class B actions are conceptually least desirable as an independent action since, although substantial travel disutility improvements may be produced, substantial VMT demand increases will be accommodated. Depending on the demand elasticity, energy and emissions may actually increase as a result of implementing Class B actions. Conversely, however, energy and emissions rates may be reduced by amounts which more than offset the induced VMT increases, thus reducing total energy and emissions.

If mobility goals are paramount, as they may be if current levels of congestion are severe, or if energy availability or air pollution are not perceived as major problems, then conceptually (without reference to the <u>magnitudes</u> of impacts of the four different classes of TSM action):

- Class D actions should receive highest priority, since the direction of shift in equilibrium is near optimum for mobility improvement and energy and emissions will also be improved somewhat.

- Class B actions are the next most desirable since they afford substantial reductions in travel time while permitting increased VMT demand to be served. However, there is an uncertainty as to whether energy and emissions will be increased or decreased.

- Class A actions are also desirable from a mobility standpoint since travel time is substantially reduced and changes in travel demand are the result of free choices. Energy and emissions are also significantly reduced.

- Class C actions are least desirable with respect to mobility improvement since travel time may actually be increased and portions of the VMT reduction may require undesired individual changes in travel behavior as well as user cost increases for those who must continue to rely on private automobiles.

If the goals formulated for a given urban area strike an even balance between mobility and environment, then:

- Class A and Class D actions are most desirable since certain improvements in both mobility and energy and emissions reduction will result, and user costs are likely to be reduced.

- Class C actions are less desirable since, although energy and emissions will be substantially reduced, benefits may be gained at the cost of reduced mobility.

- Class B actions are also less desirable since, although mobility will be substantially improved, increases in energy and emissions may be increased.

All of these above inferences about desirability of TSM actions with respect to different goals relate only to short-term and intermediate-term conditions in which areawide personal travel demands are relatively stable. A later section addresses the consequences of future increases in personal travel demand resulting from population growth. Consideration of the growth factor sheds a different light on the desirability of implementing the alternative major classes of TSM action, as is shown in the Appendix (see A-14).

CHAPTER 2

IMPACTS OF TSM ACTIONS

In this section, the potential orders of magnitude of areawide impacts of TSM actions within each of the four major classes of action A through D are quantified. First, the primary impacts of each action either in shifting the highway supply curve or the highway demand curve, or both, are quantified. Second, supply-demand equilibrium calculations are performed to estimate the nature and magnitude of the shift in existing equilibrium brought about by each action. These equilibrium calculations of percent change in VMT and percent change in average vehicular travel time are performed separately for work and non-work travel, since the impacts and the supply and demand elasticities differ for the two trip purposes, and are then combined to estimate total travel impacts.

As part of this research effort, detailed impact analyses were performed for six generic types of TSM actions:

- Ridesharing encouragement -- using employer-oriented carpool matching and promotion, preferential employee parking, and vanpooling
- Express bus -- including park-ride and marketing to support such services, but excluding any preferential highway treatments
- Local transit service expansion -- including expansion of route coverage, route restructuring, increased frequency, extension of service hours, and supporting marketing
- Work rescheduling programs -- including staggered hours, flexitime, and four-day work week
- Truck restrictions and enhancements -- with particular emphasis on better allocation of curb space, better enforcement of curb use restrictions, and removal of features which impair truck movements, in order to alleviate interference between truck operations and general traffic flow
- Auto restricted zones in the CBD

The findings of these analyses form the basis for areawide impact quantification for these actions. Impact estimates for other TSM actions not studied in detail in this research are taken from recent studies by others.

The process of estimating the order of magnitude of areawide impacts of VMT and travel time is viewed as a significant contribution to the state of knowledge of TSM actions. Most prior summaries of TSM impact potential have focused on localized project impacts and have not systematically extrapolated these findings to estimate areawide potential. Some TSM actions may exhibit very strong localized impacts, but their areawide impacts may be quite small because the breadth of applicability of the action throughout the urban area is limited. Other actions may appear to be less potent in a given location, but, if amenable to widespread areawide application, may produce more significant areawide impacts. Consequently, in order to fairly assess the relative merits of alternatives, it is important to quantify the areawide potential of all actions considered, using a common set of impact measures. This has been attempted in the current research.

In all cases, the impacts estimated are the orders of magnitude possible through maximum application deemed feasible for each action over the intermediate term future (i.e., roughly five years). It should be noted that it is rare that current implementations of the TSM actions have yet approached these maximum potential levels, but if substantially more comprehensive implementation efforts were pursued, the estimated impact levels appear within reach in the intermediate term. This implies, of course, significant expansion of prevailing levels of TSM effort and investment in urban areas. It is also important to emphasize that the impacts expressed in this chapter are generalized results across the range of American cities; individual cities have specialized characteristics which make strategy impacts and interrelationships between measures vary somewhat from city to city.

PRIMARY IMPACTS OF TSM ACTIONS

The primary impacts of the different classes of actions are defined as the initial thrust of the action prior to the supply-demand equilibrium process. For example, for Class A actions, the initial thrust is to shift the demand curve downward, and the primary impact considered is the percent shift in VMT at fixed levels of quality of travel (i.e., average travel time). For Class B actions, the initial thrust is to improve quality of travel, and the primary impact considered is the percent shift in average travel time at fixed levels of travel demand (i.e., VMT). Subsequent calculations transform the primary impacts into supply-demand equilibrium changes by accounting for the interaction between VMT and travel time.

Although impacts in all cases are represented as point estimates, these are not meant to be interpreted as precise values, but rather as midpoints of a range of possible maximum impacts. In any case, substantive areawide applications of an action have not yet been experienced, hence the impact estimates are subject to considerable uncertainty and the range of achievable impacts may vary considerably by urban area, even assuming a high-quality implementation program.

Class A Actions

Presented in Figure 5 are estimates of the potential percent downward shift in areawide VMT, at constant levels of average travel time, of the following Class A actions:

- Ridesharing encouragement (carpooling, vanpooling, and preferential parking)
- Express bus

TSM Action	Percent Shift in VMT		
	Work	Non-Work	Total
Ridesharing encouragement (carpooling, vanpooling, and preferential parking)	-3.0	+0.5	-1.0
Express bus in all CBD corridors	-1.0	+0.2	-0.3
Local transit service expansion (bus miles + 50 percent)	-0.6	Negligible	-0.3
4-day work week (5 percent areawide participation)	-1.0	+0.5	Negligible
Combined Actions	-5.6	+1.2	-1.6

FIGURE 5

ESTIMATED ORDER OF MAGNITUDE OF POTENTIAL AREAWIDE IMPACTS OF SELECTED DEMAND-ORIENTED STRATEGIES ON VMT (CLASS A ACTIONS)

- Local transit expansion
- Four-day work week

Marketing of new or expanded transit services, ridesharing, and work rescheduling are included as integral components of these actions rather than being analyzed separately. Two other Class A actions which have not been explicitly analyzed are paratransit and bicycle/pedestrian facility improvements. It is believed, however, that in the short to intermediate term, these actions will add relatively insignificant VMT reduction to the overall Class A action impacts shown in the table.

The results indicate that combined Class A actions can potentially shift the areawide VMT demand curve downward by more than 5 percent for work trips and about 2 percent for all trips. Ridesharing appears to have the largest potential, contributing about half the total impact of the combined Class A actions. As a group, the Class A actions focus on shifting commuter types from drive-alone to higher occupancy modes of travel. As a consequence, non-work travel will tend to increase because of increased home-based auto availability during the day, an effect which substantially dilutes work-trip VMT reduction.

Another category of Class A (demand reduction) action is transportation pricing. In Figure 6, estimates of the percent shift in VMT, at fixed levels of average travel time, are given for several alternative pricing actions. These estimates are taken from recent demand forecasting research conducted by Cambridge Systematics, Inc., for the Federal Energy Administration. The pricing actions listed are major ones which have dubious short-range implementation potential. They are presented for purposes of comparison with the mode-shift actions summarized in Figure 5.

Doubling of gas price is by far the most potent demand reducer of the pricing actions considered. The other actions produce surprisingly low percent shifts in VMT. In particular, the relative insensitivity of work-trip VMT to price increases is apparent. The gas price doubling produces an estimated 5 percent downward shift in total VMT, primarily due to reductions in non-work travel. It is interesting to note that the mode shift strategies in Figure 5 appear to have greater estimated work-trip VMT reduction potential, and therefore greater congestion relief potential than the pricing actions; while the pricing actions have much greater total VMT reduction potential.

Once again, these are primary reactions, the intial thrust of action implementation before the system has responded with a shift in supply-demand equilibrium. The final impact may be dampened considerably as will be seen in subsequent paragraphs.

Class B Actions

Presented in Figure 7 are estimates of the potential percent downward shift in areawide travel time, at constant levels of VMT demand, of the following Class B actions:

Pricing Action	Percent Shift in VMT Work	Non-Work	Total
Gasoline price x 2	-1.4	-6.6	-5.1
CBD daily auto cost			
(Area licensing)			
(a) + 50¢/day	-0.7	+0.2	-0.2
(b) + $1.00/day	-1.3	+0.3	-0.3
Annual vehicle ownership tax			
(a) + $100/year	-0.2	-0.1	-0.1
(b) + $200/year	-0.3	-0.2	-0.2
Annual carpool tax rebate			
(a) $250/year	-0.2	+0.04	-0.05
(b) $500/year	-0.4	+0.1	-0.1
Combined Actions			
Gas price + Alternatives (a)	-2.5	-6.5	-5.45
Gas price + Alternatives (b)	-3.4	-6.4	-5.7

Source: Cambridge Systematics Inc. "Carpool Incentives: Analysis of Transportation Impacts," prepared for the Federal Energy Administration, June, 1976, p. 58. (Forecasts made for Washington D.C. Metropolitan Area.)

FIGURE 6

ESTIMATED ORDER OF MAGNITUDE IMPACT OF ALTERNATIVE PRICING STRATEGIES ON VMT (CLASS A ACTIONS)

TSM Action	Percent Shift in Average Travel Time Work	Non-Work	Total
*Areawide traffic signal timing optimization	-6.0	-6.0	-6.0
*Computerized traffic signal system master control (CBD + 50 percent of areawide system)	-1.5	-1.5	-1.5
*Freeway surveillance and control on congested freeways	-1.5	Negligible	-0.5
CBD truck restrictions and enhancements	-0.5	Negligible	-0.2
Variable work hours (20 percent areawide participation)	-0.5	Negligible	-0.2
Combined Actions	-10	-7.5	-8.4

*Source: Wagner, F. A. "Urban Transportation Energy Conservation: Analysis of Traffic Engineering Actions," prepared for the U.S. Department of Energy, December 1977.

FIGURE 7

ESTIMATED ORDER OF MAGNITUDE POTENTIAL AREAWIDE IMPACT OF SELECTED SUPPLY-ORIENTED STRATEGIES ON AVERAGE TRAVEL TIME (CLASS B ACTIONS)

- Optimization of Traffic Signal Timing -- The action is a continuing management effort requiring periodic measurement of traffic patterns in the areawide signalized arterial network and computation of corresponding optimum timing plans for different periods of the day. All signals in the urban area are included and can be benefited by this action.

- Implementation of Computerized Master Control Systems for the Signalized Network -- This action entails providing advanced master control systems to make possible a more flexible range of timing plans, and where appropriate, traffic-responsive control strategies which select or adjust timing based on actual fluctuations of traffic patterns. It is assumed that this action is applied to all signals in the CBD and to 50 percent of the remaining urban area signals.

- Freeway Surveillance and Control -- This action consists of various methods for real-time measurement and observation of freeway traffic conditions, incident detection and response, and entrance ramp metering systems to manage traffic demand on freeways where recurring traffic congestion occurs. Such systems can be applied to large portions of the freeway system, but the principal benefits are derived mainly along freeway sections which suffer daily recurrence of congestion due to bottleneck overloading.

- CBD Truck Restrictions and Enhancements -- This action focuses on measures to minimize interference between truck operations (particularly curbside pick-up and delivery operations) and general traffic.

- Variable Work Hours -- This action entails conversion to staggered work hours and flexitime, with the major focus on CBD employees. The intermediate term scenario assumes a maximum conversion to variable hours of 20 percent of the CBD employees, or about 5 percent of the areawide work force.

The impacts of traffic signal control improvements and freeway control systems were recently assessed by Wagner in a study for the Department of Energy, and are based on a substantial number of case studies throughout the United States using both empirical and simulation methodology. The potential impacts are quite large, especially for optimized signal timing and improved master control, because in most urban areas, signal operation is substantially sub-optimum. What's more, at least half the VMT in most urban areas is on the major surface arterial system, and travel time improvements on these facilities are possible throughout the day rather than just during peak periods. The estimated areawide impact for the two complementary signal control actions is on the order of 7.5 percent downward shift of travel time at fixed VMT levels.

Freeway surveillance and control has proven to have a large impact on congested freeways. However, benefits accrue primarily to work trips (i.e., peak periods) and only on sections of freeway where bottleneck queuing occurs, a condition characterizing only a small percentage of work-trip VMT (estimated at 4 percent of areawide work VMT in a recent San Francisco case study, for example). The estimated potential shift in areawide average travel time is estimated at 1.5 percent for work trips and 0.5 percent for total trips, impacts much smaller than achievable through surface arterial signal control improvements.

CBD truck restrictions and enhancements are viewed as having the potential to reduce the incidence of truck double parking by 50 percent through improved allocation and enforcement of curb use restrictions. Areawide potential shift in work trip travel time is estimated at 0.5 percent, and the percent improvement within the CBD would be approximately 10 times as great. Off-peak travel time improvement potential is negligible, and the areawide total impact for work and non-work approximates a 0.2 percent downward shift in travel time.

Variable work hours produce travel time improvements by shifting work trips for most congested peak periods to less congested commuting hours. Estimated potential downward shift in areawide average travel time is 0.5 percent for work trips and 0.2 percent for total trips. The most striking impact of variable hours is the reduction of peak period overcrowding in transit stations and vehicles, but no evidence exists to indicate that measurable mode shifts to transit occur as a result of variable hours. The ratio of peak to off-peak transit vehicles can potentially be reduced significantly as a result of flattening of transit demands, thereby lowering transit operating costs.

The estimated combined impact of Class B actions on areawide average travel time is 10 percent for work trips and more than 8 percent for total travel. The impact in congested zones and routes, particularly in the CBD and on radial corridors, will be substantially larger since three of the five actions considered are primarily applied in such locations. All of the Class B actions, in addition to enhancing automobile travel, also significantly reduce the line-haul travel times of buses. Consequently, the increases in travel demand due to mode shifts away from transit are not as large as one might suppose.

Class B actions aimed at enhancing highway supply appear to produce larger order-of-magnitude changes in travel characteristics than Class A actions aimed at reducing travel demand. Class B actions have frequently not received the deserved degree of emphasis in TSM planning. Furthermore, although the Class B actions analyzed are major ones, they do not represent the full range of potential traffic engineering actions. Application of additional measures such as spot improvements in geometric design on streets and freeways, on-street parking restrictions, turning movement controls, one-way street patterns, intersection channelization, removal of unwarranted signals, and the like, if more aggressively implemented, have the potential for extending the impacts of Class B actions beyond that indicated in Figure 7.

Class C Actions

Presented in Figure 8 are estimates of the potential percent shift in VMT (at fixed travel time levels) and the percent shift in travel time (at fixed VMT levels) of the following Class C actions:

- Comprehensive Areawide Preferential Treatments for High-Occupancy Vehicles -- This action encompasses application of a variety of preferential treatments for buses and carpools, including reserved lanes on freeways and surface arterials, preferential entrance ramps, and bus priority signal timing and preemption, but does not include added lanes for exclusive use by high-occupancy vehicles such as the Shirley Highway (a Class D action).

- Large-Scale CBD and Restricted Zones and Commuter Parking Supply Restraint in the CBD -- This action primarily reduces the attractiveness of work trip driving to the CBD by adding to out-of-vehicle travel time (walk time) for the private auto mode. In some instances, in-vehicle travel time of autos might also be degraded within the CBD, although recent ARZ studies for UMTA indicate that this latter effect is relatively insignificant, especially when viewed in the areawide context.

From an areawide perspective, preferential treatment projects implemented to date have been very limited, so there is a lack of hard evidence on the upper limits of potential for this action. Prior state-of-the-art reviews have only addressed localized impacts of such actions. Recent work by Cambridge Systematics for the Federal Energy Administration is one of the few known efforts to systematically assess areawide applicability and impacts on VMT of a comprehensive preferential treatments program. They divided work trips into three sets which differed with respect to directional orientation of trips, and hypothesized for each set the likely travel time differentials which could be imposed through implementation of preferential treatments. For Washington, D.C., this segmentation produced the following:

Work Trip Subsets	Percent of Trips	Changes in Travel Time for Modes: Drive Alone	Changes in Travel Time for Modes: Shared Ride and Transit
1. Outside beltway to inner core	8	+3 min.	-5 min.
2. Outside beltway to inside beltway, inside beltway to inner core, and along the beltway	31	+1 min.	-2 min.
3. Outbound (off-peak direction trips), crosstown inside the beltway, outside the beltway	61	0	0

TSM Actions	Percent Shift in VMT			Percent Shift in Average Travel Time		
	Work	Non-Work	Total	Work	Non-Work	Total
Comprehensive areawide preferential treatments (Take-A-Lane)	-0.6	+0.2	-0.1	+1.0	None	+0.4
Large-scale CBD auto restricted zone and commuter parking supply restraint	-5.7	+1.0	-1.3	*Negligible	Negligible	Negligible
Combined Actions	-6.3	+2.1	-1.4	+1.0	Negligible	+0.4

*CBD-oriented ARZ and parking supply restraint have negligible effect on in-vehicle travel time, but result in an assumed 7.5 minute-per-person round trip increase in out-of-vehicle travel time in the CBD.

Source: Cambridge Systematics, Inc. "Carpool Incentives: Analysis of Transportation and Energy Impacts," prepared for FEA, June 1976.

FIGURE 8

ESTIMATED ORDER OF MAGNITUDE POTENTIAL AREAWIDE IMPACT
OF PREFERENTIAL TREATMENT AND TRAFFIC RESTRAINT STRATEGIES
(CLASS C ACTIONS)

The above representation of comprehensive preferential treatments were then tested using disaggregate travel demand models, and the resulting areawide VMT reduction estimates were 0.6 percent for work trips and 0.1 percent for total trips. Assuming a base condition of 15 percent HOV vehicle trips on the affected travel paths, areawide average work trip travel time was shifted upward by only 1 percent as a result of preferential treatments, or about 0.4 percent increase in travel time for work plus non-work travel.

In the same study, CSI represented either large-scale auto restricted zones or extensive restraints in CBD commuter parking supply as affecting mainly the out-of-vehicle travel times of CBD commuters. Assumed walk time increases for round trips of 7.5 minutes were input to the travel demand forecasts. The resulting estimate of percent shift in areawide VMT was nearly a 6-percent reduction for work trips and more than a 1-percent reduction for total trips. Overall impacts on areawide average travel time at fixed levels of VMT demand were considered negligible.

The combined impacts of Class C actions on areawide VMT were quite significant; estimated at 6.3-percent reduction for work travel and 1.4-percent reduction for total travel.

These impacts are ones resulting from the implementation of Class C actions independently of any bus service expansion or ridesharing encouragement efforts (i.e., Class A actions) which are highly complementary. (TSM strategy combinations are considered later.)

Class D Actions

The classic form of Class D action is construction of exclusive HOV lanes within existing highway right-of-way, e.g., the Shirley Highway exclusive lanes. These actions add capacity to congested corridors, dramatically improve travel time for HOVs, but also marginally improve travel time for low-occupancy vehicles as well. This action requires relatively high capital investments and thus stretches the definition of TSM. Nevertheless, the order-of-magnitude impacts are estimated.

Exclusive HOV lanes are likely to be constructed only in a relatively small number of heavily congested radial corridors. The recent study by Wagner and CSI for the Department of Energy indicated that in Denver and San Francisco, respectively, the percents of areawide VMT occurring on freeways were 22 percent and 37 percent. In both these cases, only 10 percent of peak-period freeway VMT was on "congested zones of freeways." This level of congestion corresponds to an overall average freeway peak-period operating speed of about 40 mph. Thus, only 2-4 percent of total areawide work-trip VMT is associated with travel on congested freeway zones.

Provision of added exclusive lanes for high-occupancy vehicles dramatically improves travel times for HOVs and also enhances level of service significantly in the regular lanes since traffic volumes in these lanes result from shifting of existing HOVs out of the regular lanes into the new exclusive lanes, plus mode shifts from low-occupancy to high-occupancy vehicles.

The following assumptions are considered as reasonable expectations for changes in level of service:

- **Before Exclusive Lanes**
  - HOVs - 30 mph or 2.0 min./mile
  - LOVs - 30 mph or 2.0 min./mile

- **After Exclusive Lanes**
  - HOVs - 50 mph or 1.2 min./mile
  - LOVs - 37.5 mph or 1.6 min./mile
  - Assuming 15 percent of total vehicles are HOVs (3 or more per car) in the after case, then average level of service for all vehicles is:

    1.2(.15) + 1.6(.85) = 1.54 min./mile or 39 mph

    This represents a 23-percent overall reduction in travel time for the VMT using the freeway sections in which exclusive HOV lanes are added.

If 4 percent of the areawide total work-trip VMT are on such freeway segments, then the areawide percent shift in work-trip travel time would be only 4 percent x 23 percent = 0.9 percent.

It is assumed that vehicles with three or more occupants would be eligible to use the exclusive HOV lanes and that the number of these HOVs would triple from 5 percent of total vehicles before to 15 percent after as shown below:

Occupancy	Percent of Vehicles Before	Percent of Vehicles After
1	87	80
2	8	5
3 (HOV's)	3	10
4 (HOV's)	2	5
Average Occupancy	1.20	1.40

This represents a 16.7-percent increase in average occupancy or a 14.3-percent decrease in vehicles required to serve a fixed level of person trips. Again, assuming that only 4 percent of work VMT is affected by the exclusive HOV facilities, then the areawide work-trip VMT reduction would be only 4% x 14.3% = 0.6%.

Based on the above, the following estimates of the potential order of magnitude of shifts in areawide VMT and average travel time are made for Class D actions (i.e., exclusive HOV facilities).

Areawide Percent Shift in VMT			Areawide Percent Shift in Average Travel Time		
Work	Non-Work	Total	Work	Non-Work	Total
-0.6	+0.2	-0.1	-0.9	None	-0.4

As with other actions that cause commuter mode shifts to HOVs, the resulting work VMT reduction is significantly offset by increases in home-based non-work travel.

SUPPLY-DEMAND EQUILIBRATION

Equilibration Equations

The previously presented analyses indicate the primary, or initial, impact of the TSM actions as percent shifts in the supply curve and/or percent shifts in the demand curve. The next step is to perform the supply-demand equilibration computations to estimate the location of the new equilibrium point relative to the initial condition. Simplified equations have been derived to estimate supply-demand interaction. These equations are based on the simplifying assumption that both the areawide supply curve and demand curve are linear over the range of changes under consideration.

For TSM actions which initially shift the areawide average travel time, the new equilibrium values of VMT and travel time are estimated by:

$$PC_v = PS_t \left(\frac{e_v}{1 - e_v e_t}\right) \qquad (1)$$

$$PC_t = PS_t \left(\frac{1}{1 - e_v e_t}\right) \qquad (2)$$

where:

PS_t = the initial percent shift in average travel time

PC_v = the percent change in VMT at equilibrium

PC_t = the percent change in average travel time at equilibrium

e_v = elasticity of demand (VMT) to changes in travel time

e_t = elasticity of average travel time to changes in demand (VMT)

Similarly, for TSM actions which initially result in percent shifts in areawide VMT, the new equilibrium values of VMT and travel time are computed by:

$$PC_v = PS_v \left(\frac{1}{1 - e_v e_t}\right) \qquad (3)$$

$$PC_t = PS_v \left(\frac{e_t}{1 - e_v e_t}\right) \qquad (4)$$

where:

PS_v = the initial percent shift in areawide VMT

For actions which initially shift both the demand curve and the supply curve, two sets of calculations are made, first using equations 1 and 2, and then using equations 3 and 4, and the resulting pairs PC_v and PC_t values are then summed.

These equations have been used to calculate for each major class of TSM action the resultant supply-demand equilibrium changes. Key parameters required for the calcultions are the values of travel time elasticity, e_t, and travel demand elasticity, e_v. Because these elasticities are uniquely different for work and non-work travel periods, so are the primary initial impacts different for work and non-work trips, and the calculations are performed separately for the two trip purposes.

Elasticities

Travel time elasticities for areawide travel were recently investigated in Wagner's DOE report on Analysis of Traffic Engineering Actions. It was found for urban areas with moderate levels of congestion, such as Denver and San Francisco:

- For areawide work travel, $e_t \cong +1.0$, i.e., a 1% increase in work-trip demand results in a 1% increase in travel time
- For areawide non-work travel, $e_t \cong +0.2$, i.e., a 1% increase in non-work-trip demand results in a 0.2% increase in travel time

There is less certainty about elasticity of demand, e_v, to changes in areawide travel time. The recent CSI study for DOE found that "short-run" elasticities (the impact of total VMT to changes in travel time) are very low for work trips (e.g., $e_v = -0.01$) and not much higher for non-work trips (e.g., e_v = -0.15). However, these elasticities tend to grow larger in the intermediate and longer term future due to changes in land use, residential choice, and lengthening of trips induced by improved highway levels of service. As a result of the uncertainty, impacts are calculated for a fairly widely separated set of assumed e_v values as follows:

- For areawide work travel, e_v = -0.025 and -0.10
- For areawide non-work travel, e_v = -0.15 and -0.50

The smaller values might typify immediate demand responses to supply changes, whereas the larger values might typify intermediate term future responses. Using the assumed values for e_t and e_v, the equilibrium computations are as follows:

For supply changes (PS_t),

		Work Trips $e_t = 1$		Non-Work Trips $e_t = 0.2$	
		$e_v = -.025$	$e_v = -.10$	$e_v = -.15$	$e_v = -.50$
PC_v	=	$-.024\ PS_t$	$-.091\ PS_t$	$-.15\ PS_t$	$-.45\ PS_t$
PC_t	=	$.976\ PS_t$	$.909\ PS_t$	$.97\ PS_t$	$.909\ PS_t$

For demand changes (PS_v),

		Work Trips $e_t = 1$		Non-Work Trips $e_t = 0.2$	
		$e_v = -.025$	$e_v = -.10$	$e_v = -.15$	$e_v = -.50$
PC_v	=	$.976\ PS_v$	$.909\ PS_v$	$.97\ PS_v$	$.909\ PS_v$
PC_t	=	$.976\ PS_v$	$.909\ PS_v$	$.19\ PS_v$	$.180\ PS_v$

Equilibration for Work Trips

Calculations of work-trip areawide supply-demand equilibrium changes for each major class of action are presented in Figure 9. The impacts of three different combined TSM strategies are also computed:

1. A mobility dominant strategy, comprised of TSM action classes A + B + D

2. An energy conservation/emissions reduction strategy, comprised of TSM action classes A + C + D

3. All TSM actions combined

TSM Strategy	Initial Work Trip: Percent Shift in Supply or Demand		Work Trip: Equilibrium Percent Changes in VMT and Travel Time, $e_t \cong 1$			
			$e_v = -.025$		$e_v = -.10$	
	PS_t	PS_v	Change in VMT	Change in Travel Time	Change in VMT	Change in Travel Time
Class A (Exclusive of pricing)		-5.6	-5.5	-5.5	-5.1	-5.1
Class A, Pricing		-2.5	-2.4	-2.4	-2.3	-2.3
Class B	-10.0		+0.2	-9.7	+0.9	-9.1
Class C						
Demand Shift		-6.3	-6.1	-6.1	-5.7	-5.7
Supply shift			- .02	+1.0	-0.1	+1.0
Composite	+1.0		-6.2	-5.1	-5.8	-4.7
Class D						
Demand shift		-0.6	-0.6	-0.6	-0.5	-0.5
Supply shift	-0.9		Negl.	-0.9	-0.1	-0.8
Composite			-0.6	-1.5	-0.6	-1.3
Combined Strategies (Exclusive of pricing)						
A + B + D			- 5.9	-16.7	- 4.8	-15.5
A + C + D			-12.3	-12.1	-11.5	-11.1
A + B + C + D			-12.1	-21.8	-10.6	-20.2
			Low Demand Elasticity		Medium Demand Elasticity	

FIGURE 9

WORK TRIP SUPPLY-DEMAND EQUILIBRIUM IMPACTS OF TSM STRATEGIES FOR A PROTOTYPICAL CITY OF ONE MILLION PEOPLE

Impacts of pricing strategies are excluded from both of these strategy combinations. As shown in Figure 9, the mobility dominant strategy (A + B + D) yields work-trip impacts of:

- VMT decreases of about 5 percent
- Travel time decreases of about 16 percent

and the energy/emissions strategy (A + C + D) yields work-trip impacts of:

- VMT decreases of about 12 percent
- Travel time decreases of 11-12 percent

For a total program comprised of all strategies exclusive of pricing, the estimated work-trip impacts are:

- VMT decreases of 10-12 percent
- Travel time decreases of about 20 percent

Equilibration for Non-Work Trips

The non-work trip impacts are dramatically different than the work-trip impacts, because most of the demand-oriented strategies shift commuter trips to higher occupancy modes but result in increased non-work travel due to increased home-based auto availability. The non-work areawide supply-demand equilibrium calculations for each major class of TSM action plus the combined strategies are shown in Figure 10.

The mobility dominant strategy (A + B + D) yields non-work trip impacts of:

- VMT increases of 2.4-4.7 percent
- Travel time decreases of about 7 percent

and the energy/emissions dominant strategy (A + C + D) yields non-work trip impacts of:

- VMT increases of just over 3 percent
- Travel time increases of 0.6 percent

For a total program comprised of all TSM actions, the estimated non-work trip impacts are:

- VMT increases of 4.4-6.6 percent
- Travel time decreases of 6.6-6.8 percent

Total Travel Impact

The work trip and non-work trip impacts are then combined to give estimates of areawide total travel impacts. This final computation assumes that work trips constitute 40 percent of total VMT and non-work trips make up the

TSM Strategy	Initial Non-Work Trip Percent Shift in Supply or Demand		Non-Work Trip Equilibrium Percent Changes in VMT and Travel Time, $e_t \simeq 0.2$			
			$e_v = -.15$		$e_v = -.50$	
	PS_t	PS_v	Change in VMT	Change in Travel Time	Change in VMT	Change in Travel Time
Class A (Exclusive of pricing)		+1.2	+1.2	+0.2	+1.1	+0.2
Class A, Pricing		-6.5	-6.3	-1.2	-5.9	-1.2
Class B	-7.5		+1.0	-7.3	+3.4	-6.8
Class C		+2.1	+2.0	+0.4	+1.9	+0.4
Class D		+0.2	+0.2	Negl.	+0.2	Negl.
Combines Strategies (Exclusive of pricing)						
A + B + D			+2.4	-7.1	+4.7	-6.6
A + C + D			+3.4	0.6	+3.2	+0.6
A + B + C + D			+4.4	-6.6	+6.6	-6.8
			Low Demand Elasticity		Medium Demand Elasticity	

FIGURE 10

NON-WORK TRIP SUPPLY-DEMAND EQUILIBRIUM IMPACTS
OF TSM STRATEGIES FOR A PROTOTYPICAL CITY
OF ONE MILLION PEOPLE

remaining 60 percent of total VMT. The resulting total travel impacts of the major TSM action classes and combination strategies are summarized in Figure 11.

For the mobility dominant combined strategy (A + B + D), the total areawide travel impacts are:

- VMT decreases of about 1 percent
- Travel time decreases of 10-11 percent

For the energy/emissions dominant combined strategy, the total areawide travel impacts area:

- VMT decreases of 2.6-2.8 percent
- Travel time decreases of 3.6-4 percent

For all TSM strategies combined, the estimated total areawide impacts are:

- VMT decreases of 0.2-2.1 percent
- Travel time decreases of about 12 percent

DISCUSSION OF IMPACTS

1. The analysis to quantify the potential supply and demand impacts of a wide range of TSM actions indicates that the order of magnitude of impacts are indeed large enough to significantly improve transportation conditions in urban areas. However, for the impacts to reach the orders of magnitude indicated, vastly greater efforts and investments in TSM actions than currently prevailing are required. In particular, major extensions of skilled transportation management labor effort is required to realize the potential benefits of TSM. The required expansions of management effort are needed not only on a one-shot basis over the short range, but call for relatively permanent increases in personnel and financial resources applied to a continuing program of transportation system management.

2. Potential transportation impacts of TSM actions are especially significant in improving conditions for commuters during peak periods. Concerted application of the full range of TSM actions can potentially reduce areawide work-trip VMT demand on the order of 10 percent and areawide average work-trip travel time on the order of 20 percent. Work-trip travel time is impacted by greater percentages than work-trip VMT, because decreases in travel time are brought about in two ways:

- Supply-oriented actions which improve the operational quality of highway supply (i.e., traffic engineering and control)
- Demand-oriented actions which reduce work-trip VMT demand also result in roughly equal percentage reductions in travel time, particularly in cities with substantial existing levels of peak-period congestion.

TSM Strategies	Equilibrium Percent Changes in VMT and Travel Time: Low Demand Elasticity (Short Run) Change in VMT	Low Demand Elasticity (Short Run) Change in Travel Time	Medium Demand Elasticity (Intermediate Range) Change in VMT	Medium Demand Elasticity (Intermediate Range) Change in Travel Time
Class A Action Package (Exclusive of pricing)	-1.5	-2.1	-1.4	-1.9
Class A Pricing Package	-4.7	-1.7	-4.5	-1.6
Class B Action Package	+0.7	-8.3	+2.4	-7.7
Class C Action Package	-1.3	-1.8	-1.2	-1.6
Class D Action Package	-0.1	-0.6	-0.1	-0.5
Combined Strategies (Exclusive of pricing)				
A + B + D	-0.9	-11.0	+0.9	-10.1
A + C + D	-2.8	-4.0	-2.6	-3.6
A + B + C + D	-2.2	-12.9	-0.3	-11.7

FIGURE 11

TOTAL SUPPLY-DEMAND EQUILIBRIUM IMPACTS OF TSM ACTIONS whereas VMT reductions are brought about only through the demand-oriented strategies.

In cities with low levels of congestion during peak periods, the potential improvement in travel time is less than indicated above (ranging from 10 to 15 percent), because demand reduction strategies will induce substantially less travel time reduction than in more congested areas.

In the past, the potential of TSM to improve the quality of highway travel has been less emphasized than the potential to reduce travel demand. The results indicate that a more balanced orientation toward TSM policy is appropriate with relatively greater stress than before on potential highway congestion reduction benefits. It is especially important to remember that congestion reduction also benefits transit bus riders and, furthermore, has the potential for significant improvements in transit productivity.

3. For work trips, Class B actions aimed at reducing vehicular travel time appear to have greater orders-of-magnitude impact than the other classes of TSM action, offering the potential for roughly 10 percent improvement in areawide travel time. Class A and Class C action packages appear to have approximately equal potential work-trip VMT reduction impacts, each producing about 5 percent VMT reduction, and each simultaneously producing roughly the same 5-percent reduction in areawide average travel time. Class D actions (such as construction of exclusive HOV lanes) appear to have a far lower areawide travel-time reduction potential of only about 1 percent, because of the limited locational applicability of such strategies within an urban area. The Class D actions are also likely to produce minimal areawide reductions in work-trip VMT. However, Class D actions can produce very substantive impacts in highly congested radial corridors.

4. Impacts of combined programs comprising all classes of TSM strategies are much less powerful in producing changes in supply and demand for non-work travel. It appears that implementation of the total package of TSM strategies considered would actually result in increases in areawide non-work VMT, approximately 4-6 percent and could potentially reduce non-work areawide average travel time on the order of 6 percent. An important phenomenon is that the demand side strategies are primarily oriented to shifting work trips to higher occupancy modes, and as a result, produce increases in non-work VMT travel demand due to increased home-based auto availability during the day. This phenomenon highlights the fact that one major strategy is prominently missing from TSM strategies, i.e., a strategy for restraining or reducing non-work travel demand. This missing ingredient substantially dilutes the overall VMT reduction potential of current demand-oriented strategies. This is a problem area ripe for innovation. Of the TSM actions considered, pricing actions are the most powerful potential reducers of non-work VMT, but very drastic generalized price increases (e.g., doubling of gas prices) are needed to produce even 5 percent non-work VMT reduction. Other approaches to reduce non-work travel demand are potentially fruitful subjects for research and development.

5. For work and non-work travel combined, a concerted TSM strategy comprised of all the classes of action considered (exclusive of pricing) could potentially reduce areawide VMT by only about 2 percent in the short range and perhaps much less in the longer term, whereas areawide average travel time could potentially be reduced on the order of 12 percent. This means that if the TSM strategies could be close to fully implemented within five years from today, instead of experiencing steady worsening of congestion due to growth in travel demand causing 10-15 percent systemwide travel-time degradation at the end of five years, congestion could essentially be held in check with areawide average travel time five years hence approximating today's levels. This is just another way of saying that future travel times can be improved by approximately 12 percent compared to what would occur in the absence of concerted TSM actions.

6. The outlook is even brighter for areawide travel time improvement and VMT reduction for <u>work trips</u> where potential areawide travel time improvements of 20 percent could offset 10 years of degradation due to growth in travel demand, and potential reduction in work-trip VMT of 10-12 percent would, in effect, offset five years of normal VMT growth.

7. One should not expect, as the years progress, to see dramatic changes in transportation conditions if concerted TSM programs are implemented, because it is easy to forget what "might have been" (i.e., degradation of conditions) had not the TSM efforts been applied.

8. There is an urgent need for major order-of-magnitude increases in the levels of urban area efforts devoted to planning, designing, implementing, and evaluating the consequences of comprehensive multi-action TSM strategies.

CHAPTER 3

COST-EFFECTIVENESS OF TSM ACTIONS

A key underlying motivation for pursuing TSM actions is their cost-effectiveness in achieving objectives. In general, TSM actions have relatively low or non-existent capital costs compared with construction of major new highway or transit facilities. Annual recurring costs of operation, administration, maintenance, and enforcement make up the bulk of the costs incurred by the implementing agency in carrying out TSM actions. While these costs are relatively small, they are by no means trivial, and because the local implementing agencies must usually carry these costs with limited Federal support, there is understandably serious concern about actual TSM costs. Therefore, it is considered important to make systematic order-of-magnitude estimates of these costs for alternative types of TSM actions, and then to relate these costs to the areawide impacts of the alternatives to obtain cost-effectiveness indicators by which alternatives may be compared. Although some cost-effectiveness analysis has been done for individual projects in specific locations within urban areas, lacking is a commonly structured overview of costs of comprehensive areawide implementation of TSM actions relative to the resulting areawide impacts. This section attempts to fill that gap.

Rough order-of-magnitude estimates of annual public agency costs of implementation and continuing operation of TSM alternatives are calculated for a hypothetical urban area of 1 million population. Cost estimation methodology is briefly outlined below:

- Ridesharing program costs are estimated on the basis of actual annual costs of ongoing programs which average about 50 cents per areawide commuter, or about 20 cents per capita. These costs are doubled for the hypothesized expanded comprehensive programs.

- Express bus costs include capital expenditures for new buses @ $70,000 and operating costs of $100 to $150 per day per bus, less fares of 50 cents to 75 cents per passenger trip.

- Local bus service expansion costs include capital expenditures for new buses @ $70,000 and operating costs, less fare revenues of 40 cents per passenger trip.

- Work rescheduling efforts are estimated to require five equivalent professional-level person years annually @ $40,000 for coordination, marketing, and technical assistance.

- Signal timing optimization is estimated to require six equivalent professional-level person years @ $40,000 for data collection and optimization analysis.

- Computerized master control of 600 signals has an estimated capital cost of $5,000 per signal, and annual operations and maintenance expenditures of $300,000, mainly composed of personnel costs for traffic engineers, computer operators, electronic technicians, etc.

- Freeway surveillance and control on 35 miles of freeway has an estimated capital cost of just over $100,000 per mile (based on Minneapolis I-35 system costs, the most recently installed surveillance and control system). Annual maintenance costs are also based on Minneapolis experience and equal approximately 10 percent of capital cost.

- Truck restrictions and enhancements, focusing on improving curb use restrictions in the CBD and substantially strengthened enforcement, is estimated to require the equivalent of five professional-level person years annually.

- Comprehensive preferential treatments have capital costs based on California experience, estimated at $6,000 per priority ramp and $20,000 per facility mile for preferential lanes, and annual operations, maintenance, and enforcement of $5,000 per priority ramp and $10,000 per facility mile for preferential lanes.

- Exclusive freeway lanes have capital costs, based on Shirley Highway and San Bernardino busway experience of $3 to $5 million per facility mile, and annual costs of operation, maintenance, and enforcement of approximately 10 percent of capital costs.

Equivalent uniform annual costs of ownership and operation are calculated for each alternative using 10 percent interest rates and reasonable assumptions of service life of 10 years for traffic control systems, 15 years for buses, and 30 years for highway construction.

The resulting order-of-magnitude annual cost estimates for each TSM alternative are summarized in Figure 12.

The areawide impacts in terms of percent reductions in VMT and travel time are taken from the preceding section and are translated into total annual VMT and VHT savings based on assumed base conditions in the hypothetical urban area of 1 million population of annual VMT = 5,000 million and annual VHT = 200 million @ 25 mph average areawide network speed.

Two cost-effectiveness indicators are then calculated:

- For demand reduction strategies, cost per VMT reduced.
- For travel time improvement strategies, cost per VHT reduced.

TSM Actions	Capital Cost	Annual Operations and Maintenance Cost	*Equivalent Uniform Annual Cost
Ridesharing			
Current Programs	Nil	$200,000	$200,000
(Expanded Programs)	Nil	($400,000)	($400,000)
Express Bus			
200 New Buses Required	$14 Million	$3-4 Million	$5-7 Million
Local Bus Expansion			
200 Buses Required	$14 Million	$4.5 Million	$6.5 Million
Work Rescheduling	Nil	$200,000	$200,000
Signal Timing Optimization			
1,000 Signals	Nil	$250,000	$250,000
Computerized Traffic Control			
600 Signals	$3 Million	$300,000	$800,000
Freeway Surveillance and Control			
35 Miles	$4 Million	$400,000	$1 Million
Truck Restrictions/ Enhancements	Nil	$200,000	$200,000
Comprehensive Pref. Treatments			
(20 Ramps, 50 Miles)	$1 Million	$600,000	$800,000
Exclusive Freeway Lanes			
15 Miles	$50-75 Million	$500,000	$5-8 Million

*Capital Cost Amortization
- Buses, 15 years @ 10 percent
- Traffic Control Systems, 10 years @ 10 percent
- Highway Construction, 30 years @ 10 percent

FIGURE 12. COSTS OF SELECTED TSM PROGRAMS FOR 1 MILLION POPULATION

The results of these calculations are summarized in Figure 13.

COST-EFFECTIVENESS ANALYSIS CONCLUSIONS

With respect to the objectives of reducing VMT, ridesharing stands out as the most cost-effective demand reduction strategy, with a cost of only 1 to 2 cents per VMT reduced.

Both express bus and local bus service expansions cost approximately 40 cents per VHT reduced, while comprehensive preferential treatments for HOVs cost an estimated 16 cents per VMT reduced.

With respect to an objective of time savings through reduced VHT, signal timing optimization is the most cost-effective travel time improvement strategy--at 2 cents per VHT saved.

The least cost-effective strategy, based on VMT and VHT reduction, appears to be construction of exclusive HOV lanes on freeways, which are estimated to cost $1.30 per VMT reduced due to its very high capital costs. However, if projected people-moving capacity requires expanded physical facilities, this strategy may be more cost-effective than other alternatives with high capital costs.

Work rescheduling and computerized traffic control systems have approximately equal cost-effectiveness, at 25 cents per VHT saved. Truck restrictions and enhancements cost about 50 cents per VHT saved. Freeway surveillance and control costs approximately $1.00 per VHT saved.

Based on these findings, the alternatives are grouped qualitatively into three levels of relative cost-effectiveness, as shown in Figure 14.

TSM Action	Areawide Percent Reduction VMT	Areawide Percent Reduction Travel Time	Annual Cost	Cost Per VMT Reduced	Cost Per VHT Reduced
Ridesharing					
Current Program	0.2		$200,000	2 cents	
(Expanded Program)	(1.0)		$400,000	1 cent	
Express Bus	0.3		$5-7 Million	40 cents	
Local Bus (50 percent increase)	0.3		$5-6 Million	43 cents	
Work Rescheduling		0.4	$200,000		25 cents
Signal Timing Optimization		6.0	$250,000		2 cents
Computerized Traffic Control		1.5	$800,000		27 cents
Freeway Surveillance and Control		0.5	$1 Million		$1.00
Truck Restrictions/Enhancements		0.2	$200,000		50 cents
Comprehensive Preferential Treatments	-0.1	(+0.4) Increase	$800,000	16 cents (Increase)	
Exclusive HOV Lanes	0.1	0.4	$5-8 Million	$1.30	$8.00

Note: Base Conditions for urban area of 1 million
Annual VMT $\cong$ 5,000 million
Annual VHT $\simeq$ 200 million

FIGURE 13. COST EFFECTIVENESS OF SELECTED TSM PROGRAMS

Cost per VMT or VHT Reduced	Demand Reduction Actions	Supply Improvement Actions
Low	• Ridesharing	• Signal Timing Optimization
Medium	• Comprehensive Preferential Treatments	• Work Rescheduling • Computerized Traffic Control • Freeway Surveillance and Control • Truck Restrictions/ Enhancements
High	• Express Bus • Local Bus Service Expansion	• Exclusive HOV Lanes

FIGURE 14. GENERALIZED COST EFFECTIVENESS OF TSM ACTIONS

CHAPTER 4

DEVELOPING PROTOTYPE PROGRAMS

The very scope of TSM--in terms of relevant values, associated problems, the range of actions, permutations, and possible contexts--is so broad that a conscientious application of the normative planning process runs the danger of drowning in a mass of options. For this reason, a first-generation process has been applied which attempts to limit the number of discrete variables which must be handled analytically, yet reflects a comprehensive, goal-responsive approach. One step towards this simplification has been taken by prescreening TSM actions and presenting the results in a form of a catalog of typical problem contexts with applicable TSM solutions. The ultimate research goal is to develop a catalog which could be used as a checklist to identify TSM actions presumptively meriting consideration for implementation under various circumstances. Preliminary results were reported in Chapter I. The current status of this tool is detailed below.

The prototype catalog has separate sections by <u>city type</u>. Each city type section is subdivided according to <u>priority goal sets</u>. Within each priority set, TSM action classes are listed in a priority order for responsiveness to the "problems" which have been implicitly defined by the selection of priority sets. In each prototypical program, each TSM action class is further related to one or more <u>applications contexts</u>.

To use the catalog, the user must simply identify the city type where he wishes to apply TSM and the goal mix that is applicable, and a prototype TSM program is "automatically" given. The user then can select out actions with little or no potential due to local circumstances and tailor the remaining actions to the local context.

COMPONENTS OF THE PROTOTYPE TSM PROGRAMS

<u>City Types</u>

Experience with the range of forerunner programs to TSM--TOPICS, transit operations, Transportation Control Plans, parking, urban renewal, etc.--has suggested that similar city classes tend to experience similar problems. In the past, cities have been grouped, classified, correlated, and characterized in a bewildering variety of ways. Methods used for these classifications have ranged from sophisticated mathematics to simple labels such as "large" or "small," or "modern" and "older." Something leaning towards the latter is appropriate for a first generation TSM process. The objective of using city classes is to guide the user to the applicable part of the catalog of prototypical programs. So, the description must be in recognizable terms.

A number of candidate factors were reviewed for possible use in describing city types. These included population, density, transit use, highway supply, freeway capacity, V/C ratio, auto speeds, transit speeds, and others. After many trial classifications and cross-classifications of data, it was concluded that a simple, yet useful, system for identification of city types could be devised using the following:

- Regional Population (1970 Census)
- Transit Use (1970 Work Trips)
- Average Auto Speed (1)

The distribution of a representative set of urban areas, covering a wide population range, was as follows:

Average Auto Speed	Transit Use: 0 to 4.9%	Transit Use: 5.0% to 7.9%	Transit Use: Over 8.0%
33 to 43 Mph	Areas: 8 Population: 0.3 to 1.4 Million	Areas: 3 Population: 0.5 to 7.0 Million	Areas: None
29 to 32 Mph	Areas: 10 Population: 0.3 to 1.2 Million	Areas: 11 Population: 0.3 to 2.4 Million	Areas: 6 Population: 0.7 to 3.1 Million
19 to 28 Mph	Areas: None	Areas: 1 Population: 1.4 Million	Areas: 10 Population: 0.5 to 9.7 Million

The data was not as clean and clear-cut as might be assumed from this matrix, and a degree of judgment was necessary when allocating examples to the cells. Nevertheless, the tendency for high transit use to be related to low-average auto speeds was present, as was the tendency for the larger populations to fall to the lower right-hand portion of the matrix.

At this stage of the analysis, it would be inappropriate to try to attach these numerical values to city types. Furthermore, the purpose of the classification scheme is just to guide the TSM analyst in a general direction where he will make interpolations and extrapolations. Therefore, the city types have been generalized as follows.

<u>City Type 1</u> -- Larger cities, with relatively lower highway speeds and higher levels of congestion, and with higher levels of transit use. These generally include the larger eastern cities and some in the midwest. Examples are:

- Baltimore
- Boston
- Chicago
- Philadelphia
- Pittsburgh
- New York

City Type 2 -- These are smaller versions of Type 1. They tend to be found in the east and south, but in other areas as well. Examples are:

- Richmond
- Norfolk
- Shreveport
- Charlotte

City Type 3 -- These are larger, less congested, less transit-oriented cities. They are generally west and south. Examples are:

- Salt Lake City
- Dallas
- Denver
- San Diego
- Houston
- Phoenix
- St. Louis

City Type 4 -- This group includes the smaller versions of Type 3. Examples are:

- Albuquerque
- Austin
- Fresno
- Spokane
- Tulsa
- Tucson

While far from perfect, this grouping is more or less at the same level of significance as the supply-demand and impact effectiveness material. Additional and fine-grained data is available about city types but would not have been consistent with the generalized character of these inputs to the prototypes.

The relationship between the city type and TSM action class can be generalized in terms of transit use and area size. Since TSM strategies utilizing transit will be most effective in areas where a transit habit already exists and is demonstrated by a high level of transit use, those areas are the better candidates for transit TSM actions. At the other end of the scale, where transit usage is lower, strategies directed at highways would likely be more efficacious.

Area population may act in several ways to influence TSM. When smaller size and highway efficiency coincide, the range of possible TSM actions is likely to be limited due to a smaller set of problem types. Also, trip lengths are shorter in these smaller areas so that mode changes probably will be less attractive than in larger areas where the waiting and out-of-direction time introduced would be a smaller portion of the total trip.

Priority Sets

The normative TSM planning process can be simplified by minimizing elaborate and goal-oriented planning activities. The prototype approach sacrifices the analytic purity of tradeoff analyses for acceptance of a simple definition of basic priorities. These priorities are indicated in terms of one major and two or three minor issues, sidestepping fine distinctions among goal definitions or complex goal weighting schemes.

Three tentative priority sets have been identified. Each responds to different value orientations--any one of which reflects the adopted structure of a given region.

Set A: Mobility Dominant

- Major Priority: Mobility
- Minor Priority: Air Quality/Energy Efficiency
- Other Priorities: Community Quality, Economic Efficiency/Safety

Set B: Conservation Dominant

- Major Priority: Air Quality/Energy Efficiency
- Minor Priority: Mobility
- Other Priorities: Community Quality, Economic Efficiency/Safety

Set C: Combined

- Major Priorities: Mobility and Air Quality/Energy Efficiency
- Other Priorities: Economic Efficiency/Safety, Community Quality

Applications Context

The spatial scale of TSM program applications and effect can also be used to predefine program packages. Examples of applications contexts include:

- CBD
- Older High Activity Center
- New High Activity Center
- Residential Areas

This group covers zone applications. Also used are facility contexts:

- Radial Corridor
- Crosstown Corridor
- Secondary Streets

This classification set has been enriched by defining applicability as:

- Definitely applicable
- Possibly applicable
- Not applicable

PROTOTYPICAL TSM PROGRAMS

All of this has been combined into the prototypical TSM program in Figures 15-1, 15-2, 15-3, and 15-4. When using these programs, the following steps would be taken:

1. Select a city type that best fits the situation under study.

2. Select a goal mix. This is straightforward, but perhaps all mixes should stay in contention throughout the prototypical analysis to see if real program differences result. In addition, it may be useful to follow one goal mix on one context (perhaps emissions reduction--conservation--in a corridor) and another goal in another context (mobility in the CBD or in a different corridor).

3. Select one or more "applications context." The goal mix implies what kind of problem exists, the application context suggests where it exists. The applications context also should be useful when developing a TSM program by subarea or by corridor.

4. The actions listed for each city type and priority set are the focus, obviously, of the prototype TSM program. The full list of actions considered in the supply-demand and vector analysis appears in the programs for the larger cities (1 and 3), but the list is sharply abbreviated for Types 2 and 4. The "applications context" also changes slightly.

The actions are listed in order of their potential effectiveness, as determined by the supply-demand vector analysis. Therefore, if potential effectiveness is the desired priority characteristic, then the actions are in priority order from top to bottom within each goal mix group. This also matches well with the cost-effectiveness estimated for each action.

These prototypical TSM programs are obviously generalized, and there may be more exceptions than direct applications in an actual TSM program development environment. Therefore, the final step in the use of these programs is the suggested screening of the action classes to select types that fit local conditions and local implementation status, and the continued usage of the programs as a checklist and idea generator.

The ideal development of such prototypical TSM programs could have included a greater disaggregation of action classes so that a greater number and more specific type of candidate TSM projects could be included.

Also, an individual calculation of cost effectiveness by city type and application context would have enriched the protypes, but the state-of-the-art is not sufficiently advanced to provide the capability for such calculations.

Even with these and other shortcomings, the prototypical TSM programs are believed to offer an organized and simplifed approach to TSM planning. They provide a link to goals and priorities, a relationship sometimes not considered in early TSM programs. This relationship will be studied further in subsequent research.

Goal Mix	Action	Applications Context[1] CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
A: MOBILITY	General Traffic Engineering	●	●	●	●	●	●	●
	Ride-Sharing	●	●	●				
	Pricing	●	○			●	○	
	Freeway Management					●	○	
	Express Bus, Park-Ride					●	○	
	Local Transit Improvements	●	○	○	●	●	●	○
	4-Day Week	●	●	●				
	Truck Restrictions, Enhancements	●	●		○			
	Work Rescheduling	●	●	●				
	Bicycle Facility Improvements	●	●	●	●	●	●	●
	Pedestrian Facility Improvements	●	●	●	●			●
	Paratransit	○	●	●	●	○	○	○
	Add-A-Line HOV Facilities					●		
B: CONSERVATION	Pricing	●	○			●	○	
	ARZ, Parking Management	●	●					
	Ridesharing	●	●	●				
	Express Bus, Park-Ride					●	○	
	Local Transit Improvement	●	○	○	●	●	●	○
	4-Day Week	●	●	●				
	Comprehensive HOV Treatment	●	●			●	○	
	Bicycle Facility Improvements	●	●	●	●	●	●	●
	Pedestrian Facility Improvements	●	●	●	●			●
	Paratransit Facility Improvements	○	●	●	●	○	○	○
	Add-A-Line HOV Facilities					●		
C: BALANCED	Pricing	●	○			●	○	
	General Traffic Engineering	●	●	●	●	●	●	●
	ARZ Parking Management	●	●					
	Ridesharing	●	●	●				
	Freeway Management					●	○	
	Express Bus, Park-Ride					●	○	
	Local Transit Improvement	●	○	○	●	●	●	○
	Work Rescheduling	●	●	●				
	Comprehensive HOV Treatment	●	●	●				
	4-Day Week	●	●	●				
	Truck Restrictions, Enhancements	●	●		○			
	Bicycle Facilities Improvement	●	●	●	●	●	●	●
	Pedestrian Facilities Improvement	●	●	●	●			●
	Paratransit Facilities Improvement	○	●	●	●	○	○	○
	Add-A-Lane HOV Facilities					●		

● [1]Definitely Applicable
◉ Possibly Applicable
Not Applicable

FIGURE 15-1. PROTOTYPICAL TSM PROGRAM
CITY TYPE 1: LARGER, MORE CONGESTED, TRANSIT INTENSIVE

Goal Mix	Action	Applications Context[1]						
		CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
A: MOBILITY	General Traffic Engineering	●	●	●	●	●	●	●
	Ride Sharing	●	●	●				
	Local Transit Improvements	●	o	o	●	●	●	o
	Truck Restrictions, Enhancements	●	●	●				
	Bicycle Facilities Improvements	●	●	●	●	●	●	●
	Pedestrian Facilities Improvements	●	●	●	●			●
	Paratransit Facilities Improvements	o	●	●	●	o	o	●
B: CONSERVATION	Ride Sharing	●	●	●				
	Local Transit Improvements	●	o	o	●	●	●	o
	Bicycle Facilities Improvements	●	●	●	●	●	●	●
	Pedestrian Facilities Improvements	●	●	●	●			●
	Paratransit Facilities Improvements	o	●	●	●	o	o	o
C: BALANCED	General Traffic Engineering	●	●	●	●	●	●	●
	Ridesharing	●	●	●				
	Local Transit Improvements	●	o	o	●	●	●	o
	Work Rescheduling	●	●	●				
	Truck Restrictions, Enhancements	●	●		o			
	Bicycle Facilities Improvements	●	●	●	●	●	●	●
	Pedestrian Facilities Improvements	●	●	●	●			●
	Paratransit Facilities Improvements	o	●	●	●	o	o	o

FIGURE 15-2. PROTOTYPICAL TSM PROGRAM
CITY TYPE 2: SMALLER, MORE CONGESTED, HIGHER TRANSIT USE

[1] Definitely Applicable ●
Possibly Applicable o
Not Applicable

Goal Mix	Action	Applications Context[1]						
		CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
A: MOBILITY	General Traffic Engineering	●	●	●	●	●	●	●
	Ride Sharing	●	●	●				
	Pricing	●	o			●		
	Freeway Management					●		
	Express Bus Park-Ride					●		
	Local Transit Improvements	●	o	o	●	●	●	o
	4-Day Week	●	●	●				
	Truck Restrictions, Enhancements	●	●		o			
	Work Rescheduling	●	●	●				
	Bicycle Facility Improvements	●	●	●	●	●	●	●
	Pedestrian Facility Improvements	●	●	●	●			●
	Paratransit Facility Improvements	o	●	●	●	o	o	o
	Add-A-Line HOV Facilities					●		
B: CONSERVATION	Pricing	●	o			●		
	ARZ Parking Management	●	●					
	Ride Sharing	●	●	●				
	Express Bus, Park-Ride					●		
	Local Transit Improvement	●	o	o	●	●	●	o
	4-Day Week	●	●	●				
	Comprehensive HOV Treatment	●	●			●		
	Bicycle Facility Improvements	●	●	●	●	●	●	●
	Pedestrian Facility Improvements	●	●	●	●			●
	Paratransit Facility Improvements	o	●	●	●	o	o	o
	Add-A-Line HOV Facilities					●		
C: BALANCED	Pricing	●	o			●		
	General Traffic Engineering	●	●	●	●	●	●	●
	ARZ Parking Management	●	●					
	Ride Sharing	●	●	●				
	Freeway Management					●		
	Express Bus Park-Ride					●		
	Local Transit Improvement	●	o	o	●	●	●	o
	Work Rescheduling	●	●	●				
	Comprehensive HOV Treatment	●	●	●				
	4-Day Week	●	●	●				
	Truck Restrictions, Enhancements	●	●		o			
	Bicycle Facilities Improvement	●	●	●	●	●	●	●
	Pedestrian Facilities Improvement	●	●	●	●			●
	Paratransit Facilities Improvement	o	●	●	●	o	o	o
	Add-A-Line HOV Facilities					●		

[1] Definitely Applicable ●
Possibly Applicable o
Not Applicable

FIGURE 15-3. PROTOTYPICAL TSM PROGRAM
CITY TYPE 3: LARGER, LESS CONGESTED, LOWER TRANSIT USE

Goal Mix	Action	Applications Context[1]						
		CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
A: MOBILITY	General Traffic Engineering	●	●	●	●	●	●	●
	Ride Sharing	●	●	●				
	Local Transit Improvements	●	o	o	●	●	o	o
	Bicycle Facilities Improvements	●	●	●	●	●	●	●
	Pedestrian Facilities Improvements	●	●	●	●			●
	Paratransit	o	●	●	●	o	o	o
B: CONSERVATION	Ride Sharing	●	●	●				
	Local Transit Improvements	●	o	o	●	●	o	o
	Bicycle Facilities Improvements	●	●	●	●	●	●	●
	Pedestrian Facilities Improvements	●	●	●	●			●
	Paratransit Facilities Improvements	o	●	●	●	o	o	o
C: BALANCED	General Traffic Engineering	●	●	●	●	●	●	●
	Ride Sharing	●	●	●				
	Local Transit Improvements	●	o	o	●	●	o	o
	Bicycle Facilities Improvements	●	●	●	●	●	●	●
	Pedestrian Facilities Improvements	●	●	●	●			●
	Paratransit Facilities Improvements	o	●	●	●	o	o	o

[1] Definitely Applicable ●
Possibly Applicable o
Not Applicable

FIGURE 15-4. PROTOTYPICAL TSM PROGRAM

CITY TYPE 4: LESS CONGESTED, LOWER BUS USE

REFERENCES

1 U.S. Department of Transportation. _1974 National Transportation Report,_ Washington, D.C., May 1976.

PART TWO

Supporting Papers

CHAPTER A

IMPACT OF RIDESHARING ENCOURAGEMENT PROGRAMS

INTRODUCTION

In urban areas nationally, average vehicle occupancy among commuters using private automobiles approximates 1.2 persons per car, and the percent of commuters using the private ridesharing mode is about 25 percent. Ridesharing is, thus, already a highly significant mode of work travel. Nonwork travel is characterized by an even higher percent of private ridesharing due to the frequent pooling of trips among family members. Encouragement of increased use of ridesharing has been viewed as a strategy having significant potential for reduction of total vehicular travel.

Various methods can be and have been employed to encourage expansion of private ridesharing in urban areas. Efforts to encourage ridesharing have been virtually totally focused on increasing ridesharing among commuters. The principal activity of most ridesharing programs has been carpool matching and promotion. Most urban areas have approached this process by working cooperatively with major employers to promote increased ridesharing among their employees, to perform carpool matching services to groups of employees and individuals, and to foster the use of various ridesharing incentives which employers can implement--such as preferential parking, working hours flexibility, financial incentives, and vanpool systems.

Most urban area projects have also employed some form of mass distribution of public information and advertising to increase the awareness of and the attitudinal receptivity towards the use of ridesharing among the general public. Frequently used techniques have included: advertising, news, and editorial features in the electronic and print media; billboards; mass mailers; bumper stickers; information booths and displays; roadside signs; speeches, films, and slide shows presented to civic associations; and so forth. It is hypothesized that comprehensive public information and promotion using such methods will gradually effect significant changes in the attitudes about and usage of private ridesharing.

The development of vanpooling, a specialized form of private ridesharing, is receiving increasing attention as a viable travel reduction strategy. Most experience in vanpooling, to date, has resulted from the efforts of individual employers acting independently to sponsor vanpools for their employees. However, many state and local transportation agencies are in the early stages of spearheading the development and marketing of both an increased number of employer-sponsored and third party-provided vanpool systems. These efforts are largely in the planning or embryonic implementation stage.

There are also a host of incentives to carpooling and disincentives to driving alone which can potentially be implemented by public agencies. Included are measures such as priority facilities and traffic controls for high-occupancy vehicles, various forms of transportation pricing which either increase general commuting costs or differentiate costs between low-occupancy and high-occupancy vehicles, parking supply management strategies, and other forms of automobile traffic restraint. While the expected response of all these measures is expanded use of private ridesharing (as well as public transit), these actions are not included in this working paper but are addressed separately.

Most of the prior evaluations of the impacts of ridesharing programs have been limited to assessments of the success of efforts of individual employers. Since a wealth of published information (e.g. Ref. 1-6) on individual employer programs is available, this paper will not be so addressed. Suffice to say that many exemplary employer programs exist which have dramatically increased ridesharing among their employees. The Tennessee Valley Authority (Ref. 7) in Knoxville, for example, between 1973 and 1977:

- Increased carpool usage from 30 percent to 41 percent of employees.
- Increased vanpooling from 0 percent to 7 percent of employees.
- Increased special express bus usage from 0 percent to 28 percent of employees.
- Reducing drive alone commuters from 65 percent to 18 percent of employees.

Far less systematic attention has been directed toward estimating the areawide potential of ridesharing encouragement programs as a travel reduction strategy. This working paper attempts to fill this gap by synthesizing the actual impacts estimated for a number of comprehensive ongoing areawide ridesharing programs, as well as summarizing the results of theoretical forecasts of travel demand impacts of ridesharing programs.

ESTIMATES OF AREAWIDE IMPACT

U.S. DOT Report to Congress

The 1975 DOT Report to Congress on "Carpool Incentives and Opportunities" (Ref. 3) made rough order-of-magnitude estimates of the VMT reduction potential of areawide, employee-oriented carpool matching, promotion, and incentives programs. Estimates were made by joint estimation of reasonable ranges of employee exposure to such programs and the resultant capture rate (i.e. the percent of exposed employees shifting to carpools.)

Figure 16 illustrates this simple areawide impact estimation process. Program impact is a function of: (1) the percent of work force exposed to

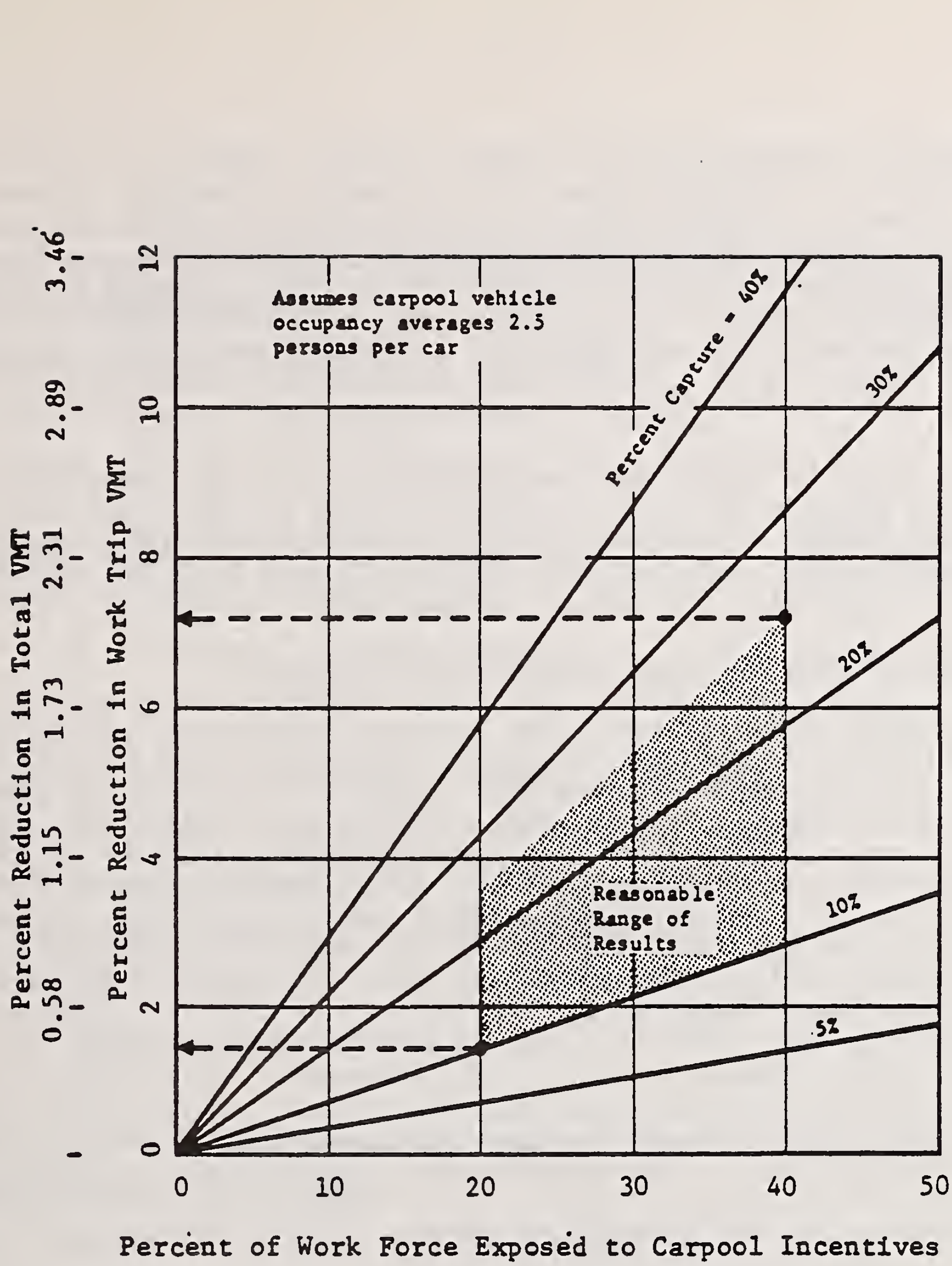

FIGURE 16

VMT REDUCTIONS RESULTING FROM
CARPOOL INCENTIVES AND PROMOTION PROGRAMS

carpool matching, promotion, and related incentives (shown on the horizontal axis); and (2) the forcefulness of the program in inducing increased carpooling (shown as diagonal lines on the graph labeled "percent capture"). For example, a program which exposed 40 percent of the work force to carpool encouragement and induced 25 percent of those so exposed to shift into carpools, would reduce work trip VMT by approximately 7 percent. Critical assumptions were that average carpool size is 2.5 persons per car, and carpool trip length was 20 percent longer than overall average work trip length.

A reasonable range for "exposure" was estimated at from 20 percent to 40 percent of the areawide work force, and capture rate was estimated from 10 percent to 25 percent of persons exposed. The resultant VMT reduction impact estimates were 1.5 percent to 7 percent of work trip VMT, and approximately 0.5 percent to 2.0 percent of total VMT.

Direct Impacts of Ongoing Carpool Demonstration Projects

Urban area carpool demonstration project funding from Federal sources was first authorized by the Emergency Highway Energy Conservation Act of 1974 and funding has since been continued and broadened. A total of 92 demonstration projects comprising a total cost of approximately $14 million have been pursued under this program. An FHWA-sponsored evaluation of this program is currently being pursued and preliminary results were published in late 1977 (Ref. 8). The referenced paper documents preliminary findings based on interpretations of evaluation studies made by the agencies conducting the demonstration projects. This evaluation introduced refinements by accounting for such factors as the trip circuity of carpools, the actual prior occupancy of "new" carpoolers, and the phenomena of short longevity of a portion of the new carpools formed. These refinements, in addition to the fact that results are based on actual experience of real programs, makes the estimated impacts more conservative than those presented in the previous section. Moreover, most of the demonstrations focused only on employer-oriented carpool matching and promotion, with little progress being made in the implementation of any tangible incentives. Figure 17 shows the sequence of calculations used to estimate impacts.

Figure 18 summarizes data on carpool matching and promotion exposure and mode shift response for selected projects. Data tabulated are: (1) total employees exposed to ridesharing encouragements efforts; (2) number of persons submitting carpool matching requests to the ridesharing agencies; and (3) estimated number of persons who joined carpools as a result of the matching and promotion effort. The percent that each of the above three numbers of persons are of total urban area employees is also tabulated.

The average results for the selected locations indicate that 27 percent of areawide employees were directly exposed to employer-based ridesharing encouragement; 4.7 percent of areawide employees, or about one-sixth of those exposed, submitted carpool matching requests; and 0.8 percent of areawide employees, or about one-sixth of those requesting matching, actually joined

Impact Characteristic	Average Value*
PC, Proportion of Carpoolers in Sample	.35
PN, Proportion of New Carpoolers in Sample	.17
PD, Proportion of New Carpoolers Dropping Out	.30
DB, Total Persons in Population Sampled	16,700
CT, Total Carpoolers = DB x PC	5,845
CN, New Carpoolers = DB x PN	2,839
CP, Permanent New Carpoolers = CN (1-PD)	1,987
TL, One-Way Trip Length of Carpoolers, miles	11.9
TC, One-Way Trip Circuity Per Carpooler, miles	0.5 est.
OCCP, Previous Occupancy of New Carpoolers	1.27
OCCC, Current Occupancy of New Carpoolers	2.85
VMTI, Daily VMT Savings per New Carpooler $= 2\left[\frac{TL}{OCCP} - \left(\frac{TL}{OCCC} + TC\right)\right]$	9.4
VMTP, Daily VMT Savings of Permanent New Carpoolers = CP x VMTI	18,700
AVMTP, Annual VMT Savings of Permanent New Carpoolers = 230 x VMTP	4,300,000

*Average values based on data from selected cities having necessary evaluation data available.

FIGURE 17

STANDARD IMPACT CALCULATIONS AND AVERAGE RESULTS

Location	Participating Employers	Total Employees Exposed, Thousands	Number of Matching Requests, Thousands	Number of New Carpoolers, Thousands
Los Angeles	490	621 (16%)*	100 (2.6%)*	11.6 (0.3%)*
Sacramento	61	156 (54%)	16.9 (5.9%)	3.7 (1.3%)
San Diego	67	128 (30%)	24.7 (5.7%)	3.2 (0.7%)
Tallahassee	78		5.0 (12%)	
Boise	20	15 (34%)	2.4 (5.5%)	.17 (0.4%)
Louisville	247		12.3 (3.8%)	4.2 (1.3%)
Baton Rouge	18	11.7 (11%)	3.4 (3.3%)	.34 (0.3%)
New Orleans	69	153 (42%)	3.5 (1%)	.42 (0.1%)
Omaha	100		11 (5.3%)	2.2 (1%)
Portland	177	104 (26%)		11 (2.8%)
Salem	73	27.5 (43%)	5 (7.7%)	.40 (0.6%)
Raleigh	73		5 (5.3%)	.91 (1%)
Rhode Island	79	62 (17%)	9.6 (2.6%)	2.0 (0.5%)
Dallas	52		26.6 (4%)	1.6 (0.2%)
Fort Worth	152	78 (25%)	10 (3.2%)	3.0 (1%)
Houston	75		10.2 (1.3%)	3.0 (0.4%)
San Antonio	60		20 (3.6%)	7.1 (2.6%)
Seattle	200	100 (18%)	15 (2.7%)	5.4 (1%)
Washington, D.C.	850	425 (36%)	110 (9.3%)	15.4 (0.9%)
Average	154	148 (27%)	22 (4.7%)	3.8 (0.8%)

*Percent of total employees based on 1970 SMSA Population.

FIGURE 18

CARPOOL MATCHING AND PROMOTION
EXPOSURE AND RESPONSE FOR SELECTED PROJECTS

carpools (an approximately equal number of matching requestors were already commuting in carpools).

The reader is cautioned that the estimate of new carpoolers is a measure of the direct impact of providing employer-based carpool matching and promotional assistance. An additional number of persons, indeterminate at this time, joined carpools as a partial or indirect result of mass forms of public information and promotion which may have increased awareness and changed attitudes regarding the benefits of ridesharing. Hence, the estimates shown in Figure 18, undoubtedly are conservatively low estiamtes of areawide impacts.

Figure 19 summarizes for 15 of the more comprehensive and continuing ridesharing projects the estimated number of permanent new carpoolers, the annual VMT reduction, and the areawide percent reductions in total VMT and work trip VMT. The results indicate that areawide work trip VMT reductions ranged from 0.14 percent to 1.0 percent for individual cities, and averaged 0.35 percent. The three most successful demonstration programs Portland, San Antonio, and Sacramento, exhibit work trip VMT reductions of 1.0 percent, 0.8 percent, and 0.7 percent, respectively. Areawide reductions in total VMT ranged from 0.05 percent to 0.28 percent and averaged 0.12 percent.

It is reiterated that these results reflect the direct impacts of employer-based carpool matching and promotion and do not include the likely additional increases in carpooling (and reductions in VMT) caused by mass media public information and promotion. Moreover, very limited use was made in the demonstration projects of employe- oriented incentives such as preferential parking, financial incentives and vanpooling. It is probable that a significant order-of-magnitude increase in VMT reduction impacts could be attributed to the inclusion of the effects of such additional measures. The total impacts could be two to three times greater than those indicated above, raising the upper range estimates of work trip VMT reduction to perhaps as high as 2 to 3 percent and total VMT reduction close to 1 percent.

Theoretical Forecasts Using Disaggregate Demand Models

In a recent study for the Federal Energy Administration, (Ref. 9) Cambridge Systematics, Inc. employed disaggregate demand models of work and non-work travel to forecast impacts of a wide range of strategies for increasing ridesharing and public transit usage and reducing VMT and fuel consumption. One of the strategies tested was a comprehensive employer-oriented ridersharing encouragement program comprised of:

- Carpool-matching assistance and promotion in all organizations having 100 or more employees
- Preferential parking spaces for employees using carpools in all organizations having 100 or more employees

Urban Area	Number of Permanent New Carpoolers	Annual Reduction in VMT, Millions	Areawide Total VMT, Millions	Percent Reduction in Total VMT	Percent Reduction in Work Trip VMT
Los Angeles	8,100	40.0	55,156	0.07	0.2
Sacramento	2,700	8.4	3,260	0.25	0.7
San Diego	2,200	7.3	6,929	0.11	0.3
Boise	120	0.2	395	0.05	0.14
Louisville	3,000	2.8	3,914	0.07	0.2
Omaha	1,200	2.2	2,438	0.09	0.26
Salem	280	0.25	509	0.05	0.14
Portland	7,700	15.6	4,299	0.36	1.0
Raleigh	750	1.1	1,156	0.10	0.3
Dallas	1,600	2.6	7,290	0.04	0.11
Fort Worth	2,100	4.5	4,300	0.10	0.3
Houston	2,100	6.6	8,538	0.08	0.23
San Antonio	5,000	10.0	3,587	0.28	0.8
Seattle	3,200	4.9	7,153	0.07	0.2
Washington, D.C.	10,800	19.8	15,072	0.13	0.37
			Average:	0.12	0.35
			Range:	0.5 - .28	.14 - 1.0

FIGURE 19

DIRECT IMPACT ON VMT OF AREAWIDE CARPOOL MATCHING AND PROMOTION PROJECTS

- Making vanpools available as an alternative in all organizations with more than 500 employees for those with trip lengths of at least 10 miles

The estimated short-range areawide impacts of such a program were:

- Work trip VMT reduction of 6.6 percent
- Non-work trip VMT increase of 1.4 percent due to increased auto availability for home-based non-work trips during the day
- Overall VMT reduction of 1.7 percent
- Overall fuel consumption reduction of 1.3 percent

These impacts appear to be rather extreme upper limit estimates of comprehensive employer-based ridesharing programs, since the strategies tested are tantamount to mandatory carpool and vanpool encouragement activities by larger employers. However, the individual commuter mode choices are still strictly voluntary and the strategy does not include various other incentives and disincentives such as priority treatments for HOV's, pricing strategies, and traffic restraint measures.

Vanpool Potential Forecasts in Baltimore

The Baltimore Regional Planning Council recently analyzed the maximum areawide potential of vanpooling (Ref. 10). The vanpool market analysis was performed using data on work trip origins and destinations in the 145 sketch planning districts in the Baltimore region and in the 20 external districts beyond the urban region. Using these baseline travel data, the vanpool market analysis estimated the amount of vanpooling that could potentially be developed between each pair of districts and the areawide total if a comprehensive vanpool program were implemented in the area. The resulting impacts on vehicle miles of travel (VMT), fuel consumption, and transit ridership were then estimated.

The market analysis was carried out under the following set of assumptions:

1. Vanpooling is considered to apply only to peak-period work trips. These trips represent 23.6 percent of total weekday VMT.

2. Each vanpool carries an average of 10 occupants and replaces 8 automobile work trips.

3. The minimum one-way trip length for vanpools is 9 miles. These trips represent about 60 percent of the auto work trips and 82 percent of peak-period work trip VMT.

4. Vanpools would be implemented only for commuters working for large employers, i.e. those with 200 or more employees. Work trips for commuters traveling 9 miles or more and working for employers with at least 200 employees represent 42.9 percent of peak-period work trip VMT.

5. The maximum vanpool "capture" as a percent of potential vanpoolers, i.e. those who travel more than 9 miles and work for employers with 200 or more people, was assumed to be 25 percent. Since 60 percent of the work trips are 9 miles or longer, the assumed 25 percent capture rate translates to an overall capture rate of 15 percent of all persons working for employers with 200 or more persons.

The capture rate is a key assumption in the analysis, and the value selected was intended to represent the upper limit of potential shift to vanpools. More conservative estimates can be made by scaling down the assumed capture rate.

The analysis procedure was applied both to 1975 and 1985 areawide travel estimates, the results of which are shown in Figure 20. The estimates indicate that the maximum potential for VMT reduction due to vanpooling is nearly 8 percent of peak-period work trip VMT and nearly 2 percent of total daily VMT.

These estimates of the impacts of a comprehensive vanpool program, alone, are of the same order of magnitude of Cambridge Systematics' estimates of the impacts of a comprehensive ridesharing program consisting of carpool matching and promotion, preferential parking, and vanpooling. The Baltimore forecasts appear to be overly optimistic since minimum employer size of 200 employees and minimum vanpool trip length of vanpools of 9 miles may be unrealistically low, and the assumed capture rate of 25 percent of "potential" vanpoolers may be too high. What's more, both the Baltimore and Cambridge Systematics' forecasts may be substantially higher than achievable in practice since the strategies tested require mandated program efforts by all large employers. In any event, the results of both analyses are useful since they establish an extreme upper limit for the VMT reduction potential of comprehensive employer-based ridesharing programs.

Halving these extreme estimates may give a more practical estimate of the achievable upper limits of this strategy of approximately 3 percent work trip VMT reduction and 1 percent total VMT reduction. This scaling down of maximum impacts brings the forecasts in line with the order-of-magnitude extrapolations of actual experience and the simplistic forecasts made in the DOT Report to Congress on carpooling, discussed previously.

COST-EFFECTIVENESS

Using information from the ongoing carpool demonstration evaluation, project cost and impact statistics have been calculated for a representative sample of 24 urban areas for which detailed evaluation data are available and analyses have been completed. Included in the sample are most of the

Average Weekday Characteristics	Based on 1975 Travel Estimates	Based on 1985 Travel Estimates
a. Total daily VMT	30,699,000	42,835,000
b. Peak-period work trip VMT	7,245,000	9,533,000
c. Peak-Period work-trip VMT for trips 9 miles or longer	5,941,000	8,110,000
d. Peak-period work trip VMT for trips 9 miles or longer by persons working for large employers ($\geq$ 200 employees)	2,549,000	3,436,000
e. Automobile VMT eliminated due to vanpooling, assuming 25% capture of (d)	637,000	859,000
f. Number of vanpools	2,300	3,100
g. Vanpool VMT	76,000	102,000
h. Net daily VMT reduction, (e) - (g)	561,000	757,000
i. Net daily VMT reduction as percent of peak period work trip VMT	7.7%	7.9%
j. Net daily VMT reduction as percent of total daily VMT	1.8%	1.8%
k. Percent of total daily transit riders diverted to vanpools	1.7%	1.7%

FIGURE 20

ESTIMATES OF MAXIMUM POTENTIAL VANPOOL IMPACTS
FOR BALTIMORE METROPOLITAN AREA

cities which have pursued ridesharing projects on a continuing basis over several years in addition to ones which terminated projects after one year.

Figure 21 lists for the individual project locations the annual project cost, areawide total commuter population, and project cost per commuter. Annual project costs vary widely ranging from $20,000 per year in Raleigh to $5000,000 per year in Los Angeles, and average $110,000 per year for the sample. The range of project costs per areawide commuter is narrower spanning from $.09 per commuter in Dallas to $1.09 per commuter in Tallahassee, and averaging $.42 per commuter.

As the urban area commuter population increases, project expenditures per commuter tend to decrease as illustrated in Figure 22. Average project costs per commuter range from $.72 for the urban areas with less than 100,000 commuters to $.18 for areas with greater than 500,000 commuters.

In general, many of the demonstration projects have been handicapped by a lack of sufficient staff and financial resources to effectively carry out project activities. Therefore, the preliminary project cost statistics presented should not be construed as a guideline for required levels of effort to implement more comprehensive and effective ridesharing programs.

Figure 23 presents preliminary estimates of the cost-effectiveness characteristics of the selected carpool demonstration projects. Estimates shown in the table include: (1) number of persons who permanently shifted to carpools; (2) annual reductions in vehicle miles traveled; (3) average annual demonstration project costs; (4) annual project cost per VMT reduced; and (5) annual project cost per commuter shifted to the carpool mode of travel. The results indicate that the annual project costs expended were 4.4 cents per vehicle mile of travel reduced, and $64 per year per person shifted to the carpool mode. It is reiterated that these results reflect the <u>direct</u> impacts of employer-based carpool matching and promotion and do <u>not include</u> the possible additional increases in carpooling caused by mass forms of public information and promotion. Inclusion of indirect impacts would improve the cost-effectiveness indicies by a factor of approximately 2.

Even though the estimates of impacts shown are admittedly conservatively low, the cost-effectiveness characteristics of the carpool demonstration projects appear to be very promising. The cost-effectiveness of ridesharing expansion is especially good compared to alternative methods of reducing vehicular travel. For example, the annual costs and per vehicle mile costs of shifting commuters out of cars through expansion and improvement of public transit services are likely to be significantly larger than producing the same impacts through expanded ridesharing. However, this is not to imply that transit improvement versus ridesharing expansion is an either-or question. The two strategies are largely non-competitive since carpooling serves areawide destinations of medium and longer distance trips, vanpooling serves areawide destinations of very long trips, local transit improvements serve mainly short distance trips, and express bus

Urban Area	Annual Cost ($ Thousands)	Areawide Total Commuters* (Thousands)	Project Cost Per Commuter ($)
Phoenix	76	450	$.17
Los Angeles	500	3,900	.13
Sacramento	80	287	.28
San Diego	140	430	.33
Tallahassee	47	43	1.09
Boise	35	44	.80
Louisville	70	321	.22
Baton Rouge	30	103	.29
Lake Charles	37	48	.77
New Orleans	180	368	.49
Shreveport	45	100	.45
Omaha	125	207	.60
Salem	35	65	.54
Portland	250	400	.63
Luzerne Co., Pa.	85	135	.63
Lackawana Co., Pa.	86	95	.91
Raleigh	20	95	.21
Rhode Island	70	372	.19
Dallas	62	666	.09
Fort Worth	31	311	.10
Houston	120	797	.15
San Antonio	160	276	.58
Seattle	215	557	.39
Washington, D.C.	140	1,179	.12
Average	110	469	.42

*Based on 1970 SMSA Civilian Employment.

FIGURE 21

ANNUAL COSTS OF SELECTED CARPOOL DEMONSTRATION PROJECTS

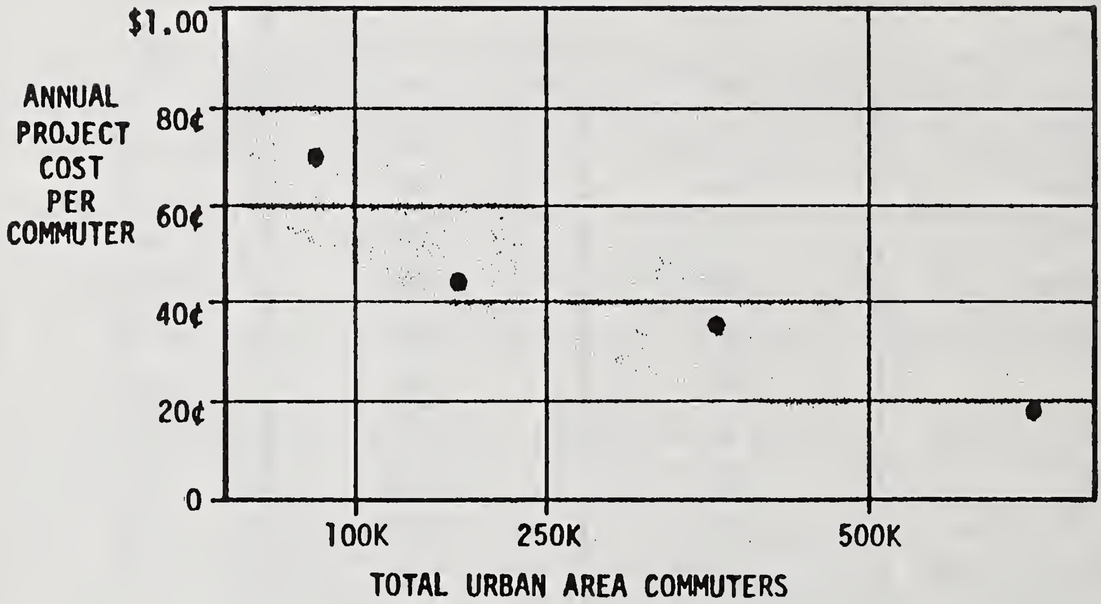

FIGURE 22

ANNUAL COST OF AREAWIDE RIDESHARING
PROGRAMS VERSUS URBAN AREA COMMUTER POPULATION

Location	Number of Permanent New Carpoolers, Thousands	Annual Reduction in VMT, Millions	Annual Project Cost $ Thousands	Annual Cost	
				Per VMT Reduced	Per New Carpooler
Los Angeles	8.1	40.0	$500	1.3¢	$ 62
Sacramento	2.7	8.4	287	0.95¢	30
San Diego	2.2	7.3	140	1.9¢	62
Boise	.12	0.2	44	17.5¢	297
Louisville	3.0	2.8	70	2.5¢	24
Omaha	1.2	2.2	125	15 ¢	88
Salem	.28	.25	35	14 ¢	125
Portland	7.7	15.6	250	1.6¢	32
Raleigh	.75	1.1	20	1.8¢	27
Rhode Island	1.5	4.3	70	1.6¢	46
Dallas	1.6	2.6	62	2.4¢	39
Fort Worth	2.1	4.5	31	0.7¢	15
Houston	2.1	6.6	120	1.8¢	58
San Antonio	5.0	10.0	160	1.6¢	32
Seattle	3.2	4.9	215	4.4¢	67
Washington, D.C.	10.8	19.8	140	0.7¢	13
			Average	4.4¢	$ 64

FIGURE 23

COST-EFFECTIVENESS CHARACTERISTICS OF SELECTED CARPOOL MATCHING PROJECTS serves mainly CBD-oriented medium-long trips. While some competition between ridesharing and transit trips is bound to exist, this competition is viewed as no more intense, and in the case of vanpooling less intense, than the competition between general low-occupancy automobile usage and public transit. Indeed a ridesharing program purposely can be planned to minimize competition for trips that are well served by public transit, and can simultaneously encourage the expanded use of all high-occupancy modes, both public and private. As a final point, it should be noted that the ridesharing program impacts estimated herein explicitly account for interaction with public transit by considering the prior modes of new carpoolers.

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CHAPTER B

IMPACT OF TRANSIT ROUTES AND SCHEDULING IMPROVEMENTS

INTRODUCTION

The geographic expansion of transit route systems and increases in service frequency represent a class of transit service improvements that offers wide opportunity for application and reasonable likelihood of positive impact on ridership.

Objective

The objective of this analysis includes the following:

- Identification of the range of ridership gains that might be expected from comprehensive programs of route and schedule improvement, including the development of new transit service.

- Identification of the range of transit service and ridership levels that might be anticipated in urban areas of varying size.

Types of Improvement

Routing and scheduling improvements are those which bring transit service closer to the potential patrons, provide it more frequently, or extend the amount of time that it is available. The specific classes of improvement include:

- Route coverage--the extension of existing routes and the addition of new ones.

- Restructuring of routes--comprehensive rerouting that reflects new travel patterns, directness of movement, and interconnection of routes.

- Service frequency--increases in the number of vehicles on routes in specific periods or during all hours.

- Hours of service--extension of the hours of service in the day, or increase in the days of service in a week.

Transit Measures

In this work a number of quantitative measures of the transit operations are presented. These are based on, or derived from, reported operating agency data and include:

- Service measures--number of buses in peak-period service, annual bus-miles operated, and bus-miles per resident of area served.

- Ridership and productivity measures--annual passenger ridership, passengers per bus-mile, and annual passenger trips per resident of area served.

- Revenue and expense measures--operating cost per bus-mile and per passenger, revenue per passenger, the subsidy per passenger, and the annual subsidy per resident of the area served.

Approach

This work is organized in three sections:

- The short-term results of comprehensive transit route and schedule improvements in a selected number of cities are examined.

- The short-term results of the introduction of new transit service into areas previously unserved are examined.

- A number of measures of the relationship between transit service, ridership, and area size and population are presented so as to provide a basis for assessing the reasonable potential of transit service.

COMPREHENSIVE IMPROVEMENTS

Eight transit systems of varying size and character have been selected for analysis of the impact on ridership of comprehensive programs of service expansion. The following considerations were involved in selection of the systems.

- The systems had increased service, in terms of bus-miles, significantly over a relatively short time span (1 to 3 years).

- The systems were mature, and public support stabilized. (For example, significant increases in ridership have been experienced on many systems soon after a change in ownership or management--apparently due to marketing or a new "image" rather than increased service.)

- The systems had made relatively minor, if any, changes in fares during the period analyzed.

Analytical Approach

In Figure 24, the eight selected systems are described in terms of the number of peak buses operated and annual bus-miles and passengers for a base

Location	Base Year					Analysis Year				Improvement Productivity Index
	Year	Peak Buses	Bus-Miles (Thousands)	Riders (Thousands)	Pass./Mile	Year	% Change Peak Buses	% Change Bus-Miles	% Change Riders	(1.0=No Change)
Seattle, WA	1974	496	21,121	35,096	1.66	1975	0	+ 9.6	+ 8.3	0.86
Miami, FL	1972	298	14,794	55,631	3.76	1975	+41.9	+12.5	+10.9	0.87
Portland, OR	1971	249	11,478	20,310	1.77	1975	+54.2	+42.5	+36.4	0.86
San Diego, CA	1974	185	10,736	29,575	2.75	1975	+35.7	+20.1	+13.3	+0.73
Madison, WI	1974	104	3,234	10,992	3.40	1975	+13.5	+ 7.6	+ 8.9	1.17
Eugene, OR	1972	35	1,082	1,098	1.01	1975	+31.4	+166.5	+271.3	1.63
Raleigh, NC	1976	21	976	1,964	2.01	1977	+66.7	+28.6	+10.9	0.38
Bakersfield, CA	1974	14	648	1,079	1.66	1977	+50.0	+50.8	+49.0	0.96

NOTES:
1. All figures are based on annual operating data. Some locations report on a Fiscal Year basis.
2. Bus-mile figures include charter operations.
3. Ridership figures include transfer passengers.
4. Analysis year comparisons for Raleigh reflect the differences between the last nine months of the fiscal year and the corresponding nine months of the base year.

FIGURE 24

SELECTED TRANSIT SYSTEMS
ANALYSIS OF PRODUCTIVITY OF SERVICE IMPROVEMENTS

year. The productivity rate--passengers per vehicle-mile--provides insight into the character of the system. In general, the higher rates are typical of systems with a large part of their operations in areas of low income or high density and with significant numbers of short passenger trips. The lower rates are prevalent among systems with operations in lower density, higher income areas, with very high levels of service, or with longer passenger trips.

For the analysis year, the percentage increase in the three-system quantity measures are shown in Table 1. An improvement productivity index (an elasticity factor) has been calculated which is the ratio of the percentage change in ridership to the percentage change in bus-miles. An index figure of 1.0 would represent a situation where the additional service attracted ridership at a rate equal to the system average before improvements.

Summary Results

A summary description of the results for the selected systems follows. Data is presented in Figure 24.

Seattle and Portland -- Seattle and Portland represent medium-to-large systems with significant improvement programs in force. Their respective passenger-per-mile rates are relatively low--1.66 and 1.77, respectively. In Seattle, improvements over a single year that did not increase the number of peak buses resulted in an improvement index of 0.86. In Portland, a broad program of improvements that included more than a 50 percent increase in peak buses over four years also produced an index figure of 0.86.

Miami -- Miami, with a high passenger-per-mile rate and perhaps reflecting a larger low-income ridership, increased its peak bus fleet over 40 percent over three years, and showed an improvement ratio of 0.87.

San Diego -- San Diego, also with a relatively high passenger-per-mile rate, in a single year increased its bus-miles 20 percent and its peak fleet 35 percent. Its improvement ratio was 0.73.

Madison, Wisconsin -- Madison, Wisconsin, with a passenger-per-mile rate probably indicative of its large university population and state government activity, achieved an improvement index ratio of 1.17, with a broad program of improvements over a single year.

Eugene, Oregon -- Eugene, Oregon, over a three-year period greatly expanded its services--more than two and one-half times--and achieved a remarkably high improvement index ratio of 1.63. It should be noted that the base year passenger-per-mile figure for the system was a very low 1.01.

Raleigh, North Carolina -- Raleigh, North Carolina instituted a service improvement program that involved increases in the peak-period frequencies and modest route extensions and adjustments. At the end of ten months an improvement index ratio of 0.38 had been achieved.

Bakersfield, California -- Bakersfield, California implemented a comprehensive program of improvements that resulted in a 50 percent increase in bus-miles in peak and other periods. After three years, the improvement ratio was 0.96.

Summary -- It seems that it may be easier to predict ridership in relation to the quantity of added service in the larger systems. The impact of special situations on a calculated index figure is probably much greater in the smaller system. Exclusive of the two extreme cases of Eugene and Raleigh, the improvement ratios ranged from 0.73 to 1.16 and averaged 0.91. In other words, a given percent increase in bus-miles produced a nearly equal precent increase in ridership for the cases considered.

Case Example

In order to look at the response to a specific set of improvements over time, the case of Bakersfield is examined in somewhat more detail.

The Golden Empire Transit District implemented an "immediate action" plan in October 1974. The program included:

- Fourteen new buses were placed into service, seven of which replaced existing vehicles, and seven of which were used to expand service. (The buses replaced were well maintained and reasonably attractive, although old.)
- A major restructuring of routes took place. Added routes provided two-way service in areas previously served by one-way loop routes. Outlying shopping areas were made a focus of several routes, significnatly improving service to those points. Some routes were extended to areas previously unserved.
- Frequency of service was not generally increased, although greater choice of routes in some areas effectively increased frequency.
- A new multi-colored system map with schedules was prepared, and several reduced multi-ride fares put into effect. Two days free riding was permitted at the time of service change.

A month-by-month listing the ridership change is shown in Figure 25. By the end of the sixth month, the monthly ridership increase had equaled the percentage increase in bus-miles, with the overall inprovement productivity index for the six-month period being 0.75. As noted previously, the index figure for the third year of operation at the higher level was 0.96.

NEW SYSTEMS

Four transit systems started in areas previously unserved have been selected in order to examine the ridership attracted by such ventures, and by

Period	Comparison With Same Period Year Ago (%) Bus-Miles	Passengers	Improvement Productivity Index (1.0 = No Change)
November 1974	+39.7	+23.0	0.58
December 1974	+39.7	+33.1	0.83
January 1975	+39.7	+31.0	0.78
February 1975	+39.7	+27.5	0.69
March 1975	+39.7	+22.4	0.56
April 1975	+39.7	+39.6	1.00
Six Months	+39.7	+29.6	0.75

NOTES:

1. Revenue service on improved route system started November 1, 1974.
2. Improvement Productivity Index for FY 76 (21st through 32nd month after service changes) was 0.96.

FIGURE 25

ANALYSIS OF MONTHLY PRODUCTIVITY CHANGE
SERVICE IMPROVEMENTS - BAKERSFIELD, CA
FIRST SIX MONTHS OF OPERATION

possible similar extensions of new systems into unserved areas. Data is summarized in Figure 26.

- Orange County, California started what was esentially a new service in the large, rapidly developing, but low-density area with a population of 1.8 million. The 88 buses in operation by the end of the first year provided a very sparse service in relationship to the potential population served, but nevertheless, very large for a new service. The passenger-per-mile figure for the first full year was approximately 1.0.

- Chapel Hill, North Carolina, the site of the University of North Carolina, developed a system to serve both the community and the school. A student-pass program tied in part to the issuance of parking permits, resulted in a large amount of student riding. A passenger-per-mile figure of approximately 2.0 was recorded for the second year of operation.

- Bay City, Michigan and Greenville, North Carolina are examples of very small new systems. Each recorded approximately 0.8 passengers per mile in their first year of operation.

Summary

There is some indication that new fixed-route transit services designed to accommodate local travel must meet a passenger-per-mile figure in the 0.6 to 0.8 range to be judged viable. Lower productivity rates likely will result in pressure to revise routing, or convert service to a demand-responsive mode.

Case Example

The Greenville, North Carolina system provides an example for a look at the specific characteristics of the small system and the month-by-month attraction of riders.

The City of Greenville initiated its three-bus system in August 1976. There had been no permanent transit service in over 20 years. The new service featured:

- Three routes, two of which were large loops. One bus was assigned to each route, making one round trip each hour.

- All three routes served downtown Greenville, the principal outlying shopping center, and the social service facility. Two routes served the regional hospital. Very little transferring was required, although the loop-type routing did require some trips to be indirect.

Location	Initial Year	Population of Service Area (Thousands)	Analysis Year				
			Year	Peak Buses	Bus-Miles (Thousands)	Riders (Thousands)	Passengers/ Mile
Orange Co., CA	1975	1,864	1975	88	6,561	7,953	1.08
Chapel Hill, NC	1974	32	1975	21	908	1,902	2.09
Bay City, MI	1975	78	1975	8	329	255	0.78
Greenville, NC	1977	24	1977	3	134	107	0.80

NOTES:
1. All figures are based on annual operating data. Some locations report on a fiscal year basis.
2. Bus-mile figures include charter operations, if any.
3. Ridership figures include transfer passengers, if any.

FIGURE 26

SELECTED NEW TRANSIT SYSTEMS
ANALYSIS OF PRODUCTIVITY

- A fare of 25 cents was charged, with transfers free. A reduced senior-citizen fare was available.
- Schedules and route maps were prepared and a limited market effort undertaken. Three days of free riding were offered at the time of initiation of service.
- Initial service operated five days a week. Saturday service started in the fourth month.

Month-by-month ridership is presented in Figure 27. The passenger total increased sharply in the eighth month and has stayed close to that level (0.9 passengers per mile). The overall figure for the first 11 months was 0.8.

SERVICE MEASURES

There are a number of measures of transit service that are useful in estimating reasonable expectations relating to:

- Service
- Productivity
- Cost

In Figures 28 and 29, a series of measures are presented for ten of the transit systems included in the previous analyses. Most figures have been derived from data from the previously identified analysis year.

Service Measures

- Annual bus-miles per resident of area served
- Annual transit trips per resident of area served

Productivity Measure

- Passengers per bus-mile

Expense Measures

- Cost per bus-mile
- Cost per passenger trip

Revenue and Subsidy Measures

- Revenue per passenger (average fare)
- Subsidy per passenger (total Federal, state, and local assistance)
- Annual subsidy per resident of area served

Month	Bus-Miles	Riders	Pass./Miles (Month)	Pass./Miles (Year to Date)
August 1976	9,328	9,082	0.97	0.97
September 1976	9,145	6,429	0.70	0.84
October 1976	9,194	6,376	0.69	0.79
November 1976	10,008	6,407	0.64	0.75
December 1976	13,493	10,531	0.78	0.76
January 1977	13,981	8,342	0.60	0.72
February 1977	13,857	9,843	0.71	0.72
March 1977	13,745	12,577	0.91	0.75
April 1977	12,460	12,072	0.97	0.77
May 1977	14,205	11,959	0.84	0.78
June 1977	14,777	13,280	0.90	0.80
Fiscal Year 1976-1977	134,193	106,898		

NOTES:
1. Revenue service started August 2, 1976.
2. In November 2976, Saturday service was inaugurated and daily service hours extended.

FIGURE 27

ANALYSIS OF MONTHLY PRODUCTIVITY
NEW TRANSIT SYSTEM - GREENVILLE, NC

FIRST YEAR OF OPERATION

Location	Year	Peak Buses	Bus-Miles (Thousands)	Riders (Thousands)	Pass/ Mile	Cost/ Mile	Cost/ Rider	Revenue/ Rider	Subsidy/ Rider	Population Service Area	Annual Subsidy/ Resident Served [1/]
LARGER URBAN AREAS											
Seattle, WA	1975	497	23,337	38,001	1.63	$1.51	$0.92	$0.28	$0.64	1,146,200	$21.22
Miami, FL	1975	423	16,648	61,708	3.71	1.37	0.37	0.24	0.13	1,450,000	5.53
Portland, OR	1975	384	16,599	27,698	1.67	1.22	0.73	0.27	0.46	953,000	13.37
San Diego, CA	1975	251	12,687	33,526	2.64	1.53	0.58	0.19	0.39	1,300,000	10.06
SMALLER URBAN AREAS											
Madison, WI	1975	118	3,481	11,975	3.44	1.26	0.37	0.21	0.16	203,600	9.41
Eugene, OR	1975	46	2,884	4,078	1.41	0.98	0.69	0.29	0.40	170,000	9.60
Raleigh, NC	1977	35	1,258	1,824	1.45	1.11	0.77	0.31	0.46	140,000	5.99
Bakersfield, CA	1976	21	982	1,479	1.51	1.07	0.71	0.20	0.51	200,000	3.77
Bay City, MI	1975	8	329	255	0.78	0.85	1.09	0.23	0.86	78,000	2.81
Greenville, NC	1977	3	134	107	0.80	0.62	0.78	0.23	0.55	24,000	2.45
Averages for Larger Urban Areas					2.41	$1.41	$0.65	$0.25	$0.40		$12.55
Averages for Smaller Urban Areas					1.57	0.98	0.74	0.25	0.49		5.67

[1/] Includes Federal, state and local assistance.

FIGURE 28

SELECTED TRANSIT SYSTEMS
RELATIONSHIP OF OPERATING COSTS TO BUS-MILES AND RIDERS

Location	Population of Service Area	Annual Bus-Miles Per Residents Served	Annual Transit Trips Per Residents Served	Passengers/ Bus-Mile	Year
LARGER URBAN AREAS					
Seattle, WA	1,146,200	20	33	1.63	1975
Miami, FL	1,450,000	12	43	3.71	1975
Portland, OR	953,000	17	29	1.67	1975
San Diego, CA	1,300,000	10	26	2.64	1975
SMALLER URBAN AREAS					
Madison, WI	203,600	17	59	3.44	1975
Eugene, OR	170,000	17	24	1.41	1975
Raleigh, NC	140,000	9	13	1.45	1977
Bakersfield, CA	200,000	5	7	1.51	1976
Bay City, MI	78,000	4	3	0.78	1975
Greenville, NC	24,000	6	4	0.80	1977
Average for Larger Urban Areas		14.75	32.8	2.41	
Average for Smaller Urban Areas		9.7	18.3	1.57	

FIGURE 29

SELECTED TRANSIT SYSTEMS
RELATIONSHIP OF POPULATION SERVED TO
QUANTITY OF TRANSIT SERVICE AND AMOUNT OF RIDERSHIP

Summary

The selected systems for which data has been presented do represent a broad range of transit operations, but have been limited to those which have expanded overall services. In particular, the high-cost operations of some of the larger systems are not included. The cost and subsidy measures for operations in locations such as Boston, New York, Washington, Chicago, and others will differ from any presented here.

GUIDELINE MEASURES

In order to make certain estimates with respect to existing and proposed transit services, it is necessary to make certain assumptions with respect to service productivity and the characteristics of transit travel.

Service Productivity

The productivity measure, passengers-per-vehicle-mile, is a key indicator of the type of transit operation. Although it does reflect many specific features of the services offered and area served, it is a generally useful tool in estimating the relationship between quantity of service and ridership. (The measure is particularly sensitive to trip length--suburban commuter and similar express operations, even with relatively high ridership, usually have low passenger-per-mile rates.)

In Figure 30, proposed productivity standards for Denver are presented. It should be noted that these standards are for a fairly large system, with a relatively high overall productivity rate. (These rates would probably be similar to those experienced in San Diego, among the cities selected for analysis.)

Trip Length

Transit trip length is not a statistic obtained by most transit operations. Transportation planning agencies have developed figures from origin-destination surveys, but it is not consistently available for all transit operations.

A very general and tentative guide to transit trip lengths is offered in Figure 31. It is based on examination of passenger off-count data for three cities, with identification of the range of trip length for approximately 70 percent of trips identified.

REDUCTION OF VMT

In Figure 32, estimates of the VMT reduction resulting from expanded transit services in the ten selected cities are presented. These calculations are based on annual new bus passenger-miles attracted by the new bus-miles of service. Average bus passenger trip length is based on the estimates given in Figure 31. It is known that a substantial portion (perhaps 50 percent) of new riders of such systems did not formerly make the trip.

Route Type	Low Ridership (Warning Range)	Normal Range	High Ridership (Warning Range)
Local Radial Route	1.75 - 2.25	2.25 - 2.75	2.75 - 3.25
Local Crosstown Route	1.50 - 2.00	2.00 - 2.75	2.75 - 3.25

SOURCE: A Transit Planning Framework, prepared for Regional Transportation District, Denver, by R.H. Pratt Associates, Inc., January 1977.

FIGURE 30

TYPICAL ROUTE PRODUCTIVITY STANDARDS
FOR A LARGE TRANSIT SYSTEM
(PASSENGERS PER BUS-MILE)

		Range of Length (70% of Trips) (miles)	Average Trip Length (miles)
1.	LARGE		
	Seattle, Miami	1 to 6	3.5
2.	MEDIUM-LARGE		
	San Diego	1 to 5	3.0
3.	MEDIUM		
	Portland, Madison, Bakersfield [1/]	1 to 4	2.5
4.	MEDIUM-SMALL		
	Raleigh,[1/] Euguene	1 to 3	2.0
5.	SMALL		
	Greenville,[1/] Bay City	1 to 2	1.5

[1/] Verified by local transit survey data.

FIGURE 31

ESTIMATED TRANSIT TRIP LENGTHS
BY GEOGRAPHIC SIZE OF SERVICE AREA

Location	Service Area Population (millions)	Annual VMT[1] (millions)	Annual New Bus Miles (thousands)	Annual New Bus Passengers (thousands)	Average Trip Length (miles)	Annual New Bus Passenger Miles (thousands)	Annual Vehicle[2] Miles if by Auto (thousands)	Annual Equivalent[3] Vehicle Miles Reduced (thousands)	Equivalent Percent Reduction in VMT	Equivalent Vehicle Miles Reduced per New Bus Pass.
Seattle	1.146	7,153	2,028	2,913	3.5	10,196	8,496	4,440	0.06	1.52
Miami	1.450	5,917	1,850	6,064	3.5	21,224	17,867	13,987	0.24	2.31
Portland	0.953	4,299	4,878	7,393	2.5	18,483	15,402	5,646	0.13	1.16
San Diego	1.300	6,929	2,158	3,933	3.0	11,799	9,833	5,517	0.08	1.40
Average for Larger Cities	1.212	6,075	2,729	5,076		15,425	12,855	7,397	0.13	1.60
Madison	0.204	1,224	246	978	2.5	2,445	2,038	1,546	0.13	1.58
Eugene	0.170	628	1,802	2,979	2.0	5,958	4,965	1,361	0.22	0.46
Raleigh	0.140	1,156	279	214	2.0	428	357	-201	-0.02	-0.93
Bakersfield	0.200	709	329	529	2.5	1,323	1,102	444	0.06	0.84
Bay City	0.078	367	329	255	1.5	383	319	-339	-0.09	-1.33
Greenville, N.C.	0.024	96 (est)	134	107	1.5	161	134	-134	-0.14	-1.25
Average for Smaller Cities	0.136	697	520	844		1,783	1,486	446	0.03	-0.10

(1) Based on 1972 data in DOT National Transportation Study
(2) Assuming average auto occupancy = 1.2
(3) Assuming one bus-mile = two equivalent passenger-car miles

FIGURE 32

COMPUTATION OF VMT REDUCTION RESULTING FROM EXPANDED TRANSIT SERVICES

However, auto VMT reduction estimates are made on the basis of "what if" these trips were served by auto at an average occupancy of 1.2 per car. New bus-miles of travel are deducted from auto VMT reduced, assuming that one bus-mile is equivalent to two passenger car units. The use of this equivalency factor for buses gives a close approximation of the impact of buses on traffic flow. However, the equivalency factor of 2 is less than the ratio of fuel consumption rate for buses to that for the average automobile, which approximates 3.

The results indicate fairly constant equivalent VMT reduction per new bus passenger trip for the four larger urban areas studied, ranging from 1.16 to 2.31 equivalent vehicle-miles reduced per new passenger, and averaging 1.60. However, the six smaller cities show widely varying VMT reduction impacts, with three of the six smaller cities actually showing VMT increases due to short trip lengths of bus passengers and low productivity indices of new bus services implemented. The average for the six smaller cities is an increase of 0.10 equivalent vehicle-miles of per new bus passenger trip.

Figure 32 also shows equivalent vehicle-miles reduction as a percentage of total urban area VMT. For the four larger cities, the percent decreases in VMT varied from 0.06 percent to 0.24 percent, and averaged 0.13 percent. It should be recalled that the percent increases in bus-miles of service for these four cities ranged from 9.6 percent to 42.5 percent, and averaged 21 percent (see Figure 24). Thus, on the average, each 1 percent increase in bus-miles of service generated a 0.13/21 = 0.006 percent reduction in equivalent areawide VMT. Even if substantially larger service expansions were made and the same improvement productivity index was maintained, the impact on areawide VMT would be slight. For example, based on the averages for the four cities, a 50 percent increase in bus-miles of service would result in only approximately 0.3 percent reduction in areawide VMT.

For the six smaller cities, percent reduction in VMT ranged from 0.14 percent (i.e. VMT increase) to 0.22 percent, and averaged 0.03 percent. Thus, it appears that transit service expansion of the type analyzed is unlikely to produce any consistent measurable VMT reductions in smaller cities.

It should be noted that the transit route and schedule enhancements considered above only include expansion of conventional local transit service and do not account for implementation of longer distance express bus service, which are separately analyzed in another section of the report. Moreover, the action is analyzed independently of any other transit incentives or auto disincentives which would result in expanded transit ridership systemwide. The intepretation of the findings should keep in mind the limited character of transit service expansions analyzed.

COST EFFECTIVENESS

Figure 33 presents cost-effectiveness results for expanded transit service for the ten cities analyzed.

Location	Net Annual Cost Per New* Bus Rider	Net Cost Per Equivalent** VMT Reduced
Seattle	$200	$0.42
Miami	41	0.06
Portland	144	0.40
San Diego	122	0.28
Madison	50	0.10
Eugene	125	0.87
Raleigh	144	VMT Increase
Bakersfield	159	0.61
Bay City	268	VMT Increase
Greenville	172	VMT Increase
Average for Larger Cities	$127	$0.29
Average for Smaller Cities	153	--

*Assuming six days per week service or 312 days per year.

**Net cost per new bus passenger divided by equivalent VMT reduction per new passenger.

FIGURE 33

COST EFFECTIVENESS OF EXPANDED TRANSIT SERVICE

Net annual cost of providing expanded service per new bus passenger trip is quite consistent ranging from $122 to $268 per new rider, except for Miami and Madison, which exhibited much lower costs. Average annual costs per new rider was $127 for the four larger cities and $153 for the six smaller cities.

Net cost of providing expanded service per equivalent VMT reduced was highly variable, and for three of the smaller cities could not be computed since VMT increases occurred. For the four larger cities, the cost per equivalent VMT reduced averaged $0.29.

SOURCE DATA

"A Transit Development Program For Greenville." Prepared for City of Greenville, North Carolina, by Alan M. Voorhees & Associates, Inc. March 1977.

"A Transit Development Program For Raleigh." Prepared for City of Raleigh, North Carolina, by Alan M. Voorhees & Associates, Inc. September 1973.

"A Transit Development Program For The Golden Empire Transit District." Prepared for Golden Empire Transit District, Bakersfield, California, by Alan M. Voorhees & Associates, Inc. March 1975.

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"Transit Operating Reports." American Public Transit Association, and predecessor, American Transit Association. 1972 to 1975.

CHAPTER C

IMPACT OF PARK-AND-RIDE AND EXPRESS BUS IMPROVEMENTS

THE CONCEPT

Express buses have operated in several U.S. urban areas with varying degrees of success in recent years. However, the advent of preferential treatment for these buses, both in the line-haul mode and at facility access points, is providing travel times which are increasingly competitive with automobile transportation to the city center. When these improved operating speeds are combined with the careful placement of outlying park-and-ride lots, a potential exists for capturing a significant portion of the longer work trips heretofore reliant solely on the auto.

Definition

Bus routing and frequency of stops are the two system characteristics most important to the definition of express bus service. A bus is said to be an express bus if it follows a route length of at least 5-10 miles, connects a limited residential neighborhood and/or parking lot(s) with a high-activity employment, transportation, or recreational center, and makes no more than one or two intermediate stops on the line-haul segment of the trip.

Service is generally provided only during peak commuting periods but, of course, different scheduling would be warranted if one of the trip ends is an airport or sports arena. To provide an attractive travel alternative, headways should be 20 minutes or less for any residential pickup/distribution and 10 minutes or less for any park-and-ride lots served.

Importance of High Service Standards

Various studies have shown that a large portion (i.e., 60-80 percent) of express bus riders have based their mode choice not on the availability of an alternative mode, but on the dependability, convenience, and comfort of the bus service. The high expectations of these so-called "choice" riders must be upheld if the public investments in the system are to be protected. In addition to convenient routing, scheduling, and headways, it is important for the transit operator to strive for reduced travel time variability (through improved operating practices and through other TSM actions in the corridor). A fairly high level of security and amenities should be maintained throughout the system, especially at park-and-ride lots.

CASE STUDIES

An extensive literature search was conducted to identify examples of successful park-and-ride/express bus utilization. Emphasis was placed on experiences since 1970, during a 7-year period in which significant advancements were made in determining the corridor and areawide potential of a modern express bus system. The more conspicuous "success stories," already well-documented, have usually involved preferential facility treatments for buses (and often other high-occupancy vehicles as well). However, of the 20 selected case studies described in Figures 34 and 35, many express buses simply operate in mixed traffic on freeways or on major arterial streets.

Physical Attributes

Those case studies involving express buses but no significant park-and-ride lots include Honolulu (Kalanianaole Highway), Portland (Banfield Freeway), Dallas-Spring Creek, and New York City (I-495). With the exception of the Spring Creek service, these cases utilize priority lanes in heavily traveled, very constrained corridors.

As revealed by the boarding information in Figure 35, several of the examples have a park-and-ride lot as the sole suburban trip end. These cases include Richmond, Hartford, Miami (Orange Streaker), and Dallas-North Central lot.

The remaining 12 examples listed in Figure 34 have some mixture of park-and-ride and residential collection/distribution by the express buses themselves. Six of the 12 examples have proven to be moderately successful by operating in general traffic without any significant preferential treatment. These six operations are in the cities of Louisville, Cincinnati, Denver, Milwaukee and Washington, D.C.

The last six express bus systems reviewed are noteworthy due to their highly successful combination of local pickup and distribution, express bus scheduling and headways, and line-haul preferential treatment provided by other TSM actions. The arterial highway example cited, the Miami Blue Dash service, currently utilizes a with-flow bus and carpool lane on the South Dixie Highway. Developed as part of the Urban Corridor Demonstration Program, the I-35W corridor in Minneapolis encourages express bus ridership by providing well-dispersed park-and-ride lots and preferential bus access to a metered freeway (however, the time savings of buses compared to auto traffic is negligible). Present and proposed future express bus operations in Seattle rely heavily on reversible freeway lanes, as does the Shirley Highway serving Washington, D.C. Finally, the San Bernardino Busway, connecting El Monte with downtown Los Angeles, is distinguished by its physically separated, one-way reserved lanes.

Operational Experiences

In approaching the issue of express bus system impacts on corridor and areawide transportation, an overview of key statistical trends is as instructive as a detailed case-by-case discussion. With emphasis on the larger, more ambitious projects listed in Figures 34 and 35, the following general conclusions can be drawn:

City and References	Project[1/]	Months of Service	Daily Bus Trips	Daily Patronage[2/]			Average Number of Passengers/Trip		
				New	Diverted	Total	Peak	Off-Peak	Overall
Richmond (1)	Parham P&R	12	--	--	--	1,100	--	--	--
Honolulu (2,3)	K-Hwy E.B.	40	32	1,050	270	1,320	41.2	--	41.2
Hartford (4)	P&R Corbins	9	26	470	130	600	23.1	--	23.1
	P&R Burr	3	26	--	--	480	18.5	--	18.5
Louisville (5)	UCDP P&R/ Express Bus	Avg. of 16 mo.	32	302	276	588	18.4	--	18.4
Portland (2,6)	Banfield Fwy. Express Bus	12	33	--	--	965[3/]	29.2		
Cincinnati (5)	UCDP P&R/ Express Bus	Avg. of 6 mo.	26 P&R 52 total	816	281	1,097	48.0	10.0	21.0
Denver (7)	Current Area P&R/Exp. Bus	N/A	276	N/A	N/A	5,903	21.4	--	21.4
	Example Plan for 1987 P&R/Exp. Bus	N/A	400	N/A	N/A	10,000	25	--	25
Seattle (8,9)	Blue Streak (1 P&R lot)	18	545[3/]	3,659	7,530	11,189	38.7[3/]	--	20.5[3/]
	1980/1990 P&R Plan	N/A	920	--	--	36,810/	--	--	40
			1,066	--	--	42,650	--	--	40
Milwaukee	Fwy. Flyer	Vari-able	--	--	--	2,800	--	--	--

FIGURE 34

EXPRESS BUS UTILIZATION: 20 CASE STUDIES

Figure 34 (continued)

City and References	Project[1/]	Months of Service	Daily Bus Trips	Daily Patronage[2/] New	Diverted	Total	Average Number of Passengers/Trip Peak	Off-Peak	Overall
Miami (2,11,12,13)	Orange Streaker (1 P&R lot)								
	I-95 Mixed	4	52	--	--	1,160	22.3	--	22.3
	NW 7th Ave.	18	52	1,272	280	1,552	29.8	--	29.8
	I-95 HOVL	14	52	--	--	1,728	33.2	--	33.2
	Blue Dash (S. Dixie Hwy) (Hovl; P&R)	29	61	1,740	360	2,100	34.4	--	34.4
Minneapolis (5,14)	I-34W UCDP P&R/Exp. Bus	38	225	4,200	2,900	7,100	31.6	--	31.6
Dallas (5)	Spring Creek Express Bus	22	27	205	200	405	15.0	--	15.0
	N. Central P&R	3	73	--	--	1,608	28.0	11.5	22.0
Washington, DC (5,15,16, 17,18)	Shirley Hwy. Reserved Lanes P&R/Exp. Bus	58	900	20,560	13,140	33,700	37.4	--	37.4
	UCDP P&R/ Express Bus								
	New Routes	--	34	990	330	1,320	38.8	--	38.8
	Expanded	--	30	1,200	400	1,600	53.3	--	53.3
Los Angeles (2,19,20)	San Bernardino Busway, P&R	48	--	13,500	4,500	18,000	36.0[3/]	--	--
New York City (2)	I-495 Contra-Flow Lane	N/A	2,000[3/]	--	--	76,000[3/]	38.0[3/]	--	38.0[3/]

[1/] After indicated months of service (unless noted as average of several months).

[2/] P&R = park and ride.

[3/] AMV estimate.

City and Reference	Project	Maturing of P&R (month)	Daily Inbound Riders 1/ Total	No. Boarding at Lot(s)	No. From Parking Cars	Lot Utilization No. of Cars Parked	Percent of Spaces	Occup. of Cars — Buses
Richmond (1)	Parham P&R	12	548	548	385 2/	330 2/	98	1.16
Hartford (4)	P&R Corbins	9	300	300	285	207	83	1.38
	P&R Burr	3	240	240	--	--	--	--
Louisville (5)	UCDP Lot 1	16	300	--	--	45	26	--
	P&R Lot 2			--	--	35	N/A	--
Cincinnati (5)	UCDP P&R	6	400	--	60	--	--	--
Seattle (8)	Blue Streak 2/	12	5,700	781	508	535	100	1.30
Miami (2,11,12, 13)	Orange Streaker							
	I-95 Mixed	4	605	605	309	160	27	1.19
	NW 7th Ave.	18	787	787	401	440	46	1.10
	I-95 HOVL	14	887	887	452	501	23	1.11
Minneapolis (5,14)	I-35W VCDP P&R/Exp. Bus	Variable (9-36)	3,700	493	301	274	--	1.10
Dallas (5)	N. Central P&R	3	850	850	620	550	55	1.13
Washington, DC (5,15, 16,17,18)	Shirley Hwy. 2/ Reserved Lanes P&R/Exp. Bus	58	17,730	--	5,850 2/	(No data for over 20 unofficial park & ride locations)		
	Springfield	36	--	--	--	400	N/A	--
	Backlick	5	--	--	321	253	63	1.27

FIGURE 35

UTILIZATION OF EXPRESS BUS PARK-AND-RIDE FACILITIES

Figure 35 (continued)

City and Reference	Project	Maturing of P&R (month)	Daily Inbound Riders[1/] Total	No. Boarding at Lot(s)	No. From Parking Cars	Lot Utilization No. of Cars Parked	Percent of Spaces	Occup. of Cars — Buses
Washington DC (contd)	VCDP P&R/ Express Bus Sum of 4 remote lots	Variable	--	--	--	329	51	--
Los Angeles (2,19,20)	San Bernardino Busway, P&R (1,400 spaces at El Monte)	48	9,125[2/]	--	--	(No data on P&R utilization)		

[1/] Only on those routes serving park and ride lots (unless indicated with a [2/]).

[2/] AMV estimate.

- The overall average ratio of "new" to "total" patronage was 62 percent. This performance measure was only slightly lower, at 60 percent, for the selected subset consisting of the Minneapolis I-35W bus-freeway project, the Shirley Highway reversible lanes, the San Bernardino Busway, and the Seattle Blue Streak.

- Peak-period bus occupancies averaged 35 passengers overall and 36 passengers for the selected subset of four projects.

- As a percentage of total inbound patronage, the portion boarding at park-and-ride lots was 13-14 percent for the Seattle and Minneapolis examples (where express buses also provided a substantial degree of local pickup and delivery service).

- Fifty to 95 percent of the bus riders boarding at park-and-ride lots arrived at the lots by automobile; the overall average was 62 percent. Other riders, of course, either were dropped off by an automobile driver ("kiss-and-ride"), rode a local bus to the lot, walked, or bicycled.

- The average park-and-ride lot had only 57 percent of its spaces filled at the end of the morning peak period; only two lots were shown to approach capacity utilization.

- Cars using a remote parking lot have occupancies slightly lower than would be expected for longer commuting trips directly to downtown. For the cases reviewed, occupancies ranged 1.1-1.4 persons and averaged 1.2 persons.

AREAWIDE POTENTIAL

Ridership

As suggested by the 20 case studies listed above, the ridership potential of an express bus system--and the resulting impacts on mode split, vehicle-miles-traveled, and the various environmental factors--varies quite significantly. The variation no doubt relates to such key contextual aspects as population, population density, corridor constraints, preexisting mode split, and the availability of preferential bus treatments. Rather than attempt a complex correlation analysis of some sort, however, it is felt that the express bus option can be adequately compared to other TSM actions if suitable ranges in ridership potential are developed. Accordingly, Figure 36 was constructed using the following four independent techniques:

- Areawide potential was taken directly from Seattle and Denver planning studies and expressed in terms of total daily bus trips per million population.

City	Project and Base Year	SMSA Population in Base Year (mil.)	Express Bus Potential for Population in Base Year: Total Daily Ridership	Riders/ Bus	Total Daily Bus-Trips	Per Million Population: Total Daily Bus-Trips
Seattle	Area Plan, 1980	1.5	37,000	40	925	615
Denver	Area Plan, 1987	2.0	10,000	25	400	200
Minneapolis	I-35W (Extrapolated, 1974)	2.0	30,000	32	940	470
Washington, DC	Shirley Highway (Extrapolated, 1977)	3.1	110,000	38	2,900	935
Los Angeles	San Bernardino Fwy. (Extrapolated, 1977)	6.9	90,000	36	2,500	360
Hypothetical	Planning Data From NCHRP 155	2.0	13,200- 31,800	35	375- 910	190) 455) 320
Hypothetical	Simplified Model of Transportation Demand	2.0	10,200- 24,480	35	290- 700	145) 350) 250
Average of 7 Cities				35		450

FIGURE 36

EXPRESS BUS RIDERSHIP POTENTIAL IN SEVERAL
REAL AND HYPOTHETICAL CITIES

- Actual ridership in three essentially "saturated" corridors (I-35W, Shirley Highway, and San Bernardino Freeway) was extrapolated areawide. As in the first technique, the ridership potential was then normalized for a hypothetical city of one million persons. The extrapolation process assumed a relationship between the number of residential trip ends in the corridor and the number in the entire metropolitan area.

- Planning data for peak-period express bus ridership for a city of two million population were extracted from NCHRP Report 155 ("Bus Use of Highways--Planning and Design Guidelines," 1975). (21) Daily bus trips were then computed by assuming the previously cited occupancy of 35 persons/trip.

- Finally, a range of potential ridership was estimated by creating hypothetical cities A and B, where A is of moderate density and B is less densely settled. The following factors were assumed and multiplied to obtain "total daily ridership":

Factor	City A	City B
Work Trips Per Day	1,700,000	1,700,000
Percent of Jobs Downtown	18	12
Percent of Downtown Work Trips Longer than 8 Miles (i.e., the assumed market area)	40	50
Percent of such work trips "captured" by express bus	20	10

Using the four different techniques described above, estimates were made of the potential for areawide total daily express bus trips per urban area population of one million. The results shown in Figure 37 indicate the average for the seven cases computed was 450 express bus trips per day per one million population. Rounded values for low and high estimates of areawide potential, respectively, were 150 and 950 express bus trips daily per one million population. At an average of 35 passengers per express bus trip, this translates into an average daily ridership on express buses of 15,750 passengers per one million population, and low and high estimates of 5,250 and 33,250 daily passengers.

In Figure 37, the daily ridership estimates are translated into areawide VMT reduction potential. The results show an average estimated annual VMT reduction of 15,692,000, or 0.31 percent of annual areawide VMT for the hypothesized urban area of one million population. The low and high range estimates of VMT reduction are 0.10 percent to 0.74 percent of areawide total VMT.

VMT reduction as a percent of work-trip VMT averages 0.89 percent and ranges from 0.29 percent to 2.11 percent. For work-trip VMT to or from the CBD, the estimated VMT reduction averages 5.93 percent and ranges from 1.93 percent to 14.1 percent.

Ridership Level	Low		Mean of 7 Cases		High	
	Low	High	Low	High	Low	High
Level of Costs of Fares						
Daily express bus trips	150		450		950	
Number of buses required[(a)]	63		188		396	
Daily operating cost per bus	$ 100	$ 150	$ 100	$ 150	$ 100	$ 150
Total daily operating cost	6,300	9,450	18,800	28,200	39,600	59,400
Fare	50 cents	75 cents	50 cents	75 cents	50 cents	75 cents
Daily fare revenues @ 35 per bus	2,625	3,838	7,875	11,813	16,625	24,938
Net Daily cost (subsidy)	3,675	5,512	10,925	16,387	22,975	34,462
Net annual cost (subsidy)	919,000	1,378,000	2,731,000	4,097,000	5,744,000	8,616,000
Daily bus riders @ 35 per bus	5,250		15,750		33,250	
Daily auto VMT reduction[(b)]	26,923		80,769		170,515	
Daily express bus VMT[(c)]	3,000		9,000		11,085	
Equivalent daily VMT reduction[(d)]	20,923		62,769		418,345	
Annual VMT reduction[(e)]	5,231,000		15,692,000		37,086,000	
Annual total VMT[(f)]	5,000 million		5,000 million		5,000 million	
Percent reduction in total VMT	0.10		0.31		0.74	
Percent reduction in work trip VMT[(g)]	0.29		0.89		2.11	
Percent reduction in work trip VMT to and from CBD[(h)]	1.93		5.93		14.1	
Net cost per VMT reduced	17.6¢	26.3¢	17.6¢	26.3¢	17.6¢	26.3¢
Net annual cost per bus rider	$175	$263	$175	$263	$175	$263
Net annual cost per new bus rider diverted from auto[(i)]	$261	$393	$261	$393	$261	$393
Net annual cost per two-way commuter diverted from auto	$522	$786	$522	$786	$522	$786

FIGURE 37

SUMMARY OF AREAWIDE EXPRESS BUS IMPACTS FOR URBAN AREA
OF ONE MILLION POPULATION

Figure 37 (continued)

(a) Assuming 1.2 revenue trips per bus each of two peak periods

(b) Assuming 33 percent of riders formerly rode local bus, 10-mile average trip length, 1.3 passengers per car

(c) Assuming 50 percent deadheading and 10-mile trip length

(d) Assuming one bus mile = two equivalent passenger car miles

(e) Assuming 250 annual days of express bus operation

(f) Assuming annual VMT = 5,000 per capita

(g) Assuming work trip VMT = 10 percent of total VMT

(h) Assuming CBD work trips = 15 percent of total work trip VMT

(i) Assuming 67 percent of riders are diverted from auto

Thus it is seen that, while the areawide VMT reduction potential of express bus is minimal, the work-trip VMT reduction potential is fairly significant, approximating 1 percent. Moreover, since express bus trips are focused on CBD work trips, the work-trip VMT reduction potential in radial corridors serving the CBD can be quite substantial, averaging close to 6 percent reduction for a fully developed system.

Express bus systems are primarily applicable to medium to larger urban areas with substantial volumes of CBD-oriented commuter trips longer than 8 miles. It should be noted that the VMT reduction potential estimated above includes all express bus trips in an urban area, both preexisting and new ones. Thus, if an urban area already has a partially developed express bus system, the existing system characteristics should be compared with the maximum potential estimates to determine the remaining potential for expansion of the express bus system.

Cost Effectiveness

The results of the analysis of potential ridership and VMT reduction potential, and estimates of net costs of providing express bus service, are combined in Figure 37 to compute cost-effectiveness indices.

The average estimated cost per VMT reduced through diverting auto commuters to express bus ranges from 17.6 cents to 26.3 cents. Net annual cost per new express bus rider ranges from $175 to $263, and if only new bus riders are considered (i.e. those formerly commuting by auto), the estimated annual cost per new rider ranges from $261 to $393. If it is assumed that all express bus riders are commuters who travel both to and from work daily by this mode, then the annual cost per two-way commuter diverted from auto ranges from $522 to $786.

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CHAPTER D

IMPACT OF WORK RESCHEDULING PROGRAMS

INTRODUCTION

Peak concentrations of work trips during short periods of time during the commuting hours is a phenomenon which is an evident cause of congestion in urban areas. The severity of peaking varies as a function of travel mode, city size, and employment location within the urban areas. Peaking is typically most extreme for transit trips where very sharp concentrations of demand can be observed during periods as short as 15 minutes. Peak periods are longer (i.e. the overall distribution of demand during commuting hours is flatter) for automobile work trips. Small cities and outlying work centers in all city sizes may have auto commuting peaks as short as 15 to 30 minutes. The peaks tend to lengthen and flatten for larger cities, encompassing periods as long as two hours or more in extreme cases.

The main thrust of the work rescheduling strategy is to reduce congestion within and to and from major employment centers, particularly CBD's, by spreading out the peak (i.e. increasing the total span of time during which commuting occurs and/or decreasing the percent of commuters traveling during the busiest period.) The anticipated effects of peak flattening are greatest for transit users who characteristically have more extreme peaks currently, but the potential for congestion reduction is viewed as significant also for automobile commuters traveling to high density employment centers.

There are two basic alternative forms of variable work hours:

- Staggered hours in which changes in fixed schedules of starting and quitting times are implemented either for all employers or subsets of employees within an employment location.

- Flexitime in which employees are permitted freedom to adjust their own working hours, within limits. A classical form, for example, is that all employees must be present only during specified core hours (e.g. 10 a.m. to 3 p.m.) and that the full complement of hours must be worked during a standard one-week or two-week pay period.

A specialized form of work rescheduling is the shortened work week, principally conversion from a 5 day/8 hours per day schedule to a 4 day/10 hours per day schedule. The principal thrust of this strategy is to reduce total work-trip travel demand per day and thus alleviate congestion during peak periods. This strategy also may flatten peaks since the 4-day workers' starting and quitting times would likely fall outside of the busiest periods. Implementation of 4-day work weeks can take on a variety of forms, for example:

- Equal rotation of days worked from Monday to Friday
- Equal rotation of days worked from Monday to Saturday
- One-half work Monday to Thursday, one-half work Tuesday to Friday
- One-half work Monday to Thursday, one-half work Wednesday to Saturday
- One-third work Monday to Thursday, one-third work Tuesday to Friday, one-third work Wednesday to Saturday

EXTENT OF CURRENT APPLICATIONS

A survey of variable working hour activities conducted by the Port Authority of New York and New Jersey in 1975 (Ref. 1) indicated that although transportation officials in U.S. cities perceive commuter peaking as a major cause of congestion, organized programs to foster work rescheduling are very underutilized. Officials in 98 U.S. cities responded to a questionnaire, and:

- 74 percent believed that traffic demands are sharply peaked in their city
- 59 percent felt that existing work schedules are a major cause of CBD congestion.

However,

- Only 19 percent had ever made surveys of CBD work schedule practices
- 16 percent were currently pursuing staggered hours programs
- 16 percent had in the past tried staggered hours programs
- 10 percent had tried flexitime programs
- 19 percent had made some effort to encourage 4-day work weeks.

PENETRATION OF COMPREHENSIVE PROGRAMS

As of 1976, only a handful of cities had made major accomplishments with variable work hours program. Selinger presented an excellent state-of-the-art review of the more noteworthy efforts at the Minneapolis TSM conference held in late 1976 (Ref. 2). Information from his paper is summarized in

Figure 38 to indicate the degree of penetration of comprehensive variable work hours programs.

For the seven cities shown in the table, the percent of CBD workers who were participating in formal programs varied from 11 percent to 47 percent, and averaged 28 percent. The number of variable hours participants as a percent of total urban area employment ranged from 2 percent to 16 percent, and averaged 5 percent. Cities dominated by public sector employment (i.e. Washington, D.C., Ottawa, and Madison) had significantly greater penetration as might be expected. These results are useful in establishing target levels for penetration of such programs. It appears reasonably practical to set a goal of 20 percent of CBD employees (or about 4 to 5 percent of areawide employees). An absolute upper bound for any city probably couldn't exceed 50 percent of CBD employees, and it is unlikely that very many cities could approach this limit even with comprehensive and aggressive programs continued over several years.

It is encouraging to note that a wide range of city sizes are represented in the list in Figure 38. However, the variable working hours strategies are viewed as more likely to receive high priority in larger cities, with severe traffic congestion and transit crowding, than in smaller cities. Conversely, though, it is probably easier to accomplish measurable impacts in smaller and medium size cities, currently having shorter and steeper peaks, than in very large cities where current peak periods for autos are already fairly long and flat.

TRANSPORTATION IMPACTS

Variable Work Hours

Time Distribution of Demand -- The most significant impact of variable work hours programs is the flattening of peak transit demands. Selinger (Ref. 2) reports that in Lower Manhattan, the maximum 10 minute passenger arrival volumes at the three busiest subway stations were reduced by an average of 26 percent as a result of the staggered work hours program which concentrated on shifting standard work hours of 9 a.m. to 5 p.m. to 8:30 a.m. to 4:30 p.m. In Ottawa, where nearly 50 percent of the CBD employees in a staggered hours program, which shifted working hours primarily either one half hour earlier or one-half hour later, resulted in reductions of the peak-hour percentage of peak-period CBD transit arrivals of participants by 20 percent. The effect on overall transit demand at the CBD cordon line was a 15 percent reduction in the peak-hour percentage of peak-period volumes.

In the Queen's Park government complex in Toronto, where about half of the 11,000 employees shifted to earlier or later work schedules, the peak 15-minute volume of government employees using the subway was cut in half in the a.m. peak (from 40 percent to 20 percent of the 2 hour and 15 minute total) and was reduced by 25 percent in the p.m. peak (from 33 percent to 25 percent).

Urban Area	Estimated Total Employment	Estimated CBD Employment	Total Employees in Formal Variable Hours Program	Percent of Total	Percent of CBD
New York, New York	7,500,000	2,000,000	220,000	3	11
Philadelphia, Pennsylvania	1,800,000	300,000	43,000	2	14
Toronto, Ontario Canada	1,000,000	260,000	68,000 (+29,000 potential	7	26
Washington, D.C.	1,200,000	500,000	200,000	16	40
Madison, Wisconsin	122,000	17,000	5,000	4	30
Riverside, California	50,000	N.A.	3,200	6	
Ottawa, Quebec Canada	?	70,000	33,000	___	47
			Average	6	28

FIGURE 38.

PENETRATION OF COMPREHENSIVE VARIABLE WORK HOURS PROGRAMS

While transit arrival and departure peak hours can be cut by 20 percent in the peak hour, and by even greater amounts during the peak 15-minute period, Ottawa findings indicate that the impacts on total transit loads and automobile volumes past CBD boundary screenlines are diluted by other traffic. Figure 39 illustrates this dilution effect showing reductions in peak-hour percentages of the peak period for different modes and locations. Generalizing on these results it can be concluded that if 50 percent of the workers are participating in a variable hours program and, if transit terminal arrival/departure percentages are reduced by 20 percent:

- Peak-hour auto arrivals at parking lots in the CBD are reduced by almost as large a percentage, approximating 17 percent
- Peak-hour auto volumes at a CBD core screenline are reduced by only about half as much, approximating 10 percent
- Peak-hour auto volumes at a screenline at an important radial route bridge crossing near the CBD is reduced by only about one-quarter as much, approximating 5 percent.
- Peak-hour bus passenger loads at the CBD core screenline are reduced by substantial percentages, approximating 14 percent.

The impacts listed immediately above are considered to be reasonably representative of the maximum potential impact of a variable work hours program on peak-hour volumes, since nearly 50 percent of the Ottawa CBD employees were participants in the program.

The evaluation of a staggered hours program in 1972 at the 3M Company in St. Paul, Minnesota illustrated that such programs can also produce significant peak flattening at large suburban employment centers. Traffic counts were made before the program was implemented (in 1970) and after the program (in 1972) at entrances to the facility and on nearby access roads. The results indicate that peak volumes increased much less than the overall increase in average daily traffic (ADT) at the count stations. For inbound traffic stations, ADT increased by 35 percent from 1970 to 1972, but a.m. peak-hour volumes rose only by 17 percent and peak 15-minute volumes were up by only 13 percent. At the outbound count stations, ADT rose by 39 percent but peak-hour and peak 15-minute volumes increased by only 19 percent and 5 percent, respectively.

<u>Highway Level of Service</u> -- A simplified analysis is made to estimate the order of magnitude impacts on highway levels of service (i.e. average travel time per mile) resulting from flattening of peak volumes caused by variable hours programs. This is done by introducing a "two-regime" concept of traffic congestion as illustrated in Figure 40.

Traffic on both freeways and surface arterials is assumed to operate in one of two regimes:

Location	A.M. — 2.5 Hours			P.M. — 3 Hours			Average A.M. and P.M.
	Before	After	Percent Reduction	Before	After	Percent Reduction	Percent Reduction
Government Employee Transit Users at Work-place	86.2	71.6	16.9	85.3	65.1	23.7	20
Bus Passengers at Screenline B	67.9	62.2	8.4	62.0	50.1	19.2	14
Autos at Parking Lots	62.1	53.7	13.5	57.3	44.9	21.6	17
Autos Crossing Screen-line B (CBD Core Cordon)	55.0	49.2	10.5	46.3	41.6	10.2	10
Autos Crossing Screen-line A (River Crossing Cordon	53.0	51.6	2.6	45.7	43.1	5.7	4

FIGURE 39

IMPACT OF VARIABLE HOURS PROGRAM IN OTTAWA ON PEAK-HOUR VOLUMES AS PERCENT OF PEAK PERIOD

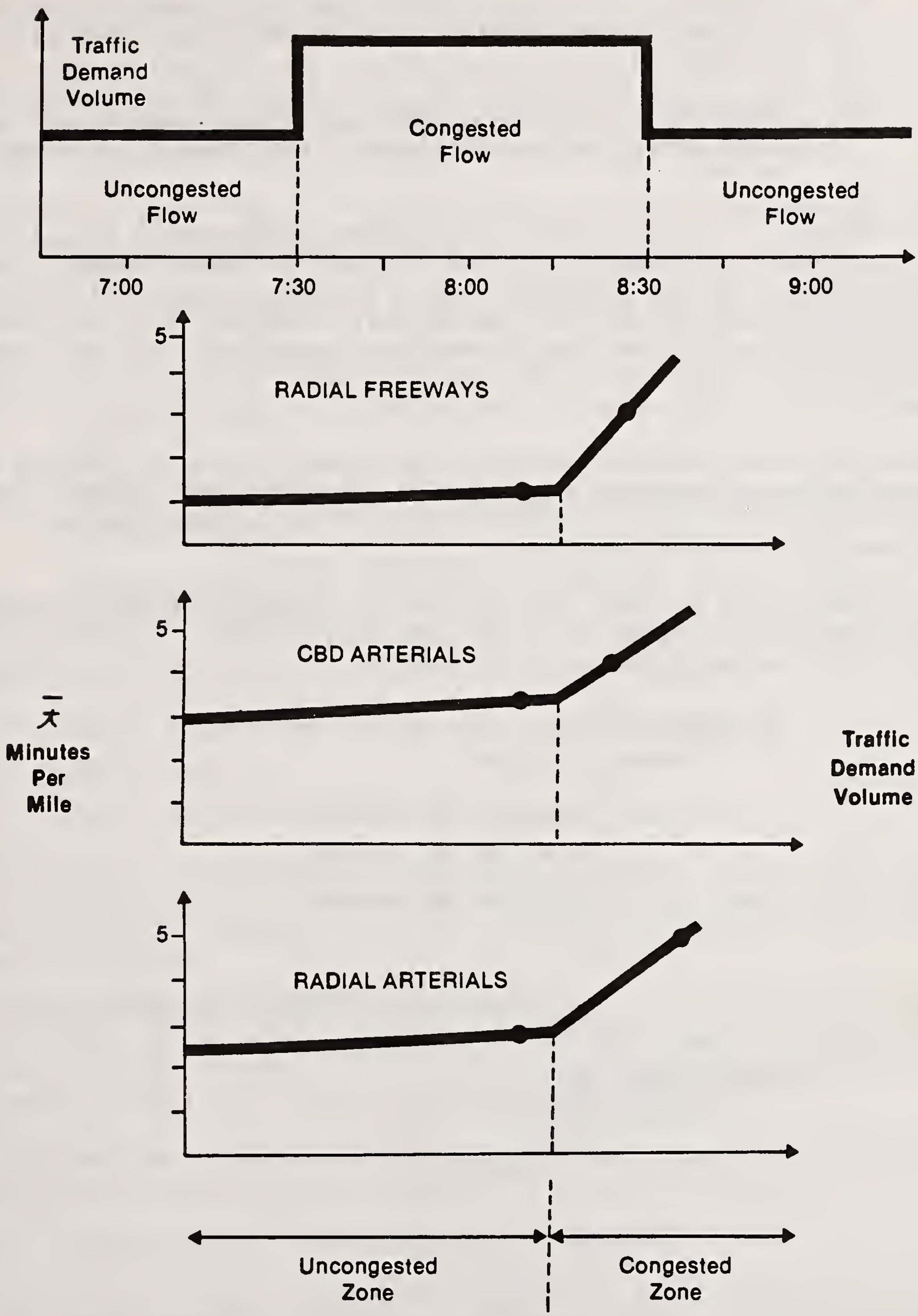


FIGURE 40

TWO-REGIME CONCEPT OF TRAFFIC CONGESTION

- Congested flow regime, when capacity is exceeded on parts of the facility and elasticity of travel time to increased volume is high.

- Uncongested flow regime, when capacity is ample on all parts of the facility and elasticity of travel time to increased volume is low.

The elasticity of travel time is the percent increase in travel time resulting from a one percent increase in traffic demand volume. The two-regime concept is very pronounced and is easily observed on freeways where bottleneck situations dominate operational conditions. Travel time elasticity is very low when the freeway is uncongested, but very high when demand exceeds capacity at any point on the freeway and queue buildup occurs.

Operation along a surface arterial is more complex, and the boundary between congested and uncongested operations is less distinct. What's more, the travel time elasticity on congested portions of surface arterials is smaller than for overloaded freeways.

An ongoing study by Cambridge Systematics and FAW for the Department of Energy derived estimates of travel time elasticities, e_t, from available data, and found as follows:

<u>Congested Flow</u>

Freeway Sections

$e_t = 2.12$ @ 41 mph

$e_t = 3.39$ @ 36 mph

$e_t = 4.43$ @ 31 mph

Arterials

$e_t = 0.6$ to 2.8 depending on severity of congestion

<u>Uncongested Flow</u>

Freeway Sections

$$e_t = 0.16 \frac{V}{C}$$

Arterials

$e_t = 0.20$

For this analysis, it is assumed that arterials and freeways serving the CBD operate in the congested flow regime during the peak hour and the uncongested regime during the other 1.5 hours of the 2.5-hour peak a.m. or p.m. period. Variable work hour shifts the peak hour-volume downward and the other 1.5-hour volume upward as shown in Figure 41. Thus, some traffic is shifted from the congested flow regime to the uncongested flow regime. The resultant travel times improve significantly during the peak hour (because peak-hour travel time elasticity is high) and travel times are only modestly increased during the other 1.5 hours (because travel time elasticity then is much lower). The net effect is a reduction in overall travel time.

This process is quantified in Figure 42 which for the peak hour and the other 1.5 hours, tabulates the following:

- P_v = proportion of 2.5-hour volume in the two subperiods
- $\bar{t}$ = travel time, minutes per mile, in the two subperiods
- Percent change in volume in the two subperiods due to variable hours
- Percent change in travel time in the two subperiods due to variable hours
- Average travel time for the full 2.5-hour period both before and after the program

The computations are made for three facility types impacted:

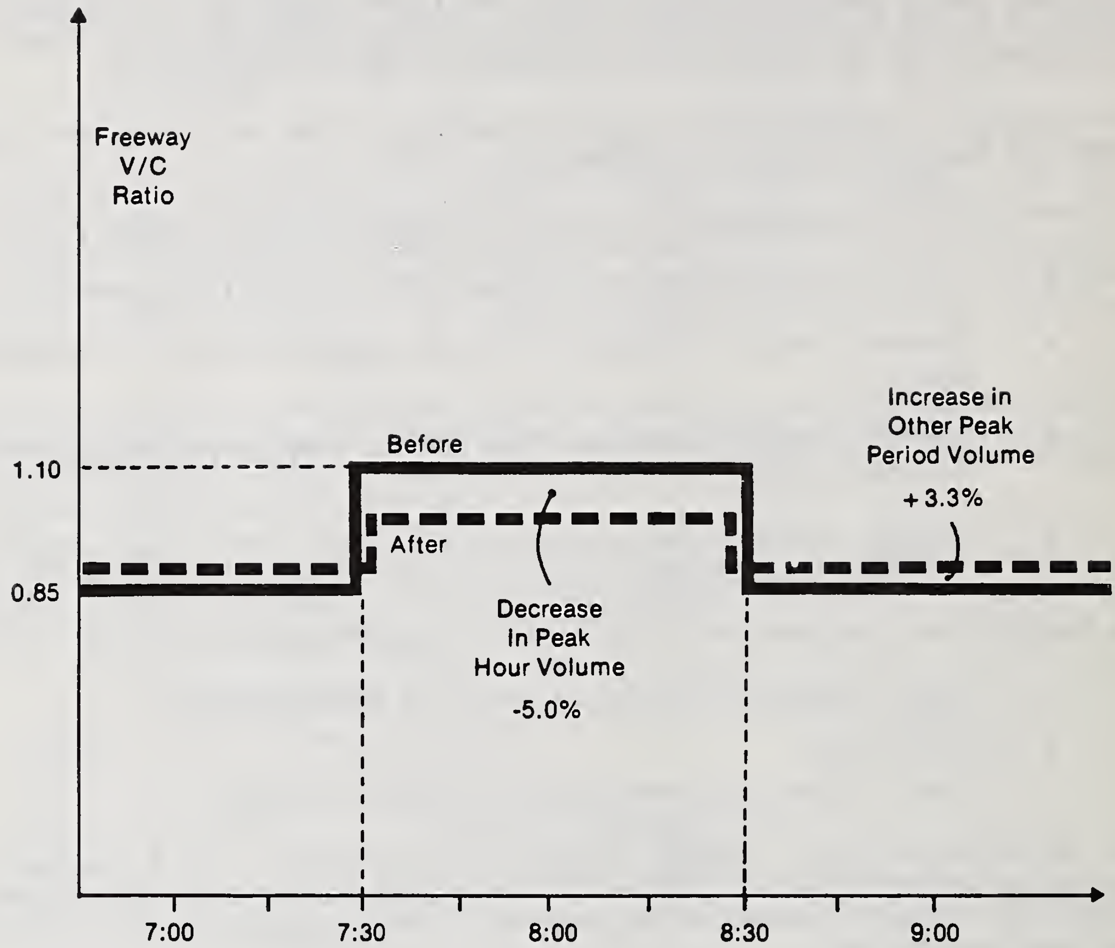
- Radial freeway serving the CBD (peak direction)
- CBD streets
- Radial arterial serving the CBD (peak direction)

Two variable work hours program scenarios are tested: (1) a "maximum" program in which 50 percent of the CBD employees participate; (2) a more reasonable "target" comprehensive program in which 20 percent of the CBD employees participate.

Assumptions are made of typical travel time rates in the peak hour and the other 1.5 hours on the three types of facilities based on experienced judgements. The travel time values selected should be reasonably valid for medium large cities (i.e. one to two million population).

Changes in peak hour volumes for the 50 percent participation maximum program scenario are based on Ottawa findings discussed previously:

- CBD peak-hour volumes decrease 10 percent
- Radial Freeway & Arterial Volumes near the CBD decrease 5 percent
- Other 1.5-hour CBD volumes increase 6.6 percent
- Other 1.5-hour radial volumes increase 3.3 percent



Before: Peak Hour Volume = 1.1 x C x 1 Hour = 1.100C
Other 1.5 Hour Volume = 0.85 x C x 1.5 Hours = 1.275C
2.375C

Peak Hour Percent = 46.3%

After: Peak Hour Volume = 1.1C — 0.05 = 1.045C
Peak Hour Percent = 44.0%

FIGURE 41

FLATTENING OF DEMAND

Facility Type	Before				After — With 50 Percent Participation					After — With 20 Percent Participation				
	V/C	P_v	$\bar{t}$ Min/Mi	e_t	Percent Change in P_v	P_v	V/C	Percent Change in t	$\bar{t}$	Percent Change in P_v	P_v	V/C	Percent Change in t	$\bar{t}$
Radial Freeway														
Peak Hour	1.1	0.463	1.8 (33 mph)	4.0	-5.0	0.440	1.045	-20.0	1.44 (42 mph)	-2.0	0.454	1.078	-8.0	1.66 (36 mph)
Other 1.5 Hrs of Peak	0.85	0.537	1.27 (47 mph)	0.12	+3.3	0.560	0.887	+0.4	1.275 (47 mph)	+1.33	0.546	0.865	+0.16	1.27 (47 mph)
Average Percent Change in $\bar{t}$			1.52 (39.5 mph)						1.35 (44.4 mph) -11.0					1.45 (41.4 mph) -5.0
CBD Streets														
Peak Hour	—	0.463	4.0 (15 mph)	1.0	-10.0	0.417	--	-10.0	3.60 (16.6 mph)	-4.0	0.444	--	-4.0	3,84 (15.6 mph)
Other 1.5 Hrs in Peak	--	0.537	3.5 (17 mph)	0.2	+6.6	0.583	--	+1.3	3.55 (16.9 mph)	+2.6	0.556	--	+0.5	3.52 (17 mph)
Average Percent Change in $\bar{t}$			3.75 (16 mph)						3.57 (16.8 mph) -5.0					3.66 (6.4 mph) _2.0
Congested Radial Arterials														
Peak Hour	--	0.463	3.0 (20 mph)	1.0	-5.0	0.417	--	-5.0	2,85 (21 mph)	-2.0	0.454	--	-2.0	2,94 (20.4 mph)
Other 1.5 Hrs. in Peak	—	0.537	2.5 (24 mph)	0.2	-3.3	0.583	--	+0.67	2.52 (23.8 mph)	+1.33	0.546	--	+0.27	2.51 (23.9 mph)
Average Percent Change in $\bar{t}$			2.73 (22 mph)						2.66 (22.6 mph) -3.0					2.71 (22.1 mph) -1.0

FIGURE 42

HIGHWAY LEVEL OF SERVICE IMPACTS OF VARIABLE WORK HOURS PROGRAM

These shifts in peak-hour volume are reduced proportionately to represent the 20 percent participation scenario:

- CBD peak-hour volumes decrease 4 percent
- Radial volumes near the CBD decrease 2 percent
- Other 1.5-hour CBD volumes decrease 2.6 percent
- Other 1.5-hour radial volumes increase 1.3 percent

The resulting reductions in average travel time per mile, $\bar{t}$, for the 2.5-hour peak period (in other words, the percent improvement in average level of service) is as follows:

<u>50 Percent Participation Scenario</u>

Radial Freeways	$\bar{t}$ down	11 percent
CBD streets	$\bar{t}$ down	5 percent
Radial Arterials	$\bar{t}$ down	3 percent

<u>20 Percent Participation Scenario</u>

Radial Freeways	$\bar{t}$ down	5 percent
CBD Streets	$\bar{t}$ down	2 percent
Radial Arterials	$\bar{t}$ down	1 percent

For the three facility types combined, the improvement in work-trip average travel time is about 6 percent for the maximum participation scenario and about 3 percent for the more practical target program. Assuming that the three facility types account for at most only 15 percent of areawide work-trip VMT, then the <u>areawide</u> improvement in work trip level of service ranges only from about 0.5 percent to 1.0 percent.

Transit buses using the facilities serving the CBD, i.e. those carrying the majority of areawide transit patrons, would obtain significant travel time improvements. Local buses making frequent stops would accrue about half the percent reduction in travel time experienced by autos, whereas radial express bus line haul times would be improved by approximately the same percent as autos on these routes.

<u>Mode Choice</u> -- In theory, improvements in highway levels of service brought about by variable work hours would increase the attractiveness of auto travel relative to transit travel, and mode shifts from transit to auto would be expected. However, this is offset by the fact that express bus and local bus users also experience level of service improvements due to decreased highway congestion. Futhermore, flattening of peak transit demand reduces crowding at transit stations and on transit vehicles during peak

periods, thereby increasing the comfort of transit usage, as well as decreasing waiting time at transit stations and stops where some users now must wait for more than one transit vehicle in order to board because of overloading. Thus, there are tradeoffs in the relative attractiveness of transit usage. Indeed, evidence to date suggests that no substantive changes in transit patronage are likely to occur as a result of variable work hours programs (Refs. 2 and 5). In Ottawa, the peak-period transit mode share increased by 2 to 3 percent after implementation of the variable hours program, but this was attributed mainly to the coincidence of program implementation in February 1974 with the energy crisis (Ref. 3). The use of variable work hours has often been mentioned by U.S. DOT as a strategy which complements. Indeed, if programs are implemented in such a way that commuters have freedom to choose regular working hours, this might enhance the likelihood of finding compatible carpool partners. Many staggered work hours programs, however, do not include provisions for much individual flexibility in choice of hours, and this could cause dissolution of existing carpools and deter formation of new ones. Moreover, flexitime in its classic form results in highly variable individual work hours and in theory could significantly reduce ridesharing.

A theoretical analysis conducted by U.S. DOT's Transportation Systems Center investigated the effects of staggered work hours on carpooling and the potential for increased transit ridership (Ref. 6). They show that if peak-hour percentage of total commuter volumes are reduced then a significant reduction in carpool potential will result. The benefits to potential transit utilization, through opportunities to fill available transit capacity outside of the peak hour, would outweigh the potential reduction in carpooling.

In practice, no evidence exists which indicates that carpool mode share is significantly changed as a result of implementing variable work hours. Only one project, the Queen's Park program in Toronto (Ref. 4) directly evaluated impact on carpooling. It was found that the use of carpooling increased from 15 percent of employees before the program (in 1973) to 17 percent after the program (in1974). Only 7 employees abandoned carpools but more than twice as many joined carpools after implementation of the program. These impacts, however, were attributed to the energy crisis and not to the variable hours program.

VMT Impact -- The foregoing review of known mode choice impacts of staggered and flexible hours programs indicate that such programs are not likely to have significant short-range direct impacts on vehicle miles of travel in urban areas. Improvement of highway level of service would theoretically tend to induce some small increases in auto work-trip VMT but this would be largely offset by concurrent improvements in transit levels of service and comfort. Moreover, it is known that the short run elasticity of auto travel demand to improvements in level of service is very small for work trips, and since variable work hours programs produce negligible impacts in off-peak levels of service (when demand elasticity is higher) no significant increases in non-work auto VMT would occur.

4-Day Work Week

The primary thrust of 4-day work weeks differs from that of variable work hours programs. Whereas the principal impact of variable work hours is to improve peak-period levels of service through peak flattening, without changing VMT significantly, 4-day work week programs all aimed at reducing average daily work trips and VMT during peak periods, and thereby producing the derivative impact of improved levels of service.

Implementation of 4-day work weeks is socially and institutionally more complex than variable work hours, and the motivation for implementing the shortened work week is perhaps much broader, transcending a transportation problem solution orientation. Consequently, it is believed that 4-day work week implementation is less likely to be as strangly focused on the CBD and other congested employment centers as the variable hours concept. The social and institutional complexity also means that conversion to 4-day weeks cannot come about nearly as rapidly as variable work hours programs, and is more dependent on national policies and trends than on actions instituted by urban area transportation agencies.

For the above reasons, the impacts of 4-day work weeks are considered in less detail, and in an areawide context rather than segmented by specific locations within an urban area.

Average Daily Work Trips

Desimone (Ref. 7) analyzed the impact on commuter work trips of five alternative forms of 4-day work weeks as shown in Figure 43. This table presents data only for those persons who have changed to the 4-day schedules and does not account for the remainder of commuters whose work schedules are unchanged. The reduction in the overall number of work trips is dependent on the percentage of the areawide work force which converts to the shortened work week. The areawide work trip reduction impact can be computed as follows:

$$PR_A = P_p \; PR_p$$

where:

PR_A = the proportion reduction in areawide average daily work trips, i.e. percent reduction/100.

PR_p = the proportion reduction in average daily work trips among participating commuters

P_p = the proportion of commuters converted to shortened work weeks.

4-Day Work Schedule	Percent of 4-Day Work Schedules						Average Workday	Average Percent Reduction
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday		
1. Equally rotated Monday-Friday	80	80	80	80	80		80	20
2. Equally rotated Monday-Saturday	67	67	67	67	67	67	67	33
3. 1/2 Monday-Thursday, 1/2 Tuesday-Friday	50	100	100	100	50		80	20
4. 1/2 Monday-Thursday, 1/2 Wednesday-Saturday	50	50	100	100	50	50	67	33
5. 1/3 Monday-Thursday, 1/3 Tuesday-Friday, 1/3 Wednesday-Saturday	33	67	100	100	67	33	67	20

FIGURE 43

PERCENTAGE OF EMPLOYEES WORKING EACH DAY WITH ALTERNATIVE 4-DAY WORK SCHEDULES

The resulting impacts on areawide number of average daily work trips for various assumed levels of participating employees is given in Figure 44. These results indicate that even though average work trip reductions are much less dramatic when one accounts for the percent of employees converted to the shortened week, the impacts are nevertheless highly significant.

VMT Reduction

All the forms of 4-day work schedules would tend to deter the formation of carpools and dissolve existing carpools. The reduction in average daily work-trip VMT would thus be less than the reduction in average daily work trips. However, since average vehicle occupancy levels for work trips are relatively low, there are limits to the potential dilution of 4-day work week impacts due to reduction in carpooling among the 4-day workers. For example, even in the extreme case of a drop in average occupancy of from 1.2 to 1.1 persons per car among the 4-day workers (or an 8 percent increase in VMT per PMT), this represents a dilution of only 25 percent to 40 percent of the VMT reduction attributed to the shortened work week. A more reasonable expectation might be a dilution of only 10 to 20 percent of the work-trip VMT reduction impacts for 4-day work weeks shown in Figure 44.

Work trip reductions in VMT, however, may be largely offset by increases in non-work travel during days off. To the extent that much of this extra travel might be recreational trips made on long weekends, the total daily VMT within urban areas could still be reduced somewhat even though aggregate VMT for urban and non-urban travel combined might be unchanged or even increased. It appears reasonable to assume, on balance, that overall changes in VMT resulting from 4-day work week schedules would be negligible.

Conversion of 5 percent of the work force to 4-day work schedules would produce approximately 1 percent reducton in work-trip VMT, or about the same order of magnitude reduction in VMT which could be achieved by a comprehensive express bus program. Conversion of 10 percent of the work force to 4-day schedules would reduce work-trip VMT by about 2 percent, or roughly the same order of magnitude achievable through a comprehensive voluntary carpool/vanpool program. In the long range, shortened work weeks is potentially a much more powerful peak-period travel reduction strategy than inducing increases in public and private vehicle occupancy, although it is unlikely that urban area transportation officials could be the primary actors in bringing about widespread shifts to the 4-day work week.

Highway Level of Service

Because the 4-day work scheduling strategy produces reductions in VMT for work travel only, i.e. mainly during peak periods when congestion problems exist and travel time is very elastic to changes in travel demand, the strategy would also produce significant improvemetns in peak-period levels of service of the highway system. The ongoing Cambridge Systematics/FAW study for the Department of Energy analyzed areawide travel time elasticities, e_t, and estimated values of 0.6 and 1.2, respectively, for Denver

4-Day Work Schedule	Percent Reduction of Average Daily Work Trips by Participants	Areawide Average Daily Work Trip Reduction Assuming			
		5 Percent Participate	10 Percent Participate	20 Percent Participate	30 Percent Participate
Equally rotated Monday-Friday or 1/2 Monday-Thursday, 1/2 Tuesday-Friday	20	1.0	2.0	4.0	6.0
Equally rotated Monday-Saturday or 1/2 Monday-Thursday, 1/2 Tuesday-Saturday or 1/3 Monday-Thursday, 1/3 Tuesday-Friday, 1/3 Wednesday-Saturday	33	1.6	3.3	6.6	10.0

FIGURE 44

REDUCTION IN AREAWIDE AVERAGE DAILY WORK TRIPS AS A FUNCTION OF PERCENT OF EMPLOYEES ON 4-DAY SCHEDULES AND TYPES OF SCHEDULING and San Francisco areawide work travel. If areawide peak-period travel time elasticities approximate 1.0 for medium large cities, then each 1 percent reduction in work-trip VMT would cause an equal percent reduction in average work trip travel time. For very large and/or very congested urban areas the areawide work trip level of service improvement might be double or more the percent reduction in work-trip VMT, whereas in smaller and/or less congested urban areas, the work trip level of service might improve by half or less the percent by which work-trip VMT is reduced. The level of service improvement for work trips to the CBD would be approximately double the areawide work trip impact.

Summary of Transportation Impacts

Based on the preceding analyses, a summary is given in Figure 45 showing the rough order of magnitude of changes in level of service and VMT resulting from work rescheduling strategies. It is important to note that the impacts on total travel (i.e. work and non-work trips combined) neither variable work hours or 4-day work week strategies are likely to produce significant changes in VMT, although implementation of 4-day work week schedules will result in reductions in VMT during peak periods. Both types of work rescheduling strategies can produce significant improvements in highway levels of service during peak periods. Variable work hours level of service improvements tend to be concentrated in congested CBD's and radial corridors where congestion relief is most needed, whereas the 4-day work week tends to have a more uniform peak-period level of service improvement impact throughout the urban area.

COST-EFFECTIVENESS

The nature and magnitude of the costs of carrying out a work rescheduling program in an urban area are similar to the costs of a ridesharing encouragement program. Both types of programs require primarily professional staff efforts to persuade employers to implement the strategy and to provide technical assistance in planning and implementation of employer-based efforts. Comprehensive ridesharing program annual costs typically range from 40 to 50 cents per areawide commuter. Hence, for an urban area of 1 million population and a work force of 400,000, the annual costs might run $200,000. Work rescheduling programs should cost no more than this amount for a city of 1 million, and potentially could be lower if ridesharing and work rescheduing encouragement activities can be jointly pursued as an integrated program. What's more, work rescheduling might requre less continuing follow-up with employers than ridesharing efforts, because once an organization has changed their working hour practices, these would tend to be fairly permanent. Ridesharing encouragement, on the other hand, requires continuing efforts with most employers to maintain high levels of motivation and to respond to employee turnover. Work rescheduling encouragement may require 5 to 10 years of effort to produce steady increases in the percentage of employees participating, whereas ridesharing efforts could achieve high levels of penetration in fewer years.

Impacts	Variable Hours: 20 Percent CBD Participation	Variable Hours: 50 Percent CBD Participation	4-Day Week: 5 Percent Areawide Participation	4-Day Week: 10 Percent Areawide Participation
Work Trips				
Areawide				
VMT Reduction	Negligible	Negligible	1.0	2.0
Level-of-Service Improvement	0.5	1.0	1.0	2.0
CBD and Radials				
VMT Reduction	Negligible	Negligible	1.0	2.0
Level-of-Service Improvement	3.0	6.0	2.0	4.0
Total Trips				
Areawide				
VMT Reduction	Negligible	Negligible	Negligible	Negligile
Level-of-Service Improvement	0.2	0.4	0.4	0.8
CBD Radials				
VMT Reduction	Negligible	Negligible	Negligible	Negligible
Level-of-Service Improvement	1.0	2.0	0.8	1.5

FIGURE 45

SUMMARY OF IMPACTS OF WORK RESCHEDULING STRATEGIES

It appears that both ridesharing and work rescheduling programs require a continuity of effort with faily uniform annual (say 10 years) costs over similarly long time periods to achieve and maintain impacts. Therefore, it seems reasonable to assume an annual cost of $200,000 for comprehensive programs to encourage either ridesharing or work rescheduling in an urban area with 1 million population.

As shown previously in Figure 45, reasonable upper limit estimates for the areawide level of service impacts of work rescheduling efforts are on the order of 0.2 percent to 0.4 percent areawide reduction in travel time. In an urban area of 1 million, annual VMT approximates 5,000 million, and if areawide average network speed is on the order of 25 mph, total annual vehicular travel time in vehicle hours (VHT) totals about 200 million. Thus a 0.2 percent to 0.4 percent travel time reduction translates to an annual time savings of 400,000 to 800,000 vehicle hours.

At an annual cost of $200,000, the cost per vehicle hour reduction in travel time ranges from 25 cents to 50 cents.

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CHAPTER E

IMPACT OF TRUCK RESTRICTION AND ENHANCEMENT PROGRAMS

There are at least six distinct approaches to implementing truck restrictions and enhancements which will produce an improvement in vehicular flow by reducing truck and auto interference. Most of these will also facilitate truck operations though several are restrictions which will inhibit truck operations. These approaches are:

- Better allocation of curb space
- Better enforcement of curb use restrictions
- Removal of features which impair truck movements
- Rescheduling of truck pickup and delivery (PUD) times
- Reductions of PUD dwell time
- Consolidation of goods movement

<u>Better allocation of curb space</u> can be accomplished through a series of actions which are designed to locate curbside PUD zones in the right places and of the right size, and to restrict parking of automobiles in locations where they inhibit the curbside PUD activities. Opportunities to utilize infrequently used curb space should be sought. Through curb management, truck operations will be facilitated and a greater number of trucks will be able to conduct their PUD movements at the curb. Truck/auto interference will also be reduced. By providing adequate curbside PUD space, the frequency of double parking and lane blockages will be reduced.

Actions which provide <u>better enforcement of these curb use restrictions</u> are also critical. Automobile use of truck loading/unloading areas negates the establishment of these zones and results in double-parked trucks. Enforcement of the restrictions against auto parking and standing will facilitate truck operations and reduce truck/auto interference; however, enforcement may have a negative effect on truck operations if the enforcement is directed against trucks. This is particularly true for the enforcement of no double-parking restrictions against trucks. Many trucks find it necessary to conduct some of their PUD activities while double parked, and preventing this would seriously affect their operations.

The <u>correction of physical features which impair truck operations</u> at intersections, alley entrances, and at off-street PUD locations would also facilitate truck operations and reduce truck/auto interference. Poor geometric standards and improperly placed utility poles make maneuvering difficult and may result in a truck making several movements in order to clear the obstacle. Many of these obstructions can be corrected with relatively inexpensive improvements.

Rescheduling truck pickup and deliveries to avoid these activities during peak periods, or to distribute them more evenly during the rest of the day, or to distribute them in a manner which will insure that some streets remain free flowing, is a description of another group of action that may be taken. These actions will reduce truck/auto interference by minimizing double parking and congestion, but they will also hamper truck operations by reducing the hours during which these activities may be performed.

Truck operations can be facilitated and truck/auto interference reduced by reducing the dwell time of PUD vehicles. Although several small on-street improvements can be made to reduce PUD dwell time, the overwhelming majority of this activity takes place indoors and deals with the internal movement of goods and the billing and shipping procedures.

The consolidations of goods will also result in reduced truck/auto interference and facilitates truck operations by reducing the number of truck trips. Consolidation covers a broad range of actions which result in fewer but larger shipments.

We shall devote most of our emphasis to the first three strategies: curb management, enforcement, and the removal of obstructions. The primary responsibility for implementation of these strategies rests with various branches of government. They can be achieved in many cases at fairly low costs within a comparatively short timeframe.

Although government can impose time-of-day restrictions on PUD movements, the major burden of implementation of PUD rescheduling strategy falls on the trucking companies and shippers/receivers. It is a complex process involving many factors and a long education/implementation period. Similarly, reduced PUD dwell times and the consolidation of shipments are actions dependent on the private sector. These may involve considerable expense and change in current practices, and it is unlikely that major progress with these strategies can be implemented as short-range actions. A summary of these strategies, their effect on truck/auto interference, truck operations, and the parties responsible for implementation is shown in Figure 46.

CURB MANAGEMENT

There are three major objectives of curb management: to provide adequate space by the curb for trucks conducting PUD operations; to provide on-street queuing space by the curb for trucks waiting to enter off-street shipping/receiving docks in a manner which minimizes interference with traffic; and to provide room at intersections, alleyway entrances, and near off-street docks which is needed to facilitate truck-turning movements.

Not only must curb space be provided for PUD operations at the curb, it must also be provided in the right locations, and must be of sufficient size to accommodate number and type of vehicles anticipated. Studies have shown that approximately 60 percent of all deliveries in large cties are made

Strategy	Reduce Truck/Auto Interference	Facilitate Truck Operations	Implementation Responsibility
1. Better Allocation of Curb Space	*	+	Government
2. Better Enforcement of Curb Use Restrictions			Government
Cars	*	+	
Trucks	*	-	
3. Removal of Physical Features That Impair Truck Movement	+	+	Government/ Utilities/Private
4. Reschedule Truck Pick-Up and Delivery	+	-	Government/Private
5. Reduce Pick-Up and Delivery Dwell Time	+	+	Private
6. Consolidate Pick-Up and Delivery	+	+	Private

* = Major Improvement

+ = Improvement

- = Adverse Effect

FIGURE 46

SUMMARY OF TRUCK STRATEGIES

through the front door.(1) It has also been observed that few drivers will park more than 100 feet from their destination, probably because of security and goods-handling time considerations.(2) Thus, it becomes critical to provide on-street loading facilities in the right locations. Designing for light and medium trucks will accommodate 96 percent of PUD activities. Light trucks make up about 66 percent of the total truck traffic with 30 percent being medium-sized trucks and 4 percent heavy trucks.(1,2,3)

On-street queuing space to wait for a clear off-street dock is a need most commonly found in older business districts. In the study of downtown Brooklyn, two-thirds of the delay at loading docks resulted from waiting in line to get to a loading dock.(2) In cities of 250,000 and over, only 6 to 12 percent of the CBD buildings have off-street loading facilities.

Truck-turning movements at intersections and near on-street loading docks often exceed the spatial allocations that have been made. These situations can be improved by eliminating parking near intersections where trucks regularly turn to provide a turning lane and adequate clearance. Similarly, the number of turning movements necessary to maneuver a medium or large truck into an off-street bay can often be reduced by removing parking from across the street. Although these delays are particularly noticeable, they are a fairly rare occurence. Overall, a truck spends only 22 percent of its working day in motion ;(1) the effect of these movement delays is only a small percentage of total delay. While these situations should be improved whenever possible, they are only a small part of the overall picture and have not been included in the analysis.

Enforcement

It is doubtful that a curb mangement plan will be effective if it is insufficiently enforced. This is true both for on-street and off-street situations.

Two factors influencing the success of enforcement are the frequency of enforcement and the severity of the punishment. Regulations will be ignored if enforcement is infrequent or non-existent. Increasing the frequency of enforcement is expected to result in stricter adherence to the law. Similarly, as the severity of the penalty increases, the regulation will be obeyed more often. Once a curb use regulation is established, it becomes more cost effective to increase the penalty rather than the frequency of enforcement.

A significant amount of off-street loading docks are occupied by parked vehicles not actively conducting PUD operations. Enforcement in this case is complicated because these vehicles are on private property.

It is important to note that enforcement of regulations, in particular laws against double parking, can have a negative impact on truck operations if these regulations are strictly enforced against double-parked trucks. Trucks not being able to double park will have to find an alternate loading/unloading area either by accepting an area further away, or by circling around the block until an acceptable space becomes available.

The enforcement of restrictions against double parking by trucks is more frequent in smaller cities. A survey of 57 cities revealed that restrictions against trucks double parking were strongly enforced in 32 percent of the cities under 100,000, and in about 55 percent of the cities between 100,000 and 500,000 population.(1) Illegal double parking by trucks is tolerated in 83 percent of the cities with over 500,000 people.

Removal of Physical Features

The removal of physical features delaying truck movements will also have a positive benefit. Substandard geometric design at intersections, utility poles near corners, height restrictions, and load restrictions will all affect travel times. The first two conditions are relatively inexpensive to correct but usually have a minor impact on travel time. The latter two conditions are major physical obstructions which may entail considerable rerouting to avoid, and result in major delays.

Again, it must be remembered that trucks in the CBD only spend 20 percent of their time in motion and minor incremental improvements will have only negligible effects on areawide VHT totals.

While the correction of structural deficiency may result in VMT reduction, the improvement will only affect the one-third of truck movements involving medium weight and heavy trucks. These are also measures requiring capital investive projects which are beyond the scope of this discussion.

Truck Operations

For most of the day the average truck is parked, waiting to be loaded or unloaded, or waiting to be used. Between 6 a.m. and 6 p.m., it is in motion only 22 percent of the time. A 1950 study indicated that only 15.9 percent of this running time involved delays, and less than 1 percent of these delays were created by double-parked vehicles of all kinds. Thus, over the 12-hour period, the average truck experienced about 15 seconds of delay that was attributable to double parking. The data used in this computation is admittedly old, but even if the delay due to double parking had increased tenfold, it would still account for less than 3 minutes out of the 12-hour period.

In selecting a parking location, drivers will try and get as close to their destination as possible. This minimizes the time that goods must be moved by hand, and allows them to maintain maximum surveillance of the truck. These efficiency and security concerns are reflected in the willingness of many trucking companies to accept the cost of parking tickets as a normal business expense. Thus, double parking becomes an accepted company policy. A survey of 700 pickups/deliveries in downtown Brooklyn showed that less than 2 percent of the vehicles parked legally or illegally more than 100 feet away from their destination.

Before proceeding with impact assessment, it should be noted that the travel time of the majority of vehicles coming to the CBD (or other high PUD activity center) can be divided into two major portions; the stem time spent outside the CBD and the zone time spent within the CBD. The stem times of vehicles can be reduced with standard traffic engineering improvements which will not be discussed here. This work will focus on that portion of the trip within the CBD zone.

Calculation of Delay Reduction and Speed Increased

We have concluded that the major reduction of delay to vehicles, including trucks, will occur because of a decrease in the number of double-parked vehicles. This will be the result of a combined effort to develop a curb management and enforcement plan. The curb management portion of this plan will review the need for truck maneuvering and loading areas and establish these zones where necessary. This activity will be complemented by the enforcement plan which will insure that these areas are not occupied by illegally-parked vehicles through appropriate fines and frequency of enforcement.

Cities of two hypothetical sizes were examined; a very large city, population 2 million, and a medium sized city with a population of 250,000. These sizes were representative of Class I and Class III cities as described in an earlier goods movement study.(4) This study uses a number of basic parameters in the development of the delay and speed estimates. They are summarized in Figure 47 and were used to develop VMT estimates for the total day and for the peak period on arterials in the CBD and within the entire city. These estimates are shown in Figure 48.

Figure 49 shows the average speeds and VHT totals for these time periods and locations. Average citywide speeds are taken from the earlier study.(4) Average speeds on CBD arterials were selected from Figure 50 using v/c ratios typical of peak and off-peak operation in medium size and very large cities. VHT totals shown in this table were obtained by dividing the VMT estimates by the associated average speeds.

Truck travel to, from and within the central business district increases at a slower rate than overall urban population. There are approximately four CBD truck trips per 100 persons in urban areas of 250,000 as compared with fewer than two in areas of 2,000,000 or more.(5) Gross numbers of truck trips were obtained in this manner.

The number of truck trips was divided by 2 to produce an estimate of truck trip ends in the CBD. This produces an estimate of the number of PUD transactions within the CBD. It assumes that the truck starts its first trip outside the CBD, and that the second trip is from this point to a point outside the CBD. While this assumption underestimates the number of internal trips within the CBD, it provides a better match to the available data

	City Class			
	I	II	III	IV
VMT per person	9.8	10.2	9.7	10.0
Truck VMT as a % of total VMT	14	14	14	14
% of total VMT in CBD	6.0	5.4	6.3	6.3
% of CBD VMT of Truck	18	15	13	10
% of CBD VMT on Freeway	27	43	6	4
% of other VMT on Freeway	28	24	11	12
% of total VMT at night	5	5	5	5
% of total VMT in peak hour	18	18	18	18
% of total truck VMT in peak hour	16	16	16	16
% of total CBD VMT in CBD peak hour	18	18	18	18
% of total CBD peak hour VMT by truck	13	10	11	11
% night truck CBD VMT of total CBD truck VMT	5	5	5	5
% external truck VMT of total VMT	3	5	7	10

FIGURE 47

FACTORS USED TO DEVELOP DISAGGREGATE
VMT SUMMARY

VMT Estimates	Medium-Size City	Very Large City
Population	250,000	2,000,000
VMT Per Person	9.7	9.8
Total VMT	2,425,000	19,600,000
Percent of VMT in Peak-Hour	18	18
Adjustment for Peak-Period	1.8	1.8
Total VMT in Peak Period	785,700	6,350,400
Percent of VMT in CBD	6.3	6.0
Percent of CBD VMT on Arterials	94	73
VMT on CBD Arterials	143,609	858,480
Percent of CBD VMT in CBD Peak-Hour	18	18
Adjustment For Peak Period	1.8	1.8
CBD VMT on Arterials in Peak Period	46,329	278,148

FIGURE 48

VMT ESTIMATES

Average Speed and VHT Totals	Medium-Size City	Very Large City
24-Hour City-Wide Average Speed	27	26
Peak-Period City-Wide Average Speed	23	17
24-Hour CBD Arterial Average Speed	20[1/]	17[2/]
Peak-Period CBD Arterial Average Speed	17[3/]	14[4/]
24-Hour City-Wide VHT	89,815	753,846
Peak-Period City-Wide VHT	34,161	373,553
24-Hour CBD Arterial VHT	7,180	50,499
Peak-Period CBD Arterial VHT	2,737	19,868

[1/] Based on an average V/C ratio of 0.6

[2/] Based on an average V/C ratio of 0.8

[3/] Based on an average peak-period V/C ratio of 0.8

[4/] Based on an average peak-period V/C ratio of 0.9

FIGURE 49

AVERAGE SPEEDS AND VHT

V/C[1/]	CBD Freeway MPH	CBD Arterial MPH	OTHER Freeway MPH	OTHER Arterial MPH
0.0	48	25	60	35
0.1	46	24	60	34
0.2	44	23	59	33
0.3	42	23	59	33
0.4	40	22	58	32
0.5	38	21	57	31
0.6	36	20	55	30
0.7	34	19	52	29
0.8	32	17	47	27
0.9	30	14	41	24
1.0	28	12	34	15

V/C Range

A Level of Service = (0 - 0.6) - 0.3
B Level of Service = (0.6 - 0.7) - 0.65
C Level of Service = (0.7 - 0.8) - 0.75
D Level of Service = (0.8 - 0.9) - 0.90
E Level of Service = (0.9 - 1.0) - 1.00

1/ Based on Level of Service E as absolute capacity.
V/C Speed Data based on Highway Research Board, Highway Capacity Manual, 1965.
See Characteristics of Urban Transportation Systems, A Handbook for Transportation Planners, UMTA, May, 1974. Tables 33, 34 and D1 to D5.

FIGURE 50

SPEED VS. V/C RATIO

than the gross truck trip figure which is always going to include an origin/destination outside of the CBD.

To obtain the total number of truck trips to a curbside destination the number of trip ends was multiplied by the percent of deliveries received at the curb. This was shown to be 56 percent to 65 percent for cities in the 100,000 to 500,000 person range and 60 percent in cities over 500,000.(1) This 60-percent figure was used for both typical cities.

Numbers of double-parked vehicles were obtained by applying a percent double-parking adjustment to the curbside deliveries. These percentages wre obtained from three cities with populations ranging from 130,000 to 260,000 and two large cities with populations of appriximately 2 million.(1,2) This data is shown in Figure 51. The overall averages are double parking by 3.3 percent of the trucks making curbside deliveries in small cities and 7.2 percent in very large cities. This data is summarized in Figure 52.

An additional set of assumptions is now required to derive the delay data. All double parking is expected to take place between 6 a.m. and 6 p.m. This coincides with the times during which most truck PUD operations take place.(1)

Four hours of the twelve were considered as the peak period, two in the morning and two in the evening. Double parking was proportionately distributed; one-third during the peak periods and two-thirds off-peak. VMT and VHT peak-hour values in the goods movement report were for two hours; this total was expanded by 1.8 to get the peak hour for a four-hour peak period. It was also assumed that the links were 600-feet long and normally consisted of three moving lanes. It was also assumed that only one vehicle would be double parked on a line at any given time.

The frequency of double parking was separated into peak and off-peak periods, and appropriate v/c ratios were noted.

Average incremental delay incurred by all traffic on a link per double-parking event were approximated using the data developed by the Polytechnic Institute of New York.(6) (Shown in Figure 53.) This delay is a function of the duration and location of the double-parking event, the v/c ratio, and length of the arterial. For a given v/c ratio, the delay resembles a parabola with a minimum value in the middle of the arterial. Its maximum value for v/c ratios greater than .75 occurs at the downstream intersection. The values in the figure are based on a 12-minute double-parking event. Since the location of the double-parking event is unknown, an average value for this delay was used.

An adjustment factor was also included to increase the incremental delay to account for a double-parking event longer than the one used in the figure. The TE Handbook reports that the average duration of downtown truck parkers was 22 minutes in Dallas (population 1,340,000) and 33 minutes in Chatta-

City	Population	Double Parked Trucks As Percent of Trucks Parked at Curb
Chattanooga	130,000	6.2
Tulsa	262,000	1.2
Nashville	171,000	2.4
Average	188,000	3.3
Los Angeles	2,480,000	0.3
Brooklyn	1,600,000	14.1
Average	254,000	7.2

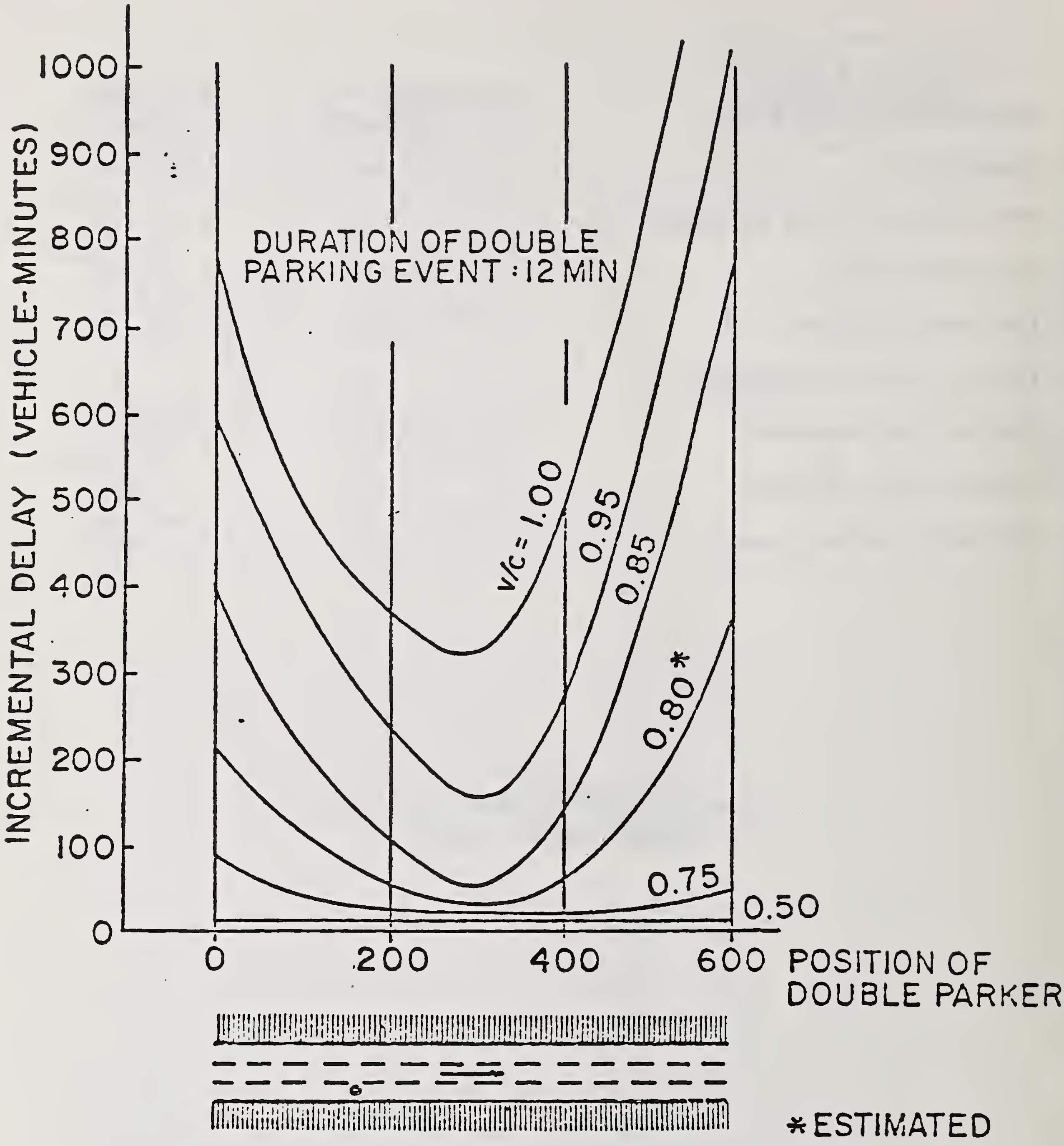
FIGURE 51

PERCENTAGE OF DOUBLE PARKED TRUCKS

Number of Trucks Double Parked in the CBD	Medium-Size City	Very Large City
Population	250,000	1,000,000
CBD Truck Trips Per 100 People	4	2 or less
CBD Truck Trips	10,000	40,000
CBD Truck Trip Ends	5,000	20,000
Percent Curb PUD Operations	60	60
CBD Curb PUD Operations	3,000	12,000
Percent Double Parking	3.3	7.2
CBD Double Parked Trucks	99	864

FIGURE 52

DOUBLE PARKED TRUCKS



Source: NCHRP 3-18(2) Traffic Control in Over Satuated Street Networks. Polytechic Institute of New York, February, 1975.

FIGURE 53

ILLUSTRATION OF DELAY CAUSED
BY DOUBLE-PARKER

nooga (population 130,000).(5) A duration of 30 minutes was used for both the very large city and for the average size city resulting in an adjustment factor of 2.5 (30/12).

Total delay in vehicle minutes was obtained by multiplying the number of double-parking events in the peak and off-peak periods by the incremental delay per event and the adjustment factor. This was then divided by 60 to determine vehicle hours of delay.

It was hypothesized that through a comprehensive combined curbside management and enforcement plan the incidence of double parking would be reduced by 50 percent. This was used to determine the potential savings in VHT due to double-parked trucks.

Figure 54 was then used to develop percent savings in VHT for peak periods and the total day in the CBD arterial zone and in the whole city.

Conclusions

The percent VHT savings on CBD arterials in peak periods ranges from 1 to 6 percent in medium size cities and 4 to 12 percent in very large cities. These ranges were developed by using two v/c ratios in the computation of peak-period VHT savings in each city. This indicates that the incremental delay per double-parking event increases very rapidly as the volume/capacity ratio on the arterial exceeds .75.

The percent VHT savings on CBD arterials over the total day is approximately half the peak-period saving. This reduction in VHT savings occurs because the additional VHT generated in the off peak due to each double-parking event is substantially smaller than during the peak period. This can be attributed to the reduced v/c ratio of the arterial operation. From the table, it can be seen that 576 double-parking events at v/c = .75 causes less delay than 288 events at v/c = .80.

On a citywide basis, it is clear that the percent VHT savings is negligible, totaling probably less than one-half percent in both the peak period and for the entire day in both cities because the overwhelming majority of VHT does not occur on CBD arterials. However within the CBD, the travel time reduction potential of comprehensive truck restrictions and enhancements could range as high as 1 to 3 percent for medium sized cities and 3 to 6 percent in very large cities.

Percent VHT Savings	Medium Size City Peak	Medium Size City Off-Peak	Medium Size City 24-Hour Total	Very Large City Peak	Very Large City Off-Peak	Very Large City 24-Hour Total
1. Double Parked Trucks	33	66	99	288	576	864
2. V/C	.75-.85	.6	--	.8-.95	.75	--
3. Incremental Delay Per Dbl. Pkd. Trk.	45-245	30	--	130-410	45	--
4. Average Dwell Time	30 minutes	30 min.	--	30 min.	30 min.	
5. Adjustment Factor	2.5	2.5	--	2.5	2.5	--
6. Total Delay (Vehicles-Minute)	3713-20,213	4950	--	93,600-295,200	64,800	--
7. Total Delay (Vehicles-Hour)	61.9-336.9	82.5	--	1560-4920	1080	--
8. Percent Delay Reduction	50	50	--	50	50	--
9. Delay Reduction (Vehicles-Hour)	30.95-168.45	41.25	72-210	780-2460	540	1320-3000
10. VHT CBD Arterial	2737	--	7180	19,868	--	50,499
11. Percent Savings	1.1-6.2	--	1.0-2.9	3.9-12.4	--	2.6-5.9
12. VHT City-Wide	34,161	--	89,815	373,553	--	753,846
13. Percent Savings	0.1-0.5	--	0.1-0.2	0.2-0.7	--	0.2-0.4

FIGURE 54

VHT SAVINGS

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CHAPTER F

IMPACT OF AUTO RESTRICTED ZONES

I. INTRODUCTION

One element in the Transportation Systems Management approach that has special applicability to central business districts is the increasingly popular concept of auto restricted zones (ARZ). Like other types of transportation improvements, ARZ plans for the reallocation of street space between autos, transit vehicles, and pedestrians are designed to serve a number of community goals. Transportation, economic, environmental and energy-related goals often figure prominently in the objectives and orientation of ARZ's. Among the primary transportation goals are the desires to reduce traffic congestion, encourage a shift to public transportation, and reduce pedestrian/auto conflicts. Because of the technical nature of transportation impact evaluation and the importance attributed to non-transportation goals, however, evaluation of ARZ's has centered on the impacts of auto restriction on retail sales, concentration of air pollutants, reduction of noise levels and other similar indicators. Thus, although transportation-related objectives are an integral part of any ARZ project, analysis has been concentrated in other areas.

As a result, the literature on auto restricted zones provides adequate documentation of economic and environmental effects, but lacks a full examination of the transportation impacts of these transportation-based plans. The purpose of this paper is to examine the available data on auto restricted zones in both the U.S. and abroad, and use this data to establish a detailed picture of the transportation impacts of implementing auto restricted zones. Before turning to the consideration of these impacts, however, it is appropriate to briefly review the basic nature of auto restricted zones and the objectives they are designed to serve.

THE CONCEPT

The term "auto restricted zone" or ARZ can apply to almost any land area where vehicular travel is regulated, controlled or restricted in some manner. Thus, although we seldom think of it in this way, all of our urban areas are already functioning as ARZ's, for vehicular traffic is presently subject to a wide range of controls. The underlying characteristics of an ARZ then, is that of a district or zone distinguished by a higher degree of control over vehicular traffic than the surrounding area.

The degree of restriction, however, can vary over a wide range. Restrictions can range from minimal disruption of existing patterns such as that brought about by a ban of on-street parking to severe readjustments in traffic circulation and accessibility occasioned by a complete area auto prohibition and the creation of an auto free zone. Other techniques for traffic restriction in common use include turn prohibitions, parking restrictions, preferential transit lanes, and circulation and access controls.

The nature of the restrictions or the measures utilized are as variable as their degree of application. They can be grouped into four basic categories:

- Physical Measures -- which utilize the design, location, and capacity of facilities to control traffic.

- Operational Measures -- which utilize signs, signals, or mechanical devices to control traffic.

- Regulatory Measures -- which utilize enforcement of regulations to control traffic.

- Economic Measures -- which utilize monetary disincentives as tools to control traffic.

A variety of ARZ auto control measures of each type are displayed in Figure 55. The fourth category, economic measures, includes some of the most innovative traffic restraint techniques. The Singapore area licensing scheme, which requires the purchase of a license for the use of an auto in the central city during certain hours of the day, has achieved significant results.(1) Not only has the area licensing scheme increased the use of transit and ridesharing, but its limited daily hours have also served to spread the former peak-hour traffic over a longer period, thus reducing congestion. Other economic measures to restrict traffic include congestion pricing and parking taxes or surcharges. All of these economic measures, as well as other monetary disincentives to auto use, are outside the scope of this investigation, which focuses on the transportation impacts of the physical and operational implementation measures likely to be employed by U.S. cities in the immediate future.

ARZ IMPLEMENTATION OBJECTIVES

As noted above, auto restricted zones are implemented to serve a broad array of community goals and objectives. The primary objectives of auto restricted zones include transportation, environmental, and economic factors. Within the transportation sphere, reduced traffic congestion and a shift to non-auto travel modes are the objectives most often put forward. Stimulation of downtown retail markets and the preservation of the CBD tax base are primary economic objectives. In serving environmental objectives, improved air quality and noise levels are the major justifications for the consideration of ARZ.

I. PHYSICAL MEASURES • Street closing • Street barricade • Street width reduction • Low design speeds • Cul-de-sacs • Placement of parking facilities • Number of parking spaces • Ring road/bypass • Medians	III. REGULATORY MEASURES • Area permits • Loading/unloading • Parking restrictions • Vehicular regulations • Staggered work hours • Land use regulation • Regulation of ownership
II. OPERATIONAL MEASURES • Signalization systems • Ramp meters • Variable route signing • Turn restrictions • Special use lanes/ streets • One-way streets	IV. ECONOMIC MEASURES • Area license • Parking price/tax • Tolls • Congestion pricing • Fuel tax • Gas rationing

FIGURE 55

ARZ AUTO CONTROL IMPLEMENTATION MEASURES

It is important to note, however, that in a strict sense "auto restriction" is almost entirely negative. That is to say, that these transportation-related modifications deal largely with constraining, reducing, and re-directing rather than improving and ameloriating. Many of the objectives of ARZ implementation, however, are related not to these negative aspects of traffic restriction, but to the positive side of the coin that deals with the improvements made possible by the reduction of auto traffic. Thus, the achievement of other objectives such as economic growth and environmental enhancement rests directly on the degree of success attained in fulfilling the transportation goals.

TRANSPORTATION EVALUATION FACTORS

Planning the transportation elements of auto restricted zones presents a set of unique problems. The objective of reducing traffic congestion is constrained by the need to maintain a high level of accessibility to the ARZ area. Thus restrictive measures must be "fine-tuned" to the particular characteristics of the study area so that attractiveness and vitality are retained. Similarly, measures intended to encourage a shift to non-auto travel modes will achieve little if available transit services provide inadequate coverage or capacity. In addition, ARZ planning must recognize the special requirements of goods movement and the importance of service vehicle accessibility. Other aims include the reduction of auto accidents, parking requirements, and energy resources consumed in transportation.

From among the many possible indicators implied by this set of transportation objectives, two impact categories have been selected. These are impacts on vehicle miles traveled (VMT) and impacts on transportation level of service. Although investigation of impacts in these two areas cannot provide comprehensive documentation of every transportation-related impact, they can satisfactorily summarize ARZ impacts in the major areas of concern. Moreover, the concepts of VMT and level of service are familiar to transportation planners and fit well with available data sources.

II. ARZ TRANSPORTATION IMPACTS

EUROPE

Applications

The concept of auto restriction is most advanced in Europe where over 130 cities have instituted some form of ARZ. Copenhagen, Bremen, Amsterdam and Vienna are among the major cities that have succeeded in creating pedestrian circulation and public transport systems that are simultaneously functional and enjoyable elements of the city center. These European ARZ's embody the most innovative techniques available, and range from extensive pedestrianization schemes as in Copenhagen, to combined pedestrianways and light rail transit rights-of-way as in Bremen, to sophisticated traffic diversion and compartmentalization plans as typified by Gothenberg.

Impacts

Most of these projects, are seen as major successes. Evaluation of these leading examples of auto restriction, however, has not been rigorous. Published reports have described the planning process and ARZ plan elements, and provided general descriptions of implementation results. Data on transportation impacts are incomplete, ete, but are illustrated in the following summaries of three cases.

In Gothenburg, the major impact noted was a change in route for through traffic which formerly passed through the CBD. Traffic volumes on streets within the CBD declined as much as 70 percent, with corresponding increases of up to 45 percent on circumferential routes. Despite the highly effective traffic compartmentalization scheme which significantly reduced the utility of the auto for trips between district traffic cells, no shift in mode choice toward transit was reported.

In Bologna, comparison of cordon counts from before and after the implementation of an ARZ in the historic center of the city shows a 20 percent reduction. This significant decline is attributed to the diversion of through traffic and a shift in mode for work trips. The extent of the mode shift due to traffic restraint, however, is unclear because of the simultaneous introduction of fare-free transit service to and from the CBD.

The evaluation of the Oxford Street Experiment in London illustrates the effects of an auto ban on a single link in the highway network. Auto traffic was prohibited from a 1 km section of Oxford Street between 11 a.m. and 7 p.m. The evaluation disclosed that although volumes on adjacent streets increased, overall corridor traffic declined 15 percent. Moreover, auto traffic on Oxford Street declined 42 percent over former volumes during the unrestricted hours prior to 11 a.m.

Evaluation

Although European experience with auto restricted zones is extensive, the significance of impacts on transportation for U.S. applications appears to be limited. Basic differences between European and American cities suggest strongly that these reported impacts of auto restriction on traffic volumes and mode shift will have little transferability to U.S. applications. The three major reasons for this are patterns of urban development, modal orientation, and the extent of auto restriction imposed.

Differences in the patterns of urban development for European and American cities have a major influence. Generally, European cities are more dense, with less of the suburban sprawl that is commonly found in the U.S. The center city is also more tightly structured, offering a mix of land uses and activities within walking distance. In addition, street systems in the historic cores of European cities are unsuited to the auto age and basically unable to accommodate large amounts of traffic.

Differences in mode shares are also significant. European cities typically show a much greater use of public transit than American cities. Transit is frequently an attractive travel mode in Europe, offering convenient service at reasonable costs. Moreover, rates of car ownership are far lower in Europe than in the U.S. and importantly, the adaptation of urban functions to auto access is less.

Finally, the impacts of European experience with auto restriction have limited transferability to the U.S. because of the extent and degree of restrictive measures employed. The auto restricted zones created in Gothenburg, Copenhagen, Bremen, Uppsala, and Vienna are far more extensive than any traffic restraint scheme yet implemented in the U.S. These ARZs cover the entire center city in many cases, including commercial, retail, and residential areas as well as historic structures and open spaces. Furthermore, these European ARZs together with such experiments as the Singapore area licensing scheme represent a degree of restriction applied to a broad area that is far higher than that seriously considered for U.S. applications. Because these U.S. applications of the ARZ concept are so different from the well-known and documented European examples, their impacts on transportation must be considered separately.

UNITED STATES

Applications

In the United States, experience with the ARZ concept has been more limited. Aside from special use districts, such as college campuses, parks, and amusement/recreation areas, experience with auto restricted zones in American cities has been mainly confined to downtown pedestrian and transit malls. Although these malls are highly restricted, they are essentially one-dimensional commercial strips, offering few of the opportunities of their European counterparts.

At present, over 70 U.S. cities of varying sizes have instituted some form of auto restriction. The technique predominately utilized has been the closure of the downtown shopping street and its conversion to a pedestrian area with a high degree of emphasis placed upon improved urban design features. The Burdick Mall in Kalamazoo, Michigan, and the Fulton Mall in Fresno, California, typify this approach.

An alternative approach which is lately receiving increasing emphasis is the conversion of the downtown shopping street to a transit mall. As part of the CBD plan to create a mall area, a principal shopping street is typically closed to automobiles, with transit vehicles (buses, taxis, and possibly light-rail vehicles) continuing to use the street. This scheme is generally characterized by widening of sidewalks and improved pedestrian facilities and urban design features. The Nicollet Mall in Minneapolis, Minnesota, is a typical example of this particular approach.

Case Studies

The Urban Mass Transportation Administration is currently seeking to expand U.S. applications of the ARZ concept by funding demonstration auto restricted zones in four cities. From the feasibility analysis and design of demonstration plans for this program, several ARZ case studies have been selected here for evaluation of impacts on transportation. A recently completed planning study of a proposed transit mall provided an additional source of data on the various types of auto restricted zones commonly implemented in the U.S. today.

The case studies provide a cross-section of current ARZ approaches which create a measurable impact on the transportation system. The first case study is computer simulation of hypothetical ARZs in two cities. Burlington, Vermont, and Memphis, Tennessee, are used as case studies of pedestrian malls created as initial increments in downtown ARZs. The proposed Salina Street Transitway in Syracuse, New York, provides an example of the transit preference approach within the ARZ concept. Figure 56 displays information on the length of the street segments proposed for ARZ treatment and the traffic volumes to be directly affected.

Impacts on Vehicle Mile Traveled

Sources of Change in VMT -- As discussed above, vehicle miles traveled (VMT) is one indicator of transportation system performance that is well-suited to ARZ evaluation. ARZ effects on VMT, however, can be complex because of the different sources of change in VMT. Three major sources of VMT have been identified:

- Changes in route
- Changes in mode share
- Changes in origin/destination

City	ARZ Project	Length (Ft.)	Average Daily Traffic
Burlington, Vt.	Church Street Pedestrian Mall	1,650	11,000
Memphis, Tenn.	Mid-America Mall	3,850	10,500
Syracuse, N.Y.	Salina Street Transit/Pedestrianway	2,200	17,830

FIGURE 56

CHARACTERISTICS OF SELECTED ARZ PROJECTS

Changes in travel route are the most immediate effect of an auto restricted zone. Vehicles that formerly traveled on restricted links may be forced to take other paths. For traffic destined for downtown, this may involve the use of a more circuitous route than before, resulting in additional VMT. Similarly, traffic that formerly passed through the CBD for other destinations may now find it advantageous to change routes and avoid downtown altogether, thus adding to VMT.

Implementation of an auto restricted zone may produce a shift of auto drivers to transit, particularly if the ARZ plan incorporates transit preference elements. Disincentives to auto use, such as increased travel time due to revised circulation patterns and increased out of vehicle time due to reduced or relocated parking, could shift auto users to public transportation. This would result in decreased VMT.

Change in the regional pattern of origins and destinations is a long-term potential source of change in vehicle miles traveled. The impact on VMT can be increasing or decreasing depending on trip length and choice of mode. Implementation of an auto restricted zone could result in more trips being made to the ARZ area. As a result of improvements in the physical environment such as landscaping, seating areas, and pedestrian pavement, some trips, particularly shopping trips, may be attracted to the area from other outlying retail centers. This improved environment, along with improved access via transit, could also result in the generation of new trips destined for the ARZ. On the other side of the coin, however, decline in accessibility for auto users could result in a shift of shopping trips away from downtown to other, more accessible areas. Similarly, in the long term, decreased auto accessibility may lead to a migration of jobs and retail outlets to areas outside the downtown, resulting in decreased travel to the ARZ.

Examination of the case studies illustrates the potential impacts of various ARZ approaches on these components of VMT change.

<u>Simulation Analysis</u> -- The first two case studies are examinations of the effects of hypothetical auto restricted zones in two cities. Both of these prototype ARZ's covered approximately 30 acres of the CBD, an area approaching the size of auto restricted zones found in Europe. Four different policies were tested, all based on the complete prohibition of auto traffic from the area. The prototype cities differed primarily in the quality of transit service and the present use of public transportation for work trips. The results of the analysis are shown in Figure 57. Although the results cannot be aggregated on the basis of impact on VMT, effects on travel demand and mode choice are shown. For both cities, a 24-hour ban on traffic in the area shows the greatest impact on shopping trips which are shifted to other areas as auto access decreases. The same 24-hour auto ban accompanied by an internal shuttle bus shows greatest impact on the transit share of work trips in City B. Because of the location of parking facilities, shuttle service to peripheral parking areas in this example actually results in a net improvement in auto travel times and results in a decrease of the

ARZ Policy	CITY A		CITY B	
	Work Trips	Shop Trips	Work Trips	Shop Trips
BASE DATA				
Total Trips	3528	5220	10,000	6132
Per Cent Transit	60	60	20	50
1. 24-HR. AUTO BAN NO IMPROVEMENTS				
Changes in Total Trips	0	-2%	0	-1%
Change in Transit Share	+1%	0	%.1%	0
2. 24-HR. AUTO BAN INTERNAL TRANSIT IMPROVEMENTS				
Change in Total Trips	0	-2%	0	-1%
Change in Transit Share	+1%	0	-10%	0
3. 24-HR. AUTO BAN AREAWIDE TRANSIT IMPROVEMENTS				
Change in Total Trips	0	+15%	0	+12%
Change in Transit Share	+5%	+28%	+7%	+26%
4. PEAK PERIOD AUTO BAN NO IMPROVEMENTS				
Change in Total Trips	0	+2%	0	0
Change in Transit Share	+1%	0	0	0

Source: Alan M. Voorhees and Associates et al., Auto Restricted Zones Background and Feasibility (Draft). Urban Mass Transportation Administration, March 1977.

FIGURE 57

IMPACTS OF PROTOTYPE ON TRAVEL DEMAND AND MODE CHOICE transit share. Areawide transit improvements create the greatest impact when coupled with auto prohibitions. These access improvements result in a significant shift to transit for both work and shop trips and the generation of a number of new shopping trips to the ARZ. A ban on autos during peak travel periods only results in little or no change including a slight shift to transit for work trips and the attraction of off-peak auto shopping trips to the area in City A.

Burlington, Vermont -- The auto restricted zone being implemented in this city of 39,000 people demonstrates the applicability of ARZ concepts to small and medium size cities. The major feature of the ARZ plan is the creation of the Church Street Mall on four blocks of the downtown's major shopping street. This pedestrianization scheme built upon the earlier closure of other street segments as part of the urban renewal program for the 15-square-block CBD. As shown in Figure 56, estimated traffic volumes on Church Street totaled 11,000 vehicles per day. VMT impacts were estimated on a "worst case" basis that assumed that all existing traffic would have to be accommodated on other streets in downtown and that no auto users would shift to transit. Under this assumption, the closure of Church Street would generate an additional 457 vehicle miles of travel daily due to increased circuitry of routing for downtown traffic. As shown in Figure 58, this change is very small in the perspective of regional VMT, totaling an increase of only .08 percent on a daily basis. Within the downtown area, the increase is only slightly more significant comprising an estimated 2-percent increase in the peak hour.

Memphis, Tennessee -- The auto restricted zone implemented in Memphis illustrates the effects of a major pedestrianization scheme within a region that is no longer strongly oriented toward the downtown. The Mid-America Mall, one of the longest malls in the United States, was created out of the former Main Street which previously carried traffic volumes of 10,500 vehicles on an average day. As shown in Figure 56, the analysis of VMT impacts under the same "worst cast" assumption as in Burlington yields an estimate of 820 additional vehicle miles traveled daily as a result of revised routes for downtown traffic. Although the added VMT in Memphis is nearly twice as large as in Burlington in absolute terms, its impact on regional VMT is much less, due to differences in regional population and travel patterns.

Syracuse, New York -- The proposed Salina Street Transitway in Syracuse further illustrates the VMT impacts of auto restriction. Because of the characteristics of the downtown street network and existing traffic volumes, extensive re-routing of Salina Street traffic was proposed. As shown in Figure 56, an estimated 4,967 vehicle miles of travel could be added under the same "worst case" assumption. This amounts to .1 percent of the estimated daily regional VMT.

Potential for Mode Shift -- The quantification of VMT impacts of auto restriction for Burlington, Memphis, and Syracuse focused on the first component of VMT change identified earlier, changes in route. The analysis was based upon the assumption that the demand for travel to the area would

City/ARZ Project	Added VMT	Regional VMT[1]	Per Cent Change
Burlington, Vt. Chirch St. Mall	457	590,000	.08
Memphis, Tenn. Mid-America Mall	820	9,900,000	.01
Syracuse, N.Y. Salina Transitway	4967	3,800,000	.1

[1]Source: 1974 National Transportation Report: Urban Data Suppliment. U.S. DOT. Washington, May 1976.

FIGURE 58

ARZ IMPACT ON REGIONAL VMT

remain constant, and that no change would occur in modal shares. This assumption cast the calculation of VMT changes in the "worst case", as in reality, the disincentives to auto use implemented in each of these cities could create some potential for a shift to public transit and a consequent reduction of VMT.

Because these projects have not been fully implemented, transit ridership data on a before-and-after basis is not available. Even if it were available, ridership data would show the effects of a number of concurrent transit service improvements and not just the impacts of the restrictive measures employed. Research in the mode split field, however, has produced some useful formulae for the estimation of changes in mode split attributable to marginal changes in travel time.(2) In a simple calculation, a two-minute increase in driving time due to increased circuity of routing as a result of downtown street closures produced an estimated 1-percent shift to transit in an area where transit's share previously amounted to about 25 percent. For the transit mall case, a one-minute decrease in transit run times due to transit preference measures incorporated in the ARZ would result in an additional .3 percent transit over the 1-percent increase attributed to decreased auto access. These calculations are consistent with the results of the computer simulation of ARZs discussed earlier. In those cases, a complete auto ban over approximately 30 acres of the CBD produced a shift of 1 percent or less to public transit.

Level-of-Service Impacts

The second indicator of transportation system performance is level of service (LOS). This is a composite concept strongly related to travel time and convenience. In the evaluation of transportation impacts of auto restricted zones, it is important to note that level-of-service considerations pertain to all three major downtown travel modes-auto, transit and pedestrian.

Sources of Change in LOS -- Like the case of VMT discussed earlier, changes in level of service due to an auto restricted zone can arise from three major sources. These three factors, which illustrate the close relationship between LOS changes and the characteristics of a particular city considering an auto restricted zone, include:

- Characteristics of the network
- Network capacity
- Concurrent improvements

The first category, characteristics of the network, is concerned with the coverage, availability and connectivity of a particular modal network of services or facilities. The second factor is related to the capacity of the network, its present utilization, and the existence of excess traffic handling capacity. The concurrent improvements that frequently accompany restrictive measures is the third major influence on changes in level of service. Unlike the VMT analysis, no attempt is made here to examine level of service from a regional standpoint. Instead the focus is on impacts by mode within the auto restricted zone and the surrounding area.

Impacts on Auto LOS -- The impacts of auto restriction on automobile level of service are potentially significant within the downtown area. As discussed earlier, auto restriction on the limited scale commonly found in U.S. cities creates some additional requirements for traffic circulation within the downtown. The extent of the additional traffic movement is a function of the surrounding street network, its capacity, and operation.

Experience in Burlington and Memphis suggests that downtown traffic congestion is less than severe in some urban areas. Despite the common image of downtowns teeming with traffic, many urban centers appear to have street networks and intersections operating at levels well below design capacity. In such cases, rerouted traffic due to ARZ street closures has only minor impact on congestion. Moreover, such impacts are frequently very localized in nature, consisting of deteriorated operation of a few critical intersections.

In other urban areas considering ARZ, such as Boston, existing traffic congestion is severe. The old street network has only limited capacity, which is nearly fully utilized throughout the day. The impacts of rerouted traffic due to street closures within this context are substantial.

In these cases, however, the ARZ approach offers the opportunity to completely revise downtown circulation patterns and institute other traffic operations improvements that will make the operation of the downtown street network more efficient. Such measures may include changes in street direction, signal timing or enforcement of existing parking regulations. Without such concurrent improvements, the impacts of auto restriction on auto level of service are clearly negative. With such improvements, auto LOS can be maintained or even improved.

Impacts on Transit LOS -- The impacts of auto restriction on the level of service to transit users depends upon the separation achieved between autos and transit vehicles. If transit vehicles are routed on peripheral streets along with rerouted auto traffic, noticeable delays in running times may result. If the street network is pushed to capacity operation due to street closures, traffic congestion may cause significant deterioration in transit performance. Moreover, if transit vehicles are removed to peripheral streets as a result of ARZ implementation, level of service will be reduced due to increased walking distances to the point of destination.

Alternately, ARZ plans frequently incorporate elements that give preference to transit vehicles. In these schemes, auto and transit traffic is separated, and a number of improvements oriented toward transit travel, such as improved waiting areas and revised signal timing, are instituted. In these cases, transit level of service is clearly enhanced through greater convenience and improved transit travel time performance.

Impacts on Pedestrian LOS -- Among the most commonly neglected of the transportation impacts of auto restriction are the impacts on pedestrian travel. Pedestrians are frequently the principal beneficiaries of ARZ schemes, and thus impact on their travel patterns is most notable. The restriction or full prohibition of auto traffic enhances the pedestrian environment, expands the capacity of the pedestrian network, and makes pedestrian travel a more attractive mode within the CBD.

In the great majority of cases, creation of downtown malls in U.S. cities has resulted in increased pedestrian volumes. This increase in demand is in direct response to the improved pedestrian level of service. One factor is the improvement to the pedestrian environment. The absence of auto traffic and its accompanying air and noise pollution is a major improvement to the pedestrian environment. The creation of these exclusive pedestrian areas results in increased capacity for the pedestrian network. It is not uncommon for sidewalk conditions in a crowded CBD like Boston's, to actually exceed capacity and force pedestrians to walk in the streets. Widened sidewalks or entire auto-free streets thus expand the available walking area many times over. Frequently, ARZ plans create unified pedestrian networks that enable pedestrians to travel throughout the CBD without conflicts with auto travel.

This reduction of pedestrian/auto conflicts and expansion of pedestrian network capacity can result in improved pedestrian travel speeds. Delays due to sidewalk crowding and traffic signals are the primary negative influences on walk speeds. Research on walk travel in New York City has suggested that these delays reduce walking speeds by as much as 30 percent.(3) Elimination or reduction of delays due to overcrowding and traffic signals would result in improved pedestrian travel times and generate more pedestrian trips for intra-CBD travel.

III. CONCLUSION

This paper has reviewed European and American experience with auto restricted zones in order to document their impact on the urban transportation systems they modify.

It is clear that auto restricted zones are proposed, planned, and implemented in American cities partly to serve community transportation objectives. Most commonly, ARZ is proposed in order to reduce traffic congestion, reduce pedestrian/auto conflicts, and encourage a shift to public transportation. Although transportation goals thus play a major part in the consideration of auto restriction, evaluation of existing ARZs has centered on economic and environmental effects. Vehicle miles of travel and level of service were two indicators of transportation system performance selected as appropriate evaluation factors.

Evaluation of auto restricted zones is somewhat hindered by their application. Although European cities have implemented large-scale ARZs which have produced measureable impacts, comprehensive evaluations have not yet been performed, and those data that are available appear to be non-transferable to the U.S. context. In this country, applications of the ARZ approach have been much more limited. Generally, the typical U.S. ARZ is a three-or four-block downtown pedestrian or transit mall. The removal of a single link from a highly developed highway network cannot produce impacts which are generalizable to all types and sizes of auto restricted zones.

Examination of several case studies suggests that for ARZ planning, every case is a special case. The direction of impact, whether positive or negative, and the magnitude of impact, depend upon a host of external conditions including the role of the central city, existing mode shares, and capacity of the downtown street network. The case studies indicate that impacts on VMT are microscopic from the regional perspective. Closure of one street segment within the CBD will most likely result in minor redistributions of traffic on surrounding streets. The potential for mode shift from auto restriction on a single street alone is very small.

Far greater potential is created by transit preference schemes or improvements in transit service which work in conjunction with auto restrictions to improve the competitive position of transit travel over the private auto. The impacts of auto restriction on level of service within the CBD are more significant than impacts on VMT. Auto restricted zones offer a unique opportunity to provide major improvements in level of service for both transit riders and pedestrians. Frequently, these LOS improvements for transit and pedestrians need not imply significant deterioration in automobile LOS. Concurrent traffic operations improvements can often relieve localized capacity and intersection problems.

Thus transportation benefits of auto restricted zones flow primarily from improvements made possible by the institution of area auto restraints rather than from the restraints themselves. Although the limited U.S. experience with the concept has not produced broadly applicable transportation impact data, it appears that auto restricted zones have some potential for contributing to community transportation goals as they develop and begin to influence travel patterns throughout the CBD.

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Appendix

APPENDIX
A SUPPLY-DEMAND APPROACH TO TSM

This appendix sets forth the conceptual framework for the approach to this research with particular attention to:

- Fundamentals of Transportation Supply and Demand Equilibrium
- Relationships Between Goals and Changes in Supply-Demand Equilibrium
- Grouping of TSM Actions into Major Classes Based on the Resultant Supply-Demand Equilibrium Effects
- Analysis of Interactions Between Major Classes of TSM Actions with Respect to Supply-Demand Characteristics
- Implications of Future Growth in Travel Demand

The conceptual framework is developed in such a manner that the results of detailed summaries of impacts of different TSM actions can be directly incorporated in the analysis to provide more specific guidelines for packaging multi-action strategies.

FUNDAMENTALS OF SUPPLY-DEMAND EQUILIBRIUM

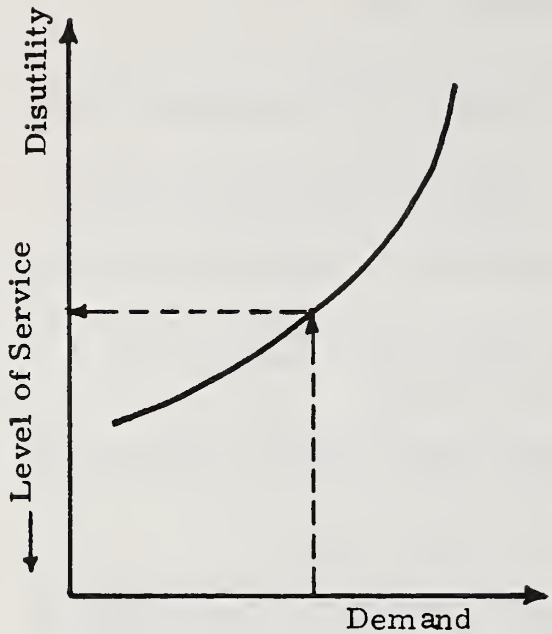
The conceptual framework used for analyzing TSM impacts and interactions is based on the fundamental concept of transportation supply and demand equilibrium. The existing transportation situation in an urban area can be characterized by two fundamental curves:

1. The transportation <u>supply</u> characteristics curve which depicts the level of service (or conversely the "disutility") associated with different levels of travel demand provided by the transportation system (see Figure A-1A). Increases in demand result in greater disutility (reduced levels of service), or vice-versa.

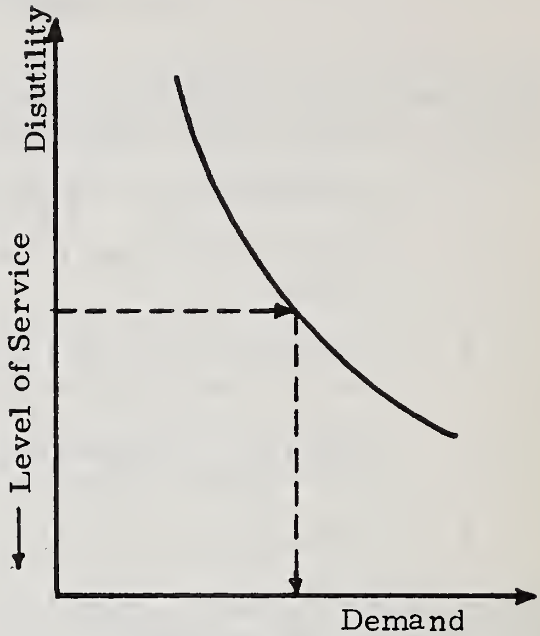
2. The transportation <u>demand</u> characteristics curve which depicts the quantity of travel demand which the public will generate, given different levels of service or disutility incurred in traveling (see Figure A-1B). Reductions in disutility (increases in level of service) result in generation of increased demand, and vice-versa.

Plotting the supply and demand curves together on the same graph (see Figure A-1C) results in the establishment of the current <u>equilibrium</u> point, where the two curves intersect, depicting the actual quantity of travel demand generated and the associated level of disutility (or level of service) experienced by the users.

A-1A. THE SUPPLY CURVE



A-1B. THE DEMAND CURVE



A-1C. SUPPLY-DEMAND EQUILIBRIUM

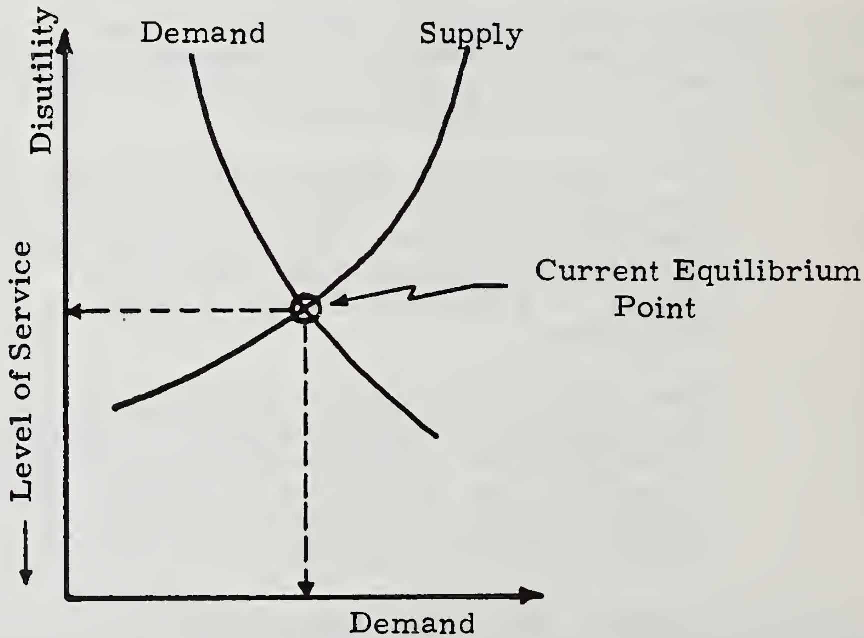


FIGURE A-1.
SUPPLY-DEMAND CHARACTERISTICS

TSM actions, indeed any event affecting transportation, change either the supply curve, the demand curve, or both the supply and demand curves. In turn, the equilibrium point where the two curves cross is shifted from the initial point to a new point. This is illustrated in Figure A-2.

For example, some actions reduce the disutility for given levels of transportation demand--represented by a downward shift in the supply curve--in turn results in increased demand and a shift in the equilibrum point down and to the right.

Other actions reduce travel demand for given levels of transportation disutility--represented by a shift to the left in the demand curve--in turn results in reduced disutility and a shift in the equilibrium point down and to the left.

Yet other actions degrade the highway supply, increasing the disutility for given levels of transportation demand--represented by an upward shift of the supply curve--in turn result in decreased demand and a shift in the equilibrium point upward and to the left.

Finally, some actions involve changing both the supply and demand curves and result in a more complex shift of the equilibrium point. The impacts of all of these various types of changes in the transportation system are illustrated in the supply-demand graphs in Figure A-2.

Because the existing transportation situation in most urban areas is so dominated by reliance on the private automobile, it is convenient and useful to simplify the conceptual analysis to use vehicle miles of travel per hour (VMT) as the measure of demand and average travel time rate of highway vehicles (e.g., in minutes per mile), i.e., the reciprocal of average speed, as the measure of disutility. This simplification does not ignore the important TSM strategy of improving transit "supply" characteristics; however, for the purposes of this analysis, improvements in transit levels of service brought about by expanding coverage or reducing transit travel time and/or cost are treated as one of the fundamental ways of reducing the VMT demand. Another potentially important TSM action, increasing the "price" of automobile travel, is represented as a reduction in demand rather than as a degradation of highway supply, since the disutility measure is represented only in time units and not as a combination of time and cost.

It should be noted that the conceptual framework is purposely simplified by using single parameters VMT, as the measure of demand, and average travel time per mile, t, as the measure of disutility. Other vital measures of travel demand include frequency of person trips, person miles of travel, frequency of vehicle trips, and distributions of trip lengths. Other important measures of quality of transportation supply include components of person travel time, including in-vehicle and out-of-vehicle time for alternative travel modes and travel cost. While the wider set of supply and demand indicators are useful for a complete understanding of traveler responses to TSM actions, these are set aside for the time being, in the

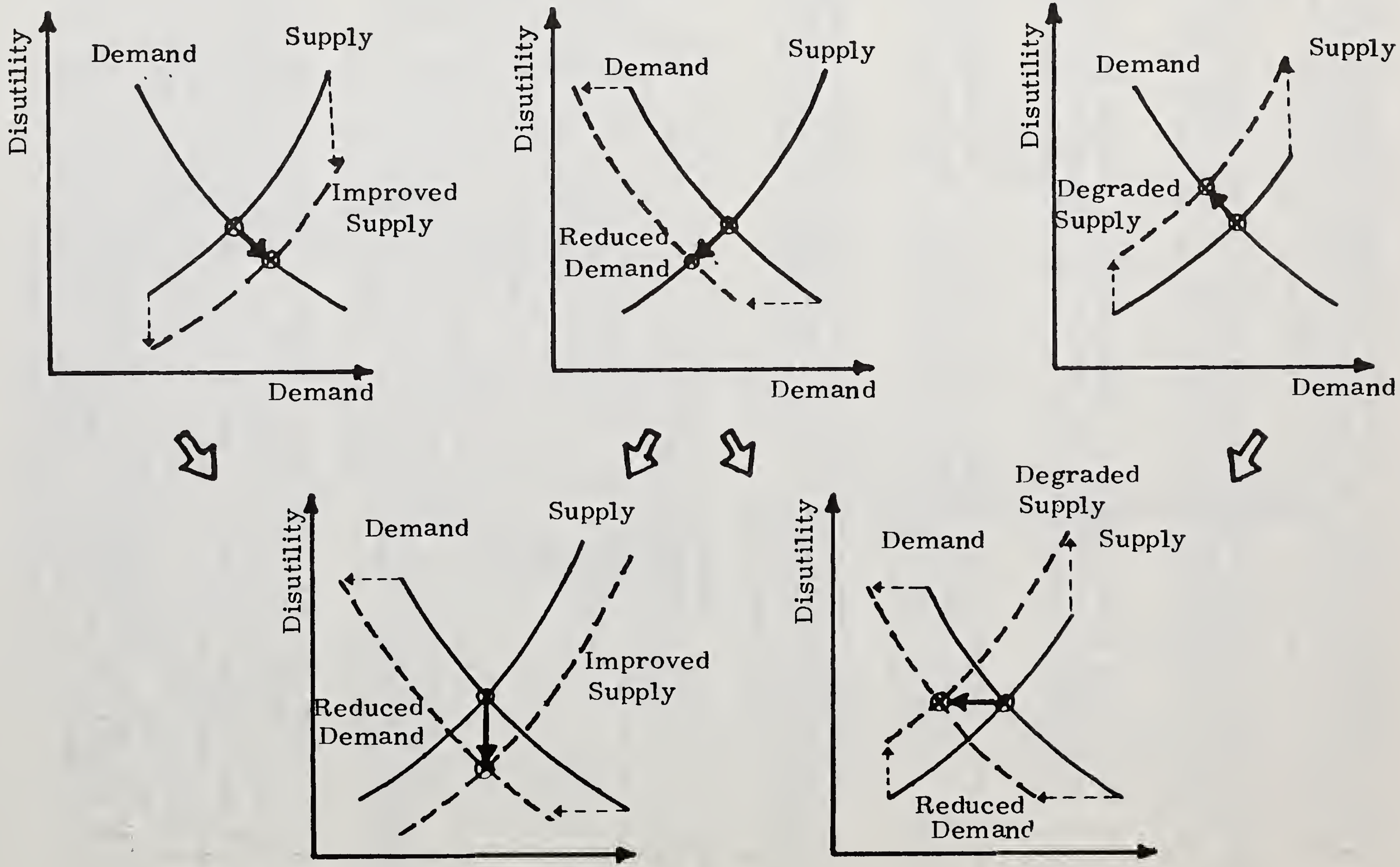


FIGURE A-2.

IMPACTS OF SUPPLY AND DEMAND CHANGES

interest of establishing a simple and understandable conceptual framework consisting only of two key indicators. This we believe is useful for strategic planning.

It is also important to note at this point that the magnitude costs and impacts of various TSM actions are not yet treated in the conceptual supply-demand analysis, but an analysis of these costs are undertaken in a subsequent study in order to assess the cost-effectiveness characteristics of alternative TSM actions.

RELATIONSHIPS BETWEEN GOALS AND DESIRED CHANGES IN SUPPLY-DEMAND EQUILIBRIUM

Given an understanding of the supply-demand equilibrium process and knowing that different TSM actions shift the equilibrium point in different directions, a key question in planning a TSM program is, "What is the most desirable direction in which to shift equilibrium from its existing point?" The answer is that the optimum direction depends on the goal mix, i.e., the relative importance of the mobility goal versus the energy and emissions reduction goals. If curent levels of mobility are poor in an urban area, and energy and emissions are not critical, then improved mobility may be the dominant goal. On the other hand, if mobility is currently of high quality, or if energy supply or air pollution are severe problems, then the goals of energy conservation and reduced emissions may be dominant. (Note that energy conservation and air quality goals tend to be closely correlated.)

What then are the most desired directions of shift in supply-demand equilibrium to serve different goals? Improved mobility can be defined in two dimensions:

1. Reduction in travel time per vehicle mile of travel (increased speed).
2. Accommodation of increased vehicle miles of travel demand at given travel time levels, thereby providing expanded accessibility to opportunities.

Therefore, the direction of shift in supply-demand equilibrium which produces the most certain benefits is downward and to the right (see Figure A-3). Small reductions in travel time may not always be beneficial from a mobility standpoint if they are gained at the expense of too great a restriction in levels of travel-demand. Conversely, small increases in travel time may be beneficial to mobility if they result from a greatly expanded accommodation of VMT. The boundary line between the benefits and disbenefits regions cannot be precisely defined, hence the boundary can be thought of as a zone of uncertainty.

If energy and emissions reductions are the dominant goals, then the desired direction of shift in supply-demand equilibrium is markedly different compared to the case of dominant mobility goals. Indeed, the desired direction

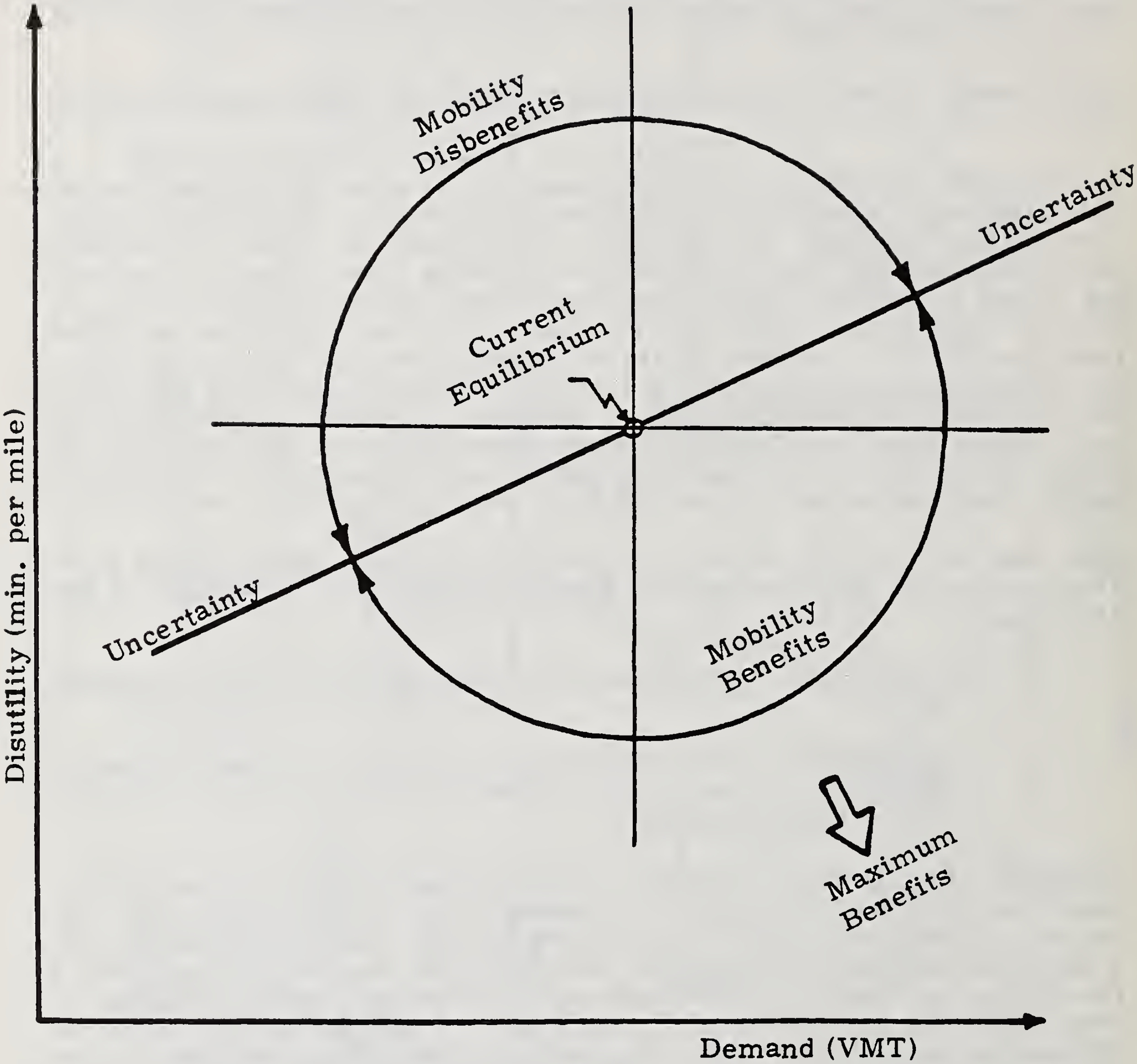


FIGURE A-3.
CHANGES IN EQUILIBRIUM PRODUCING MOBILITY BENEFITS

of shift in equilibrium for energy/emissions goals diverges by approximately 90 degrees from the desired direction of equilibrium shift for mobility goals (see Figure A-4).

Energy and emission reductions are produced in two ways:

1. Reduction of vehicle miles of travel, since no energy is consumed or pollutants are emitted for each unit of vehicle travel eliminated.

2. Reduction of travel time per mile since, in general, the rates of fuel consumed and pollutants emitted are decreased as travel time rates are reduced.

Point (1) above is derived from the fact that both pollutant emissions (CO, HC, and NOX) and fuel consumption are related at least in part to VMT. For every mile a vehicle travels, it emits pollutants and consumes fuel (energy). If a mile of travel is eliminated in some way, then the increment of pollution and energy consumption is likewise eliminated.

The second point rests on the relationship between travel speed and pollutant emissions and travel speed and energy consumption. In general, vehicle engines are most efficient from both standpoints at moderate speeds. If "supply" is improved so that speeds are increased from a congested level (15 mph for example) to a free-flowing level (30 mph perhaps), then the rate of pollutant emission and fuel consumption reduced.

Hence, the direction of shift in supply-demand equilibrium which produces the most certain energy and emissions benefits is downward and to the left.

Small reductions in VMT may not result in energy and emissions benefits if they are gained at too great an increase in travel time (and consequent increases in rates of fuel consumption and pollutants output). Conversely, small increases in VMT may still be beneficial if they result from great enough reductions in travel time per mile (and correspondent reductions in fuel consumption and emissions rates per vehicle mile). Certain disbenefits are produced, of course, when both demand and disutility increase, shifting the equilibrium point into the upper right quadrant.

Figure A-5 illustrates the region of the most desired direction of shift in the supply-demand equilibrium point if balanced goals are sought, incorporating both mobility improvement and energy and emissions reduction. The exact direction of shift corresponding to maximum benefits depends on the relative importance of weights assigned to the different goals.

INTERACTIONS BETWEEN MAJOR CLASSES

Knowing the general direction of shift in the supply-demand equilibrium point resulting from each major class of TSM action, the impacts of each class can be represented as vectors on a supply-demand graph. Each vector

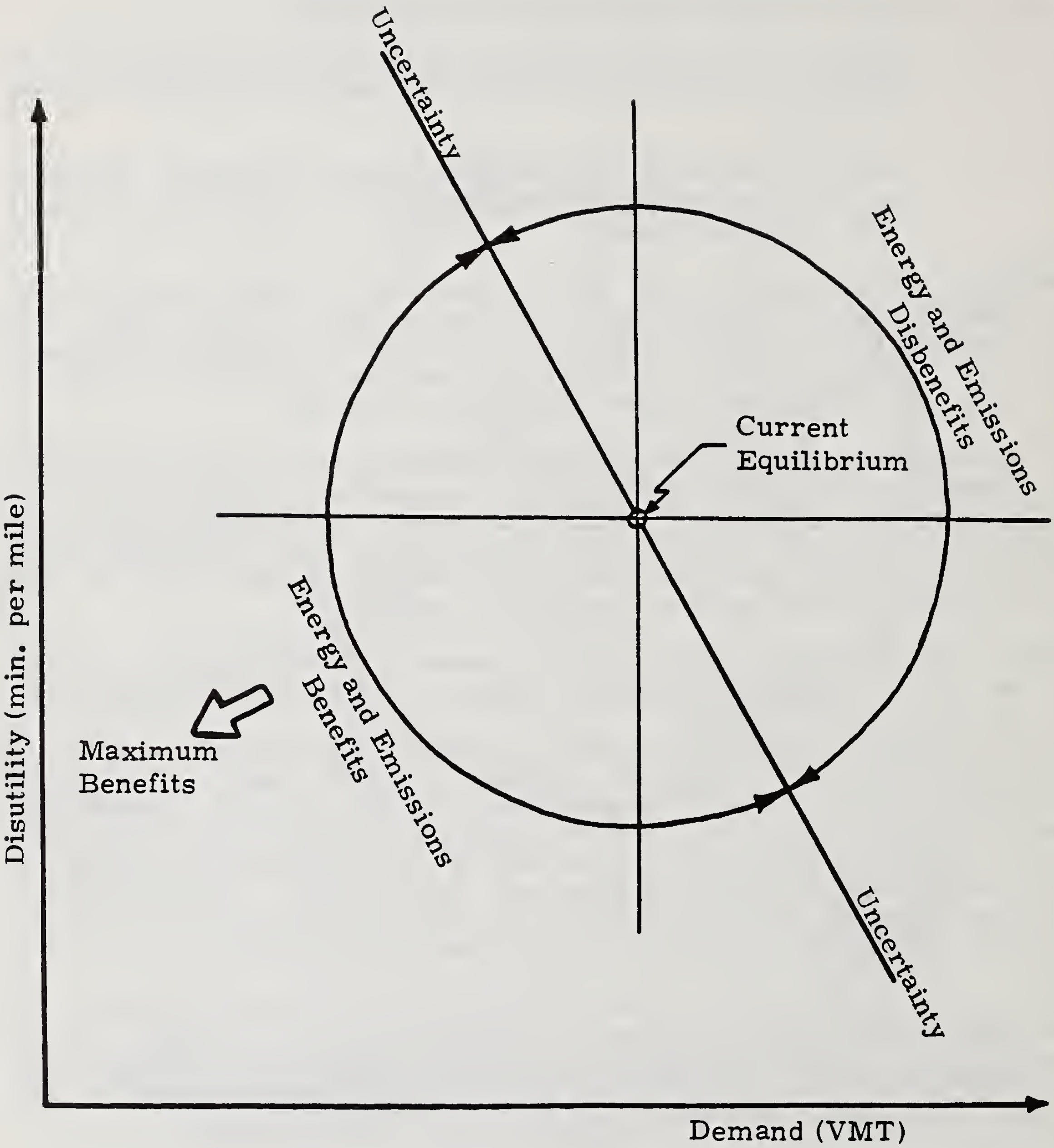


FIGURE A-4. CHANGES IN EQUILIBRIUM PRODUCING ENERGY AND EMISSIONS REDUCTION BENEFITS

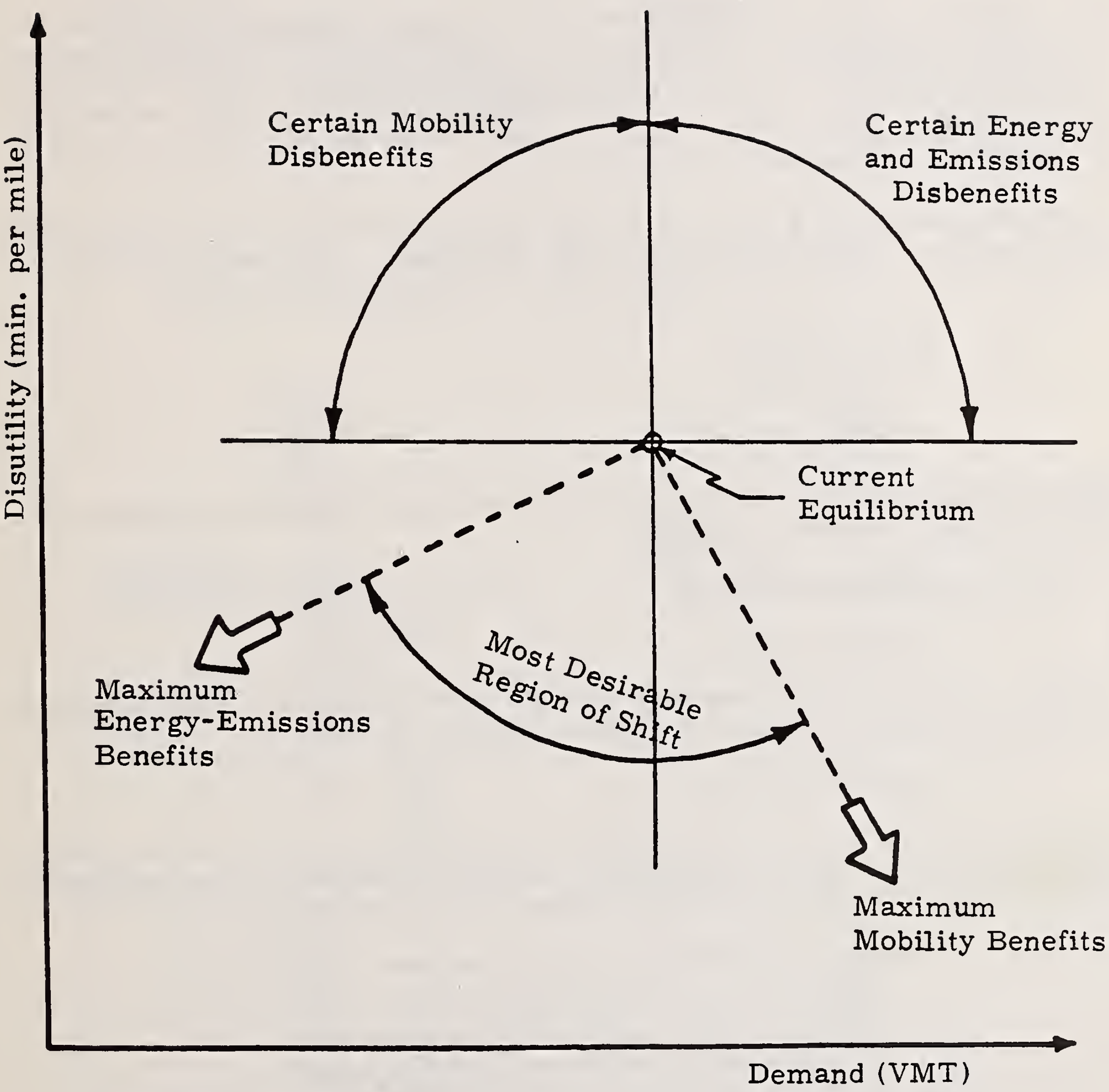


FIGURE A-5.

CHANGES IN EQUILIBRIUM FOR COMBINED GOALS originates at the current equilibrium point and is drawn in the appropriate direction of shift in equilibrium associated with the particular class of action. The length of the vector can be drawn proportional to the "strength" of the impact, i.e., in terms of the relative magnitude of change in VMT demand or travel time produced by an action.

The impacts of pairs of TSM action types (i.e., interactions) can then be determined graphically or mathematically combining or "resolving" the two vectors representing the individual impacts of the two classes of actions under consideration. This is illustrated in Figure A-6, where vector combinations are resolved for every possible pairing of action Classes A through D--six combinations in all.

The most complementary pairs of actions are those for which the direction of the respective impact vectors are least divergent. For example, classes of actions which exhibit the highest degree of complementarity are:

- Classes A and C
- Classes A and D
- Classes B and D

Less complementary actions are ones for which the direction of impact vectors are more divergent, namely:

- Classes A and B
- Classes C and D

Finally, the least complementary pair of action classes is that for which the impact vectors are most divergent, namely:

- Classes C and B

Relating the pairs of action classes to different goals, several interpretations can be drawn conceptually (without reference to the magnitudes of the impacts of the 4 different classes of TSM action):

- If Energy and Emissions Goals Dominate
    - Pair A and C is most desirable
    - Pair A and D and Pair C and D are next
    - Pair A and B and Pair B and C are next
    - Pair B and D is least desirable

  Note that all of these combinations should produce net reductions in energy and emissions with the possible exception of Pair B and D which may result in marginal increases in energy and emissions.

- If Mobility Goals are Dominant
    - Pair B and D is most desirable

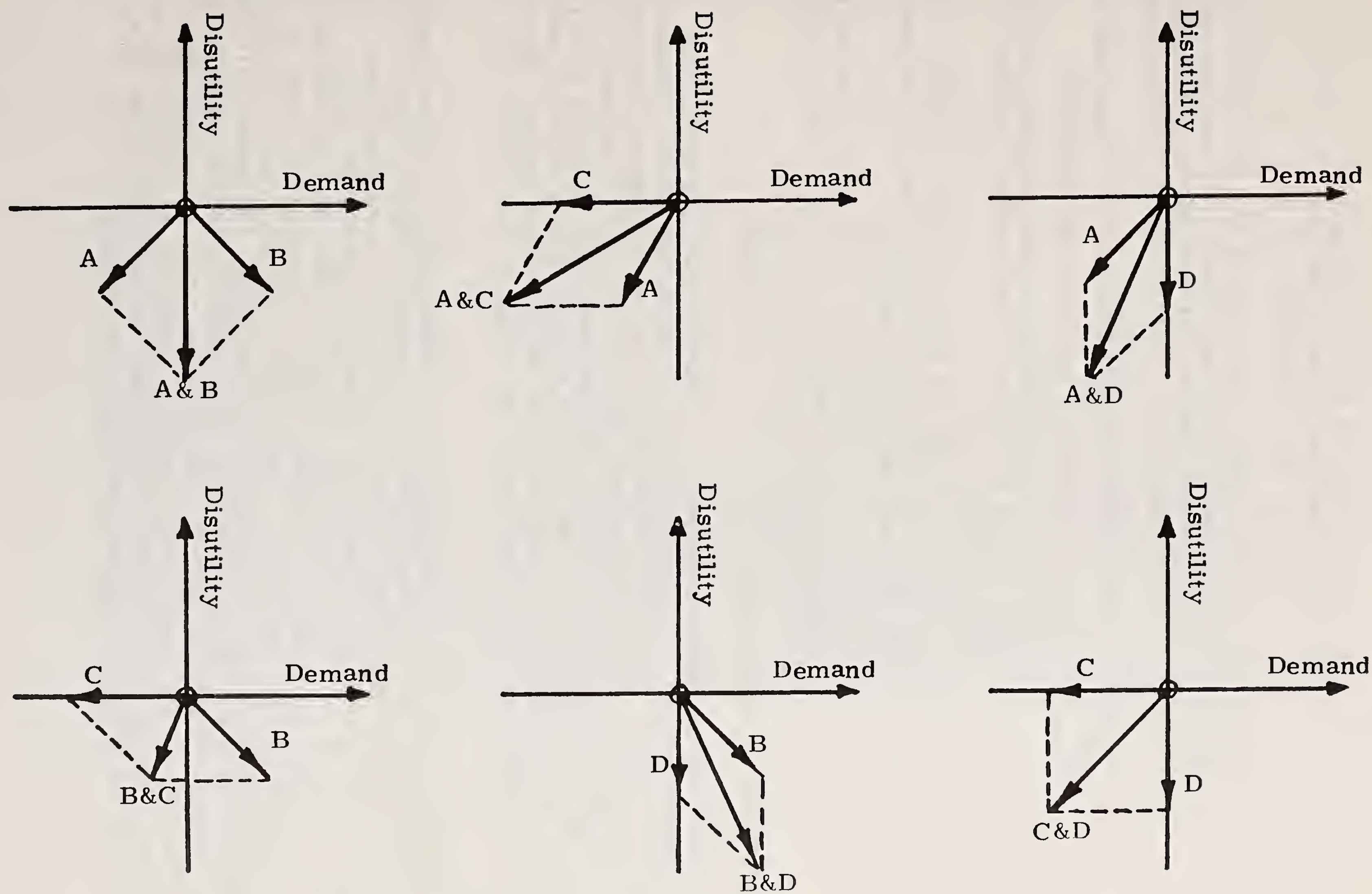


FIGURE A-6.
INTERACTIONS BETWEEN CLASSES OF TSM ACTION

- Pair A and D and Pair A and B are next
- Pair C and D and Pair C and B are next
- Pair A and C is least desirable

Note that the first three pairs provide the most certain mobility benefits, whereas the last three pairs may impinge on mobility due to reduced freedom of travel choice and increased costs of travel occurring when action Class C is incorporated.

- If Mobility Goals and Energy and Emissions Goals are Combined
  - Pair A and D and Pair A and B are most desirable
  - Pair B and D is less desirable since mobility may possibly be gained at the cost of marginally increased energy and emissions
  - Pair C and D and Pair A and C are less desirable since energy and emissions savings may be gained at the expense of marginal degradations of mobility
  - Pair B and C is less desirable since B tends to offset the energy and emissions benefits of C, and C tends to offset the mobility benefits of B

IMPLICATIONS OF FUTURE GROWTH

The foregoing conceptual analysis of impacts and interactions of TSM actions has been applied to current levels of supply and demand. However, in most urban areas, especially in medium and smaller size areas, population growth is continuing. This means that substantial growth in personal traffic demand will occur, most of which will be manifested in future growth in highway travel demand (VMT). What's more, highway supply additions generally cannot be expected to keep pace with the growth in demand. What are the implications of this future growth in demand on the efficacy of different types of TSM actions?

Figure A-7 illustrates schematically how future growth in travel demand, accompanied by less than proportionate increases in highway supply, will affect the supply-demand equilibrium compared with current conditions. The demand curve is shifted to the right to depict growth in demand. The supply curve is shifted downward by proportionately smaller amounts to depict marginal improvements in highway supply. Assuming no change in the intensity of various TSM actions, future conditions will result in a shift in supply-demand equilibrium upward and to the right. VMT demand will rise substantially and so will travel time--i.e., mobility conditions will worsen. Energy consumption and pollutant emissions would worsen even more if it were not for the expectations that the future mix of automobiles will have lower average fuel consumption and lower emissions rates per mile of travel due to Federally imposed standards on new vehicles.

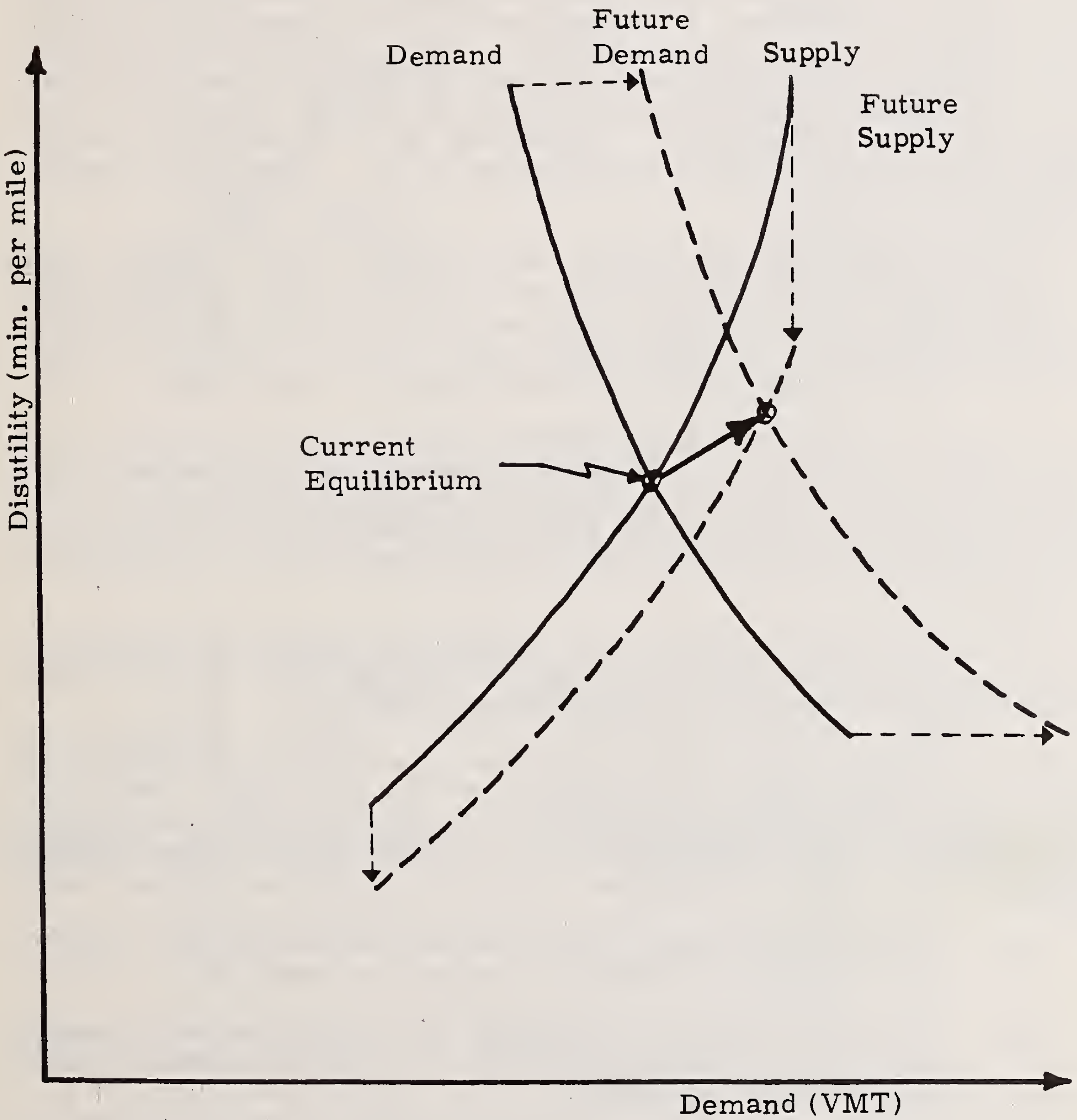


FIGURE A-7.
IMPACT OF FUTURE CONDITIONS ON SUPPLY-DEMAND EQUILIBRIUM

The impact of future growth can be depicted as a vector on the supply-demand graph just as the impacts of TSM actions were so represented. The future growth vector and the various TSM action vectors can also be plotted together to illustrate the combined effects of future growth and the expanded use of different classes of TSM action. This is shown in Figure A-8 where each of the four classes of TSM action are plotted in combination with future growth to show the future ramifications of independent application of each class of TSM action. (The length of the future growth vector wil of course depend on how rapidly growth occurs, and the exact direction of the vector will depend on the accompanying future increase in highway supply and on the slopes of the supply and demand curves for a given urban area. In the hypothetical case illustrated in Figure A-8, it is assumed that demand growth substantially outpaces construction of new transportation facilities.

It can be seen that the direction of the TSM action Class A vector is the most ideal against the future growth vector, pulling in virtually the opposite direction. Class A actions alone may not be strong enough to fully overcome the effects of a high growth vector, but will tend to hold back both the increases in VMT demand and the increase in travel time.

If TSM Class C actions are independently applied against the scenario of future growth, these will act strongly to reduce future increases in VMT demand but will have little or no effect on the future degradation of travel time. Conversely, Class D actions applied independently in the future will resist the worsening of travel time but will have little or no effect on expansion of VMT.

Finally, if TSM Class B actions are independently applied in the future, travel time increases will be retarded, but at the cost of even larger increases in VMT demand than would otherwise occur.

Clearly, if future growth trends are strong in an urban area, none of the TSM action classes, applied individually, will be sufficiently powerful to fully combat future worsening of mobility or increases energy consumption and emissions. General guidelines for TSM actions, however, based upon the direction of the impacts of different classes of action, can be established.

- Class A actions work in the most desirable direction, reducing the degradation of mobility, energy, and emissions.

- Class D actions work primarily in a direction which reduces degradation of mobility but has less effect on future energy and emissions increases.

- Class C actions work in a direction which reduces future energy and emissions, but do not improve (and may degrade) mobility.

- Class B actions will tend to hold back degradations in mobility but since additional future VMT is accommodated, the future energy and emissions increases are uncertain.

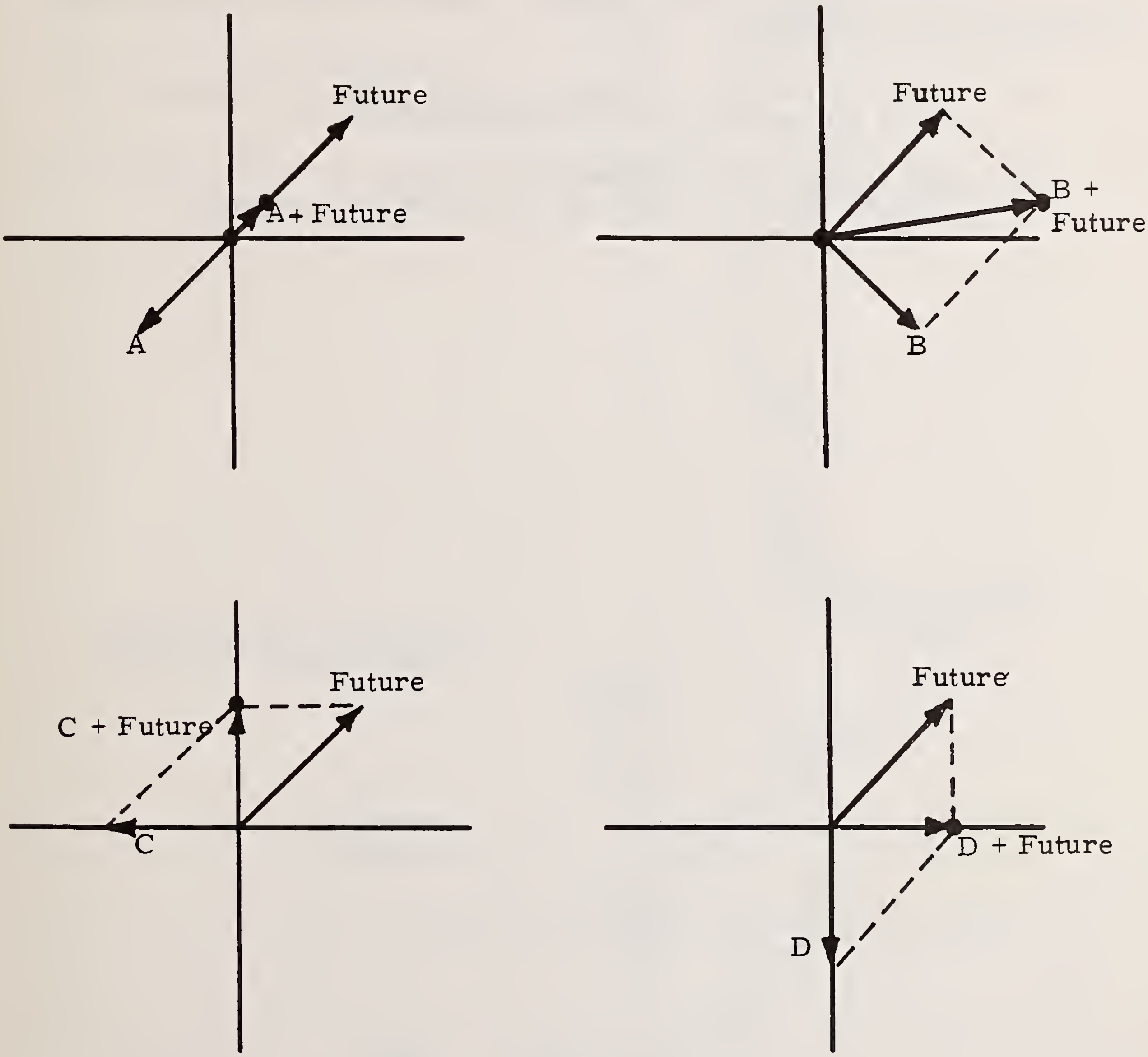


FIGURE A-8. IMPACT ON TSM ACTIONS IN THE EVENT FUTURE GROWTH IN TRAFFIC DEMAND OCCURS

Regardless of future goals mix, TSM action Classes A and D tend to produce betterment of future conditions. If energy and emissions reduction goals are dominant, then Class C actions will also work in the desired direction in combination with Classes A and D. If mobility goals dominate, then Class B actions also will be desirable in combination with Classes A and D.

Figure A-9, then, schematically illustrates two alternative strategies for multi-action TSM strategies:

- Mobility dominant strategy in which TSM action Classes A, D, and B are applied against future growth.

- Energy and emissions dominant strategy in which TSM action Classes A, D, and C are applied against future growth.

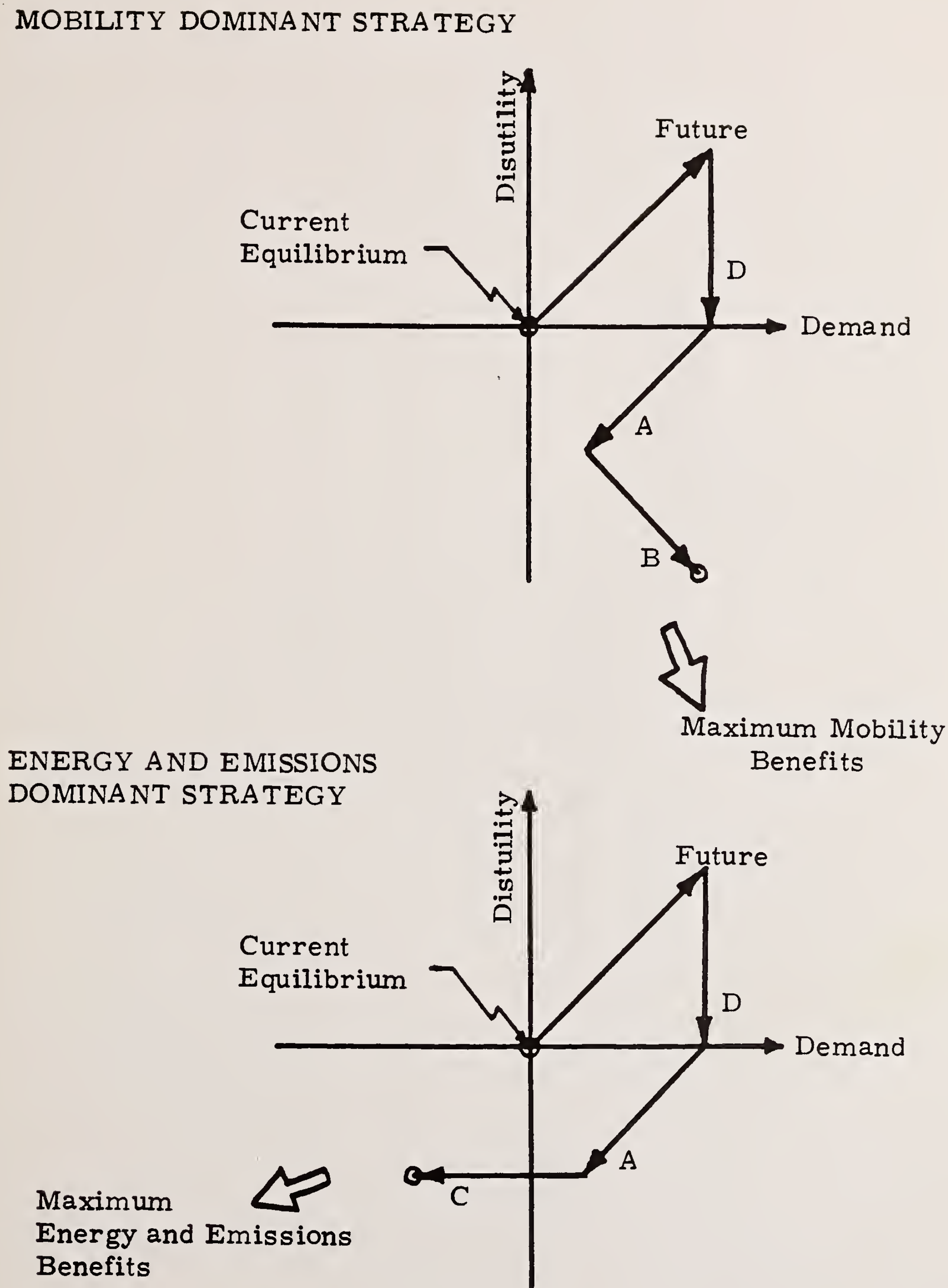


FIGURE A-9.
ALTERNATIVE FUTURE TSM STRATEGIES

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