NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 169

PEAK-PERIOD TRAFFIC CONGESTION

OPTIONS FOR CURRENT PROGRAMS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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OPTIONS FOR CURRENT PROGRAMS

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AREAS OF INTEREST:
- TRAFFIC CONTROL AND OPERATIONS
- URBAN TRANSPORTATION ADMINISTRATION
- URBAN LAND USE
- URBAN TRANSPORTATION SYSTEMS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report will be of interest to traffic engineers, transportation planners, urban planners, economists, environmentalists, and citizens. Traffic engineers and transportation planners will find a full range of possible techniques to improve the peak-period efficiency of transportation systems. Urban planners will find many of the techniques to have far-reaching effects on urban infrastructure and social programs. Economists will find techniques such as pricing and regulation to be among those which must be combined with social and engineering techniques for maximum effectiveness. Environmentalists will find that many of the techniques effective in reducing peak-period traffic congestion are also effective in reducing air pollution. Citizens concerned with transportation planning will find extensive consideration given to the impacts of implementing the techniques.

While this study was in progress the urban transportation planning process was modified to require a transportation systems management element in a transportation plan if federal funds are to be granted. The short-range techniques discussed in this report are the most promising options open to urban areas to meet the transportation systems management requirement.

Peak-period traffic congestion in urban areas is a critical transportation problem. Congestion is due primarily to the inability of transportation systems to meet concentrated spatial and temporal travel demands. The continued build-up of capital-intensive systems to provide solutions is often controversial in light of economic, social, energy, and environmental impacts. The research described evaluates a full range of possible techniques to improve peak-period efficiency of transportation systems in large and small urban areas.

Two reports have emanated from this study. The first, "Peak-Period Traffic Congestion: State of the Art and Recommended Research," is only available in the agency draft form on a loan basis by request to the NCHRP Program Director or on a purchase basis from NTIS; the second, contained herein, summarizes some of the material in the first report and presents an evaluation of techniques and packages of techniques recommended for implementation.

The first report reviews techniques falling into four classes: (1) social, (2) socioeconomic, (3) sociotechnical, and (4) technical. Social approaches include staggered work hours and shortened work weeks. Socioeconomic approaches include pricing and regulatory techniques, restriction of access, land-use planning, marketing, and carpooling. Sociotechnical approaches incorporate the expanding field of communications in lieu of travel. Technical approaches include traffic engineering techniques and transit operations that are effective in maximizing the use of existing facilities. Tables provide the means for 17 techniques to be compared on the basis of their concepts, effectiveness, costs, impacts, duration of benefits, and implementation feasibility. None of the techniques was found to offer more than marginal reduction in peak-period traffic congestion when applied individually. However, many of the techniques could be implemented in combinations, with the potential for far greater combined effectiveness than when applied singly. The first report concludes with the identification of ten recommended research studies, with highest priority given to research that would contribute to the implementation of techniques of high potential usefulness.

The report presented here continues with the evaluation of techniques identified in the first report. The compatibility of each technique is discussed. From the compatibility analysis, eight packages of techniques are recommended for implementation consideration. Each package is evaluated on the basis of (a) compatibility with other approaches, (b) applicability, (c) cost-effectiveness, and (d) feasibility. Feasibility considers institutional considerations, acceptance by private organizations, compatibility with existing laws, and readiness for implementation. For each package, the component techniques are clearly identified. In addition, other techniques and the other packages are designated "supportive," "neutral," or "conflicting." Proposed packages are related to common peak-period traffic congestion problems existing in CBD's of large cities, CBD's of small cities, urban freeways and arterials, roadways with strong one-directional flow, and roadways with limited options for alternative routes. This report concludes with the recommendation that plans to ameliorate peak-period traffic congestion should be both short-range, that would adapt to existing urban forms, and long-range, that would reshape urban areas. The techniques regarded as having the highest potential over the long range are those which would reduce distances between residential areas and places of employment and those which would substitute communication in lieu of travel.

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PEAK-PERIOD TRAFFIC CONGESTION
OPTIONS FOR CURRENT PROGRAMS

SUMMARY

Peak-period traffic congestion is a widespread urban transportation problem. The continued building of capital-intensive systems to solve this problem is often controversial in light of their potential economic, social, and environmental impacts. The purpose of this study was to develop information on other approaches to reducing peak-period congestion in order to support local congestion-reduction efforts.

The study had three major objectives: (1) a state-of-the-art survey of methods commonly used or envisioned as solutions to the problem; (2) recommendations for research to develop more effective short-term and long-range congestion-reduction measures; and (3) suggestion of methods of reducing traffic congestion that are now available as solutions to different types of existing peak-period congestion problems.

The findings and conclusions of this study are presented in two separate reports. The first, entitled "Peak-Period Traffic Congestion: State-of-the-Art and Recommended Research," addresses the first two objectives and is intended as a guide to the design of future research programs and as a source of data for current research. The second, entitled "Peak-Period Traffic Congestion: Options for Current Programs," addresses the third study objective and is directed toward assisting local governments in selecting optimum solutions for their particular congestion problems. It describes the options available within the present state of the art, compares their probable costs and benefits, and makes specific recommendations for solutions to different types of peak-period congestion.

Twenty-two individual techniques in eleven major categories were identified in the first report. These categories are:

Social approaches

1. Staggered and flexible work hours.
2. Shortened work weeks.

Socioeconomic approaches

3. Pricing and regulatory mechanisms.
4. Restriction of auto access.
5. Land-use planning.
6. Marketing.
7. Carpooling and ride sharing.

Sociotechnical approaches

8. Communications in lieu of travel.

Technical approaches

9. Practical traffic engineering.
10. Transit operations.
11. Vehicle design factors.

Information on the 22 techniques was developed to display their relative benefits and costs and their current feasibility. Among the benefits and costs considered were:

1. Effectiveness in reducing peak-period congestion.
2. Costs of implementation.
3. Indirect benefits and disbenefits.
4. Time factors.

The effectiveness of the techniques in treating different congestion problems was measured. Five congestion situations common to urban areas throughout the United States were identified:

1. CBDs of large cities.
2. CBDs of small cities and suburban activity centers.
3. Urban freeways and arterials.
4. Roadways with strong one-directional traffic flows alternating direction between morning and evening peak commuting hours.
5. Roadways for which options in alternative routes are limited, such as bridges, tunnels, and when access is otherwise restricted by nature of the terrain.

Five of the 22 techniques were eliminated from further consideration as being ineffective in reducing peak-period traffic. Costs of implementation examined included direct costs to the agency making use of the technique and secondary costs that might be incurred by the private sector or other public agencies cooperating in the program.

Two aspects of the timing of impacts were also considered in the evaluation—the lapse of time that must be expected between the adoption of a technique and the realization of benefits, and the probable duration of benefits. Some techniques were found to result in immediate improvements in traffic flow, whereas others required as much as 10 to 20 years to reach full effectiveness. Some short-term benefits were discovered to be lost over time as new drivers are attracted to the improved traffic conditions.

Nine categories of indirect benefits and disbenefits (negative benefits) were identified as factors that should be weighed in a decision to implement any of these techniques, and the candidate techniques were examined with regard to:

1. Traffic congestion in other parts of the total transportation system.
2. Long-range travel demands and patterns.
3. Energy consumption.
4. Environmental pollution.
5. Public safety.
6. Economic impacts.
7. Equity considerations.
8. Institutional considerations, public.
9. Institutional considerations, private.

Five feasibility criteria were applied, as follows:

1. Obtaining of essential institutional support.
2. Public acceptance.
3. Acceptance by private organizations.
4. Compatibility with existing laws and regulations.
5. State of the art (technological readiness for implementation).

Although some potential implementation problems were noted, none was judged to be so critical as to preclude present application of any of the 17 remaining techniques.

The extent of existing knowledge about the candidate techniques was evaluated with regard to: (1) their effectiveness in reducing congestion and direct costs of implementation; and (2) indirect benefits and disbenefits. Current knowledge of the costs and effectiveness of most techniques was rated as sufficient only for rough estimates, except in the case of traffic engineering techniques where data are of relatively high reliability. In none of the indirect impact areas were existing data considered sufficient to provide reliable guides to the probable side effects of implementing any of the 17 techniques. In many cases information was considered insufficient for even rough estimates.

The study team concluded that:

1. Individual techniques should be packaged with other supportive techniques to create a cumulative or even synergetic impact.

2. The relationship between peak-period traffic congestion and a number of critical societal problems should be investigated and clarified.

3. Research is needed to determine the indirect benefits and disbenefits and the institutional constraints inherent in a number of promising congestion-reduction techniques.

The report presented here concludes that of the 17 candidate techniques evaluated as both effective and feasible none was found to offer more than marginal reduction in peak-period traffic congestion when applied individually. It was noted, however, that many of the techniques could be implemented together, with the potential for far greater combined effectiveness than when applied singly. Carrying out several compatible techniques under one coordinated program could not only improve the benefits that can be realized from the most promising techniques, but also could achieve significant results from techniques that individually are only minimally effective.

To accomplish the third research task—the selection of optimum approaches for current application—packages of effective combinations of congestion-reduction techniques were selected. The selection was based on two criteria: (a) the compatibility of the individual candidate techniques, and (b) applicability of combinations of techniques to different types of congestion problems. First, the impact of combining pairs of techniques was examined by developing a matrix listing all 17 candidates on both axes. Next, the matrix was rearranged according to the relative compatibility of the pairs to suggest whole groupings of techniques that could successfully be combined within a single program package.

The packages tentatively selected from this analysis each focused on a central technique or combination of highly interrelated ones, as follows:

1. Work-hour changes.
2. Pricing techniques.
3. Restriction of access.
4. Land-use changes.
5. Prearranged ride-sharing.
6. Communications substitutes for travel.
7. Traffic engineering techniques.
8. Transit treatments.

The packages of techniques were then evaluated for their applicability to different types of congestion problems. When matched against the five major kinds of congestion identified earlier as common to many urban areas, the packages were found to have different degrees of relevance to these problems. The components of the packages were modified where necessary to make them more effective. Four of the packages were designed with slightly different alternative combinations of techniques to make them applicable to different types of congestion problems.

The package of transit treatments is rated as having the highest over-all applicability to the full range of common peak-period congestion problems, offering an effective, lasting solution at moderate cost to local government, with generally beneficial indirect impacts on the community as a whole. Short-term low-cost programs recommended for general application are packages of work-hours changes and prearranged ride-sharing and the simpler versions of pricing techniques and restricting access, although only modest benefits to traffic congestion can be expected. Some versions of the traffic engineering package can also be implemented at low cost, but results of these programs tend to be more localized than beneficial to the entire system.

The package of land-use changes, in spite of the difficulties of implementation and the time lag before benefits can be expected, is believed to present the best permanent solution to peak-period congestion as well as many other critical urban problems. Communications substitutes represent the most controversial approach, and rank relatively low because of current lack of experience with these techniques and low reliability of predicted benefits. It is recommended that local government adopt a dual program of short-term and long-term programs that will provide for both immediate treatment of current congestion problems and lasting, long-range solutions.

The eight packages of congestion-reduction techniques were evaluated as to the extent of current knowledge of their effectiveness, costs, and indirect impacts. Special attention was directed toward the social, economic, and environmental benefits and disbenefits that might be generated indirectly by implementation of the packages, because it was recognized that this area was the least understood and was urgently in need of further study.

All of the proposed packages of congestion-reduction techniques presented in this report are suggested as effective and feasible solutions to existing peak-period congestion problems. None of the packages has yet been implemented to test these assumptions or to be sure of the indirect impacts on the community that might result.

To determine critical needs for new information from future research, potential research topics were identified by the two major preceding analyses. Evaluation criteria were:

1. Readiness of the relevant approaches for implementation.
2. Comprehensiveness of the topic to be researched.
3. Over-all social significance of the research topic.
4. Relevance of the research topic to NCHRP concerns.

Ten research topics emerged as recommendations for further NCHRP-sponsored studies in the area of solutions to peak-period traffic congestion:

1. Development of a Standardized Monitoring System for Evaluating Congestion-Reduction Programs.

2. Impacts of Congestion Solutions on Long-Range Travel Demands and Patterns.

3. Impacts on Congestion of Increased Transit Ridership.

4. Institutional Impacts of Joint Implementation of Restrictive Congestion-Reduction Techniques.

5. Design of Demonstrations of Restricting Vehicle Access.
6. Warrants for Priority Vehicle Lanes and Exclusive Vehicle Ways.
7. Universal Guideway Concept.
8. Reassessment of Freeway and Arterial Geometric Design Criteria.
9. Economic Impacts and Equity Considerations of Pricing Techniques.
10. Demonstration of Neighborhood Work Communications Center.

The most urgent research need in this area is represented by the initial proposal, which would provide a widely applicable, standardized monitoring system for evaluating and comparing alternative approaches to alleviating peak-period traffic congestion. The proposed system would not only supply information on direct effectiveness in treating congestion, but would also examine associated costs of implementation, feasibility factors, and indirect social, economic, and environmental impacts.

Of the remaining nine research proposals, six are focused primarily on the least understood elements of congestion-reduction efforts—the indirect benefits and disbenefits to the local environment, economy, social structure, and institutions. Another study seeks to assess the direct effectiveness of improving transit services, considered by the study team as potentially the most broadly applicable of the alternative treatments. One seeks a reassessment of currently used freeway and arterial design criteria in light of recent changes in vehicle design and regulation of speed limits. Finally, a demonstration of the most innovative of the treatments is recommended—a neighborhood communications work center—in which the effectiveness, feasibility, and indirect impact of substituting communications for travel to work can be observed and evaluated.

An elaboration of these topics in the form of research problems is to be found in the first report. (See Foreword for information on availability of unpublished first report.)

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

Peak-period traffic congestion is a widespread urban transportation problem. The continued building of capital-intensive systems to solve this problem is often controversial in light of their potential economic, social, and environmental impacts. The purpose of this study conducted by Remak/Rosenbloom was to develop information on other approaches to alleviating peak-period congestion, especially low-cost alternatives, so that those implementing local congestion-reduction efforts would have available a full range of options from which to select the most effective and economical program for their particular situations.

The study had three major objectives: (1) carry out a state-of-the-art survey and analysis of techniques commonly used or envisioned to alleviate peak-period congestion; (2) suggest appropriate research to achieve implementable solutions for both short- and long-range aspects of the problem; and (3) suggest methods that would have immediate applicability to the solution of different types of peak-period traffic congestion problems. The results of the first two objectives of this study are presented in an unpublished report * entitled "Peak-Period Traffic Congestion—State-of-the-Art and Recommended Research." The results of the third objective of this study are presented in this volume.

* See Foreword for information on availability.

RESEARCH APPROACH

The research approach involved four basic tasks: (1) a state-of-the-art survey; (2) an analysis of the potential effectiveness and feasibility of alternative solutions; (3) selection of optimum approaches for current application; and (4) determination of critical needs for new information from future research. The state-of-the-art survey was carried out by means of an extensive literature search, supplemented by direct contact with agencies involved in current projects not yet adequately reported in available documents.

Twenty-two individual congestion-reduction techniques were identified through this survey. These candidate techniques were categorized into one of four major approaches, with the understanding that such distinctions were occasionally artificial but were useful in the analysis of similar techniques. These categories were:

1. *Social approaches.*—Techniques that attempt to alter travel behavior, and ultimately traffic congestion, by first altering interpersonal behavior and habit through social incentives.
2. *Socioeconomic approaches.*—Techniques that attempt to alter human social and economic behavior primarily through incentives considered to be broadly economic. Altered behavior in turn leads to travel patterns that reduce demands on transportation systems in peak periods.
3. *Sociotechnical approaches.*—Techniques that use technological devices to modify social behavior and ultimately travel patterns.
4. *Technical approaches.*—Measures that use technology directly to modify travel behavior at or near the immediate source of traffic congestion.

Analyses were next undertaken to determine the relative benefits and costs associated with each of the candidate techniques and their feasibility for current application to peak congestion problems. The benefits and costs examined were:

1. Direct effectiveness in reducing congestion.
2. Costs of implementation.
3. Indirect benefits and disbenefits.
4. Time factors.

Direct effectiveness on peak-period flow was assessed with reference to different types of congestion problems common among urban areas. Costs of implementation studied included both immediate costs to agencies carrying out the basic program and indirect costs that could be incurred by the private sector or cooperating public agencies for supplemental activities.

Indirect benefits and disbenefits considered included: effect on congestion in other parts of the regional transportation system; impacts on long-range travel demands and patterns; energy consumption; environmental pollution; public safety; economic impacts; equity considerations; and effect on public and private institutions. Time factors studied were time lapse between implementation and realization of benefits, and the duration of benefits.

Five feasibility factors were examined:

1. Obtaining essential institutional support at all levels of government.
2. Public acceptance.
3. Acceptance by private organizations where their cooperation was essential to implement some technique.
4. Compatibility with existing laws and regulations.
5. State of the art (technological readiness for implementation).

The findings of these analyses are briefly reviewed in Chapter Two and presented in detail in the companion publication previously cited. Among the major results of these analyses was the observation that although none of the candidate techniques was highly effective when implemented individually, implementation in combination with other compatible techniques could significantly improve their effectiveness. Packages of mutually supportive techniques were designed and subjected to similar analysis of effectiveness and feasibility. These packages were then evaluated and ranked with reference to their applicability to different types of peak-period congestion problems. These findings are discussed later herein.

Finally, needs for further research were identified and priorities were established on the basis of four criteria:

1. Over-all readiness of the affected approach for implementation.
2. Comprehensiveness of the topic to be researched.
3. Over-all social significance of the research topic.
4. Relevance of the research topic to NCHRP.

Ten high-priority research topics were selected and developed as specific research proposals. They are discussed briefly in Chapter Four and presented in their entirety in the unpublished report.

CHAPTER TWO

FINDINGS

The research findings of this study of peak-period traffic congestion fall into two major categories: observations of the state of the art of primary interest to those currently engaged in research in this field or designing future research programs, and findings pertinent to the selection of specific programs needed to treat present urban congestion problems. Emphasis in this report has been given to the latter category, and these research results are discussed in some detail in the following.

As a framework for this discussion, however, the findings of the state-of-the-art survey are reviewed briefly here.

STATE-OF-THE-ART SURVEY

Technique Categories

The survey conducted as the first task of this research effort identified 22 specific techniques that have been applied or proposed as solutions to peak-period congestion. These techniques represent a broad spectrum of social, socioeconomic, sociotechnical, and technical approaches, within which 11 separate categories could be identified, as follows:

Social approaches:
1. Staggered and flexible work hours.
2. Shortened work weeks.

Socioeconomic approaches:
3. Pricing and regulatory mechanisms.
4. Restriction of access.
5. Land-use planning.
6. Marketing.
7. Carpooling and ride sharing.

Sociotechnical approaches:
8. Communications in lieu of travel.

Technical approaches:
9. Practical traffic engineering.
10. Transit operations.
11. Vehicle design factors.

The major characteristics of these eleven categories of congestion-reduction techniques were found to be the following:

1. *Staggered and flexible work hours.* The techniques studied under this heading involved a variety of work-hour scheduling changes, including those called flexi- or flexible time, *gleitzeit* or gliding time, and floating hours. These schedule changes vary in the amount of discretion given to individual employees in setting their own working hours. Although many experts are convinced that there are significant differences in the actual impact of these various types of work-hour changes, there are as yet no data to substantiate this claim. These techniques also vary as to the component of the transportation network at which they are aimed; such plans may attempt to relieve peaking problems facing primarily the transit system, primarily the road system, or both systems simultaneously. Most staggered and flexible work hours plans in operation are largely concerned with the peaking problems of transit operations. The major recipient of all positive impacts of such scheduling changes have been transit systems; the impact on arterial congestion and peaking have been small to negative.

Both staggered work hours and flexible hours appear to relieve some forms of congestion in specific areas of high employment concentration and may relieve traffic congestion in the immediate vicinity of a single plant or parking facility. Such plans, however, require the cooperation of a majority of employers and employees within a given area in order to have significant impact on either transit or roadway congestion during peak periods.

2. *Shortened work weeks.* Shortening work weeks according to existing patterns—the 4/40 schedule composed of four of the five traditional weekdays—seems an unlikely solution to peak-period traffic congestion on any large scale. Most benefits occur from the initial staggering *hours* effect of the implementation of this technique. Although individual firms or compact concentrated areas might benefit from such schedule changes, the minor reduction in congestion on two days of the week would not effectively reduce the demand or pressures on existing highway or transit systems. Without effective coordination among all participating firms, even the impact of this two-day reduction might be offset by unpredictable shifts in travel patterns generated by new non-work trips.

3. *Pricing and regulatory mechanisms.* The underlying theory of pricing and regulatory mechanisms is that spatial and temporal demands for travel can be modified by the judicious application of varying penalties and incentives. Road pricing and parking controls are the means through which these penalties and incentives can be brought to bear on the motorist. Under road pricing the driver is assessed a toll for his use of a particular road segment; the amount of the toll can be increased at times when congestion is at its peak so as to persuade some drivers to use an alternative route or travel at a less crowded time. Parking controls can be used to achieve the same purpose by limiting the parking space available and manipulating permitted hours and charges. Peak-period automobile commuting is discouraged by allowing only short-term parking on streets, or prohibiting parking at times when the working day normally begins, or by a schedule of parking fees that favors the short-term user and penalizes the all-day user.

Although a system of variable road charges appears to have merit as a means of reducing peak-period use of crowded transportation facilities, immediate implementation of complex road pricing schemes does not appear feasible. The technology to produce the equipment necessary to monitor vehicle travel and assign variable fees is available, but there remain serious problems in the selection of appropriate schedules of charges, and administration, operation and enforcement of a working system. Even more importantly, public acceptance of variable road pricing schemes is considered to be unlikely, primarily on grounds of discrimination against low-income groups and commuters making essential work trips. In order to be more politically feasible, sufficient alternatives must be available in the form of other routes, public transit, and job and housing opportunities.

Parking controls appear to offer a more immediate apportunity to apply selective incentives and penalties for modifying travelers' choices of routes, times, and modes of travel. Technology of reducing the supply of parking spaces in congested areas and charging higher rates for all-day use is simple; costs of implementation are relatively low, and public acceptance is easier to gain.

4. *Restriction of access.* Use of private automobiles within selected congested areas of cities can be discouraged or completely prohibited by restricting access. The techniques used are traffic cells and auto-free zones.

Traffic cells eliminate through traffic in congested city streets by dividing the restricted area into zones. Streets are not entirely closed to traffic, but only pedestrians and public transit are permitted to cross the internal zone boundaries. Private vehicles moving from one cell to another must use circulation routes located on the perimeter of the controlled area. European experiments show significant improvements in traffic flow within the restricted areas and only moderate problems of additional congestion at entry control points.

Auto-free zones prohibit the entry of private vehicles into the restricted area, and facilities are provided to encourage walking, supplemented with public transit where desirable. They range in concept from areas in which all vehicular traffic is permanently banned and street surfaces are repaved and landscaped for pedestrian use, to areas that are closed to vehicles only for specific periods of the day, and areas in which public transit complements pedestrian movement. This technique has been used successfully both in the United States and in Europe to revitalize deteriorating downtown shopping districts.

Although the development of auto-free zones often involves years of costly reconstruction, it is amenable to staging in which the initial phase of the program may be achieved at low cost. Traffic congestion problems within the controlled areas are eliminated, and if good public transit services provide easy access to the area, traffic flow in other areas of the city may also be improved.

5. *Land-use planning.* Land-use planning probably offers the best long-run solution to problems of peak-period traffic congestion. The present arrangement of urban areas into large, single-purpose sectors devoted exclusively to residential, commercial, or industrial use generates extensive needs to travel. These needs can be reduced by locating places of work and residence closer together. Four techniques can be used: New Towns, planned communities, planned neighborhoods, and modification of zoning and building codes.

New Towns are self-sufficient, balanced communities of residential, commercial, industrial, and public facilities, arranged as satellite cities around major urban centers. Land uses are allocated so as to minimize travel needs, and special attention is given to pedestrian accommodations. New Towns can be extremely effective in reducing traffic congestion in central cities if sufficient employment opportunities exist within them to render work trips to the urban center unnecessary. Use of the central city for cultural and recreational activities by residents of the New Towns occurs primarily at off-peak periods, and therefore does not generate peak-period traffic congestion.

Planned residential communities are common throughout the United States. Characteristically, street patterns are planned to reduce speeds and vehicular traffic within residential neighborhoods by cul-de-sacs, landscaped islands and narrow serpentine roadways. Major circulation streets are generally provided at the circumference of residential neighborhoods, leading to local shopping centers and providing access to freeways.

The work force of such planned residential areas largely commutes to work within the central city because of limited local employment opportunities. Because of the low density of the residential development, this work force is largely dependent on private vehicles for making the trip. Some cities have tried to reduce the traffic generated by these commuters by promoting carpooling, developing regional mass transit systems, or providing peripheral park-and-ride lots with shuttle bus service to the principal employment areas.

Redevelopment of city residential areas through Model Cities and urban renewal programs can be very effective in reducing traffic congestion problems in the immediate area. Although problems occasionally arise through faulty planning or underestimation of the traffic-generating characteristics of a new facility, redevelopment more often serves to improve traffic flows and reduce peak-period congestion by better allocation of land uses and improvement of transportation facilities.

Zoning codes control the uses to which parcels of land may be put, such as single-family residential, multi-unit residential, commercial, and industrial. Building codes provide standards for the structures that are placed on parcels of land. Their function is primarily to guarantee the safety of the structure and to control blight by requiring repairs. They have also been used, however, to increase the local supply of parking spaces by requiring that new structures include sufficient off-street accommodations for their customers, employees, or residents.

Both zoning and building codes can have a profound effect on the generation of traffic. Zoning, in designating the uses to which land is put, determines the needs to travel between places of work, residence, shopping, and recreation. Where these activities are within walking distance, travel demands can be met on foot; where they are more widely separated, some form of public or private vehicle must be used. Building codes, in their application to off-street parking requirements, can influence how many of these trips will be made by private automobile. It is estimated that proper rearrangement of land use can reduce peak-hour travel by as much as 20 percent.

6. *Marketing.* The techniques discussed under this heading fell into two categories: those designed to divert auto travelers to higher-occupancy transit vehicles, and those designed to reorient use of facilities and services to off-peak hours. The marketing measures aimed at diverting auto travelers to transit were advertising and promotional programs, improved public informational services, systemwide fare reductions, reduced fares for special user groups and for off-peak travel, and passes and easy payment plans. Only one of these techniques was concerned with the possible peaking problems of transit operations; the rest assumed any increase in ridership to be a benefit.

In the short run, promotional and informational programs have little impact on transit ridership and ultimately on traffic congestion. Over-all system fare reductions do appear to increase transit ridership significantly. A substantial portion of this increase is new ridership, although it is not known if this new ridership represents a diversion of former peak-period car drivers.

Free or greatly reduced transit fares in downtown or congested areas also seem to be potentially useful in reducing both peak and off-peak traffic in specific areas. Such programs have shown both increased transit ridership and decreased auto congestion. Off-peak fare reductions for both the general public and special user groups hold some promise as congestion-reduction measures, because they appear to shift some transit trips from peak to off-peak periods; in fact, if the increased off-peak ridership does not exceed existing service capacity there seems to be little reason to differentiate between the general public and certain limited groups. This shift of transit ridership does not appear to attract sufficient auto drivers to have a significant impact on roadway congestion.

The marketing techniques holding the most promise for reducing traffic congestion are those which treat a specific, highly congested area, such as downtown, by providing free or reduced transit fares during peak periods at the immediate site of congestion.

Marketing measures were far more successful in reorienting trip times to off-peak periods than in diverting auto travelers to transit. It is not that such measures did not work at all, but rather that so great an input was required for so small an output. Measures that did appear to increase transit ridership marginally would be far more effective if treated as part of a total program of transit system improvement that included meaningful modifications in the type, routes, and schedules of transit vehicles. Marketing measures in themselves promise no significant reduction in peak-period traffic congestion. Intentionally or not, existing transit riders seemed to be the major beneficiaries of the implementation of all these measures.

7. *Carpooling and ride sharing.* Ride-sharing approaches aim at reducing peak-period congestion by increasing the number of occupants in each vehicle on the road. Carpools are the most familiar and widespread form of ride sharing, but subscription buses, vanpools, and group use of taxis also exist.

Their common characteristics are: (a) the ride is shared with other travelers; (b) there is some route deviation to pick up and drop off individual travelers; (c) access to the service is determined by prior arrangement with other passengers or a program coordinator; and (d) the schedule is fixed by agreement among the participants and is essentially inflexible from the point of view of the individual traveler.

Large concentrations of employment where work hours are alike provide the greatest potential for ride sharing. The larger the employment concentration the better the chances appear to be to form a sizeable pool of people with common origins and destination and travel times. Thus, the most successful carpooling programs are those strongly supported by the management of large firms or agencies.

The success of carpooling programs seems also to depend in large measure on the sociocultural homogeneity of the participants because of the close physical proximity and intimacy produced by sharing a private passenger car. Whereas most policymakers have assumed that the major barrier to the formation of carpools is lack of information, in fact the major barriers are social habits. People are often embarrassed or fearful of calling up a stranger for a ride to work, or they dislike riding with strangers, or the pattern of making stops on the way home from work precludes carpool membership.

There is strong evidence that objections to carpooling are so ingrained in most travelers that more effective solutions than simply providing information about the travel habits of others or advertising the energy or pollution savings inherent in carpooling are needed if this measure is to be effective in reducing the number of vehicles on the road and, ultimately, traffic congestion. Effective combinations of supportive incentives and sanctions are needed to bring about any useful diversion to ride-sharing modes.

8. *Communications in lieu of travel.* Most proposals for the substitution of communications for travel to work involve the introduction of home or neighborhood work centers provided with such equipment as audio systems, TV screens, facsimile printers, computer terminals, and other telefacilities linking these decentralized facilities to other work centers, data centers and libraries, and central management offices. Thus far, there is no fixed definition of the hardware package required or the most desirable type of network (telephone- or TV-based). Nor have experiments yet been carried out to demonstrate that communications can actually substitute for travel to work in ways that would effectively reduce peak-period traffic congestion. It appears probable, however, that decentralization of economic activity in and around major urban areas would benefit traffic flow in the CBD by limiting some work trips to smaller adjacent urban areas with excess street capacity and by eliminating others altogether where communications facilities permit some employees to work at home.

Two conditions must be met if these benefits are to be realized: (a) Given adequate variety of residential and job choice, people will choose a home- and work-place combination that minimizes congestion, if not total travel; (b) Decentralized urban forms can be politically, economically, and socially valid. In other words, increased use and sophistication of communications technology may be a necessary condition for decentralization. If office dispersal can be shown to be economical compared to present office location patterns and a trend should develop in this direction, the long time-frame associated with locational changes might be considerably compressed under combined efforts to encourage decentralization and substitution of telecommunications for daily work trips.

9. *Practical traffic engineering.* The methods included in this category are freeway surveillance and control systems and techniques that permit maximum use of existing roadways. The first, freeway surveillance and control, includes administrative/planning/pricing solutions, traffic control systems, surveillance systems, and driver real-time information solutions. Freeway traffic control has been most effectively demonstrated on the on-ramp, by limiting access to the freeway facility so that the demand is maintained at desirable levels. Freeway surveillance techniques are directed toward alleviating the problems caused by sudden unpredictable incidents. Direct surveillance is done through the human eye, either directly from a fixed observation point, from a moving vehicle, from a helicopter or airplane, or by means of a camera transmitting a picture to a central control office. Indirect surveillance is done through the use of electronic detector devices.

Freeway surveillance and incident detection are often operated in connection with ramp metering and with driver information systems to provide for flexibility in the total freeway traffic control system. As demand for higher levels of control increases, a simple, individual ramp-metering system can be upgraded to a traffic-responsive mode controlled by a central computer. When the freeway is under complete surveillance, a driver real-time information system can be added by means of signs that can be activated when necessary or communication through a radio broadcast system. The next step can expand this system to control not only the freeway or expressway, but also the whole transportation corridor. At this level, drivers can be provided with a continuous report of the status of congestion points, and suggested alternate routes can be given.

Effective, low-cost solutions to peak-hour traffic congestion can be derived from the application of several familiar traffic engineering techniques. These techniques employ concepts of design modifications, regulation and control. The highway or street facility could be designed or redesigned to minimize the friction between traffic and roadside objects, or between traffic in adjacent lanes. Through proper application highways and streets can be more effectively utilized to maximize traffic throughput.

One-way street operations have been shown to be effective in improving traffic flow in CBD locations. Another related technique is the operation of reversible lanes to accommodate strong one-directional congestion in the morning peak which is reversed in the afternoon peak. Other techniques include provision of left-turn lanes and signals, synchronization of signals, improved road markings and signs to direct drivers into appropriate lanes, and prohibition of on-street parking during peak commuting hours.

Traffic engineering techniques can provide for considerable improvement in traffic operations, enhanced capacity and safety, and thus reduce congestion and delay. There is considerable evidence, however, that those techniques which improve vehicular flow tend to be dysfunctional because they encourage more, rather than less travel. Thus they should be applied carefully with this serious reservation in mind.

10. *Transit operations.* This group of techniques involves changing operating characteristics of an existing transit system or providing new services so that mass transportation (a) becomes attractive enough to attract automobile commuters and (b) minimizes the negative impacts of transit operations on traffic flows. Four major types of transit service may be involved:

1. Extended-area services.
2. Priority systems on expressways and freeways.
3. Priority systems on arterials.
4. Circulation systems.

Extended-area services may involve practices that speed up the operation of bus services in mixed traffic, such as separating the collection and distribution function from the line-haul portion of the trip. Express service is supported by auxiliary facilities such as parking lots and feeder systems.

Priority systems give preferential treatment over other vehicles traveling along the same route for extended-area express buses on freeways and on the entrance and exit ramps to those freeways, or to local and express buses traveling along arterials in congested areas. These techniques include traffic signalization and preemption techniques. Finally, transit circulation systems can be developed to meet special travel needs not served by fixed-rail or fixed-route transit systems. They serve as feeders to these line-haul services both in the CBD and in residential areas, and may include jitneys and demand-actuated systems, as well as the more traditional bus services.

Extended-area services on urban highways in mixed traffic attract significant ridership in certain communities; such express services have been very successful, but only on specific routes, generally from concentrated suburban development to the CBD. Although there are many successful applications of this technique, this service appears to work well only when specific conditions apply. Reported ridership increases on express buses sometimes reflect diversion of existing transit passengers. Because new transit patrons are very sensitive to quality of service considerations, they may revert to auto use should parking costs or fares be raised. There is little evidence that even the most dramatically successful routes have had significant impact on traffic congestion.

A widely discussed priority treatment is the use of freeway traffic control techniques to reserve one or more lanes for transit or other high-occupancy vehicles. These reserved lanes can be either with-flow or contra-flow lanes. In the latter case they remove some vehicles from the heavy peak flow of traffic and thus eliminate some traffic congestion. In the former case, however, they increase traffic congestion on the lanes remaining for the use of other vehicles, and the measure is more effective in encouraging group riding than in alleviating peak congestion problems.

Although most successful freeway bus priority treatments represent either contra-flow operations on existing radial freeways or special priority on bypass lanes, most major proposals call for exclusive busways. Measured by the capital-costs-per-minute-saved criterion, busways appear far less cost-effective than contra-flow lanes on existing facilities. In addition, the lead-in and implementation times of temporary reserved-lane treatments seem to make them more promising as an immediate solution to traffic congestion problems and it seems ideal for areas with under-utilized highway capacity in the non-peak direction.

The distribution of buses at the central area terminus of busways and reserved lanes remains an important problem. Most current priority proposals, as well as existing programs, do not offer any service improvement in the downtown area and evidence indicates that savings incurred on the busway portion of a line-haul trip are often negated by vehicle reentry into congested traffic streams.

Arterial priority measures are generally introduced to speed up over-all arterial traffic flow and make transit operations more efficient. This greater operating efficiency, coupled with the attendant greater attractiveness of transit, is often cited as a way to attract more transit riders, thus reducing further impediments to traffic flow. Whereas there have been a few systematic analyses of the actual effectiveness of such measures in the United States, there is little evidence to suggest that patronage does increase due to preferential treatment of transit vehicles or that transit operators have been able to reduce the number of vehicles in service during peak periods.

Small-area and downtown circulation systems have generally proven successful in attracting a substantial ridership, but their impact on traffic congestion has not always been of a significant magnitude. It appears that such systems capture much of the midday travel of central area workers who came to work during traditional peak periods in their private autos; there is some evidence that these services also tend to increase discretionary tripmaking, a contention supported by the fact that such systems are often paid for by local merchants. It appears that such systems work best in conjunction with other improved home-to-work transit services.

Taxis and jitneys have great potential to reduce auto travel both in concentrated central areas and throughout the system, but local and state regulations generally prohibited them from providing the full amount of service demanded. There is reason to believe that these services, which are far closer to the auto in attractiveness and flexibility than traditional mass transit, might reduce auto travel for a number of trips and, thus, traffic congestion.

11. *Vehicle design factors.* Vehicle design factors affecting peak-hour congestion on city streets are those related to vehicle dimensions and those associated with the compatibility of vehicles with homogeneous or uniform traffic flow.

Although requiring all vehicles in a traffic situation to have similar operating capabilities would theoretically reduce congestion by promoting uniformity of traffic flows, attempts to reduce traffic congestion by promoting the development of smaller cars can be only minimally effective. Not only is there a substantial time lag before design changes can be translated into vehicles available on the market, but the congestion benefits associated with the use of smaller cars also can only be significant when all vehicles using the road are small so that lane widths can be reduced.

There has been no experience with changes in the capacity of city streets on which only small cars are permitted to operate. Even in London and in other European countries where the small car is much more common than it is in the United States, a few large cars, buses, and trucks are also in the traffic stream so that the full effect of small cars on congestion cannot be directly measured. Researchers who have investigated the effect of small cars on traffic flow and route capacity in the U.S. found that groups of small cars in the normal traffic stream have little effect on traffic flow. England's Ministry of Transport reported in 1967 that the shorter length of small cars has little effect on lane capacity because the headway between successive vehicles is nearly as great as that for the larger cars, even when the traffic stream is entirely made up of small cars.

Vehicle design factors that relate directly to the uniformity or homogeneity of traffic flow provide the best opportunity to relieve traffic congestion through vehicle design changes. If all vehicles are of the same size, have the same weight-power ratio, and are geared for the same acceleration and deceleration rates, vehicle flow conditions will be better than if a mixture of vehicles with different sizes, power relationships, and gear ratios operate in the same traffic flow.

Evaluation of Techniques

Effectiveness in Reducing Peak-Period Congestion

The effectiveness of the candidate techniques was measured with reference to different types of congestion problems commonly experienced in urban areas throughout the United States. The study team identified three major congestion problem areas:

1. CBDs of large cities.
2. CBDs of small cities and suburban activity centers.
3. Urban freeways and arterials.

Also identified were two special congestion problems:

1. Roadways with strong one-directional traffic flows alternating direction between morning and evening peak commuting hours.
2. Roadways for which options in alternative routes are limited, such as bridges, tunnels, and when access is otherwise restricted by the nature of the terrain.

Five techniques were estimated to be the most effective in CBDs of large cities: parking controls, road pricing, priority expressway transit treatments, staggered work hours, and auto-free zones. Eight other techniques were considered to be somewhat less effective: traffic cells, planned neighborhoods, zoning and building codes, incentives to use mass transit, communications in lieu of travel, carpooling, and two engineering approaches to improving capacity of existing roadways.

Congestion on arterials and freeways is considered to be best treated with surveillance and control systems, and transit priority systems. Road pricing, parking controls, New Towns, incentives to use mass transit, and carpooling also appear to be somewhat effective.

Where strong one-directional traffic flows are involved congestion may be most effectively reduced by engineering techniques that permit improved use of the existing roadway and extended-area services that promote mass transit ridership. Road pricing and extended-area transit are also believed to be best suited to congestion on bridges, tunnels, and other roadways where options for alternative routes are limited.

Costs of Implementation

The basic and possible additional costs of implementing the candidate techniques judged to be potentially effective in reducing peak-period traffic congestion were evaluated. Costs of implementation included direct costs of applying the technique itself and any secondary costs that may be incurred by the private sector or public agencies cooperating in its implementation by providing additional facilities or funding to improve its effectiveness.

The substitution of communications for travel on a scale large enough to have an impact on the problem is the most costly of the techniques, requiring a basic investment of $30 billion to $50 billion. New Towns offer the second most costly solution, ranging between $1 billion and $3 billion. In both cases private business interests would be responsible for implementation.

At the next highest level of cost are the techniques that require a basic investment in equipment and new construction. These include: freeway surveillance and control; priority transit systems on freeways, especially where a new lane is constructed for exclusive use of buses; and engineering improvements to maximize use of existing facilities.

Basic costs are lowest with techniques that rely either on modifying controls on land use and vehicle access or on persuading individual drivers to use their own vehicles in a different manner. Changes in zoning and building codes, as well as much of the planning for such changes, can be effected at no significant costs within the framework of normal city administrative activities. Indirect costs, however, may be very high, because the revised codes offer a new opportunity to upgrade private property and public facilities, and may even involve a major urban renewal effort. Restrictions on vehicle access require only a modest basic investment in barriers, street markings, and public information. Costs of programs to stagger work hours or encourage group riding in private vehicles are generally low.

Indirect Benefits and Disbenefits

Traffic Congestion in Other Parts of the Total System.—Area-wide improvement of traffic conditions would result from all solutions aimed at reducing the number of vehicles driven during peak commuting hours. These include both techniques that encourage higher vehicle occupancy through ride sharing, limiting parking, and promoting transit ridership, and techniques that reduce needs to travel either at peak times through staggering work hours or absolutely by bringing home and work closer together and substituting communications for travel to work.

Traffic congestion in other parts of the system can be aggravated, however, by techniques that restrict entry of vehicles, such as traffic cells, auto-free zones, road pricing, and freeway surveillance and control.

Long-Range Travel Demands and Patterns.—Travel demands are reduced significantly by land-use changes and substitution of communications for work-related trips. Techniques that restrict vehicle entry may eliminate some less essential trips and may eventually result in some relocation of residences and places of work, but their greatest impact would be felt in shifts to alternative routes. Shifts to alternative travel times could also be expected from these restrictive techniques, as well as from staggered work-hour programs.

None of the other techniques affect long-range travel demand and patterns.

Energy Consumption.—Savings in automotive fuels consumed by commuter trips could be expected to result from 13 candidate techniques. The most significant reductions would occur where basic needs to travel are lowered. Modal shifts to transit and group riding should also yield over-all savings.

The effect of the four techniques that operate through restricting vehicle access would be determined by drivers' responses to such restrictions. If they abandon trips, share rides or shift to public transit, fuel consumption would be reduced. Savings would also be realized through smoother traffic flow along controlled roadways. However, if drivers are diverted to alternative routes, energy consumption would remain the same, or even increase if the alternative routes are less direct.

Environmental Pollution.—Improvement in air quality can be expected wherever less automotive fuel is consumed and the amount of pollutants expelled by vehicle exhaust systems is reduced. Thus, the 13 candidate techniques identified as yielding savings in energy consumption would also reduce air pollution. Exceptions to this general rule can occur, however, in the case of transit solutions; increases in localized vehicle emissions may be observed at major bus terminal points in the CBD, particularly if the system is obliged to utilize old equipment with inadequate emission controls.

Public Safety.—Reductions in vehicle accidents and vehicle-pedestrian accidents would be expected generally as a result of improved traffic flow. Errors in planning for adequate access to reserved lanes or proper separation of vehicular and pedestrian movement, however, can create new hazards to public safety. The latter is particularly important in traffic cells, auto-free zones, New Towns, planned neighborhoods, and areas zoned for mixed land uses, where pedestrian travel is encouraged. Protected loading and unloading zones for transit riders must also be well planned.

Counter-flow express lanes for transit and carpools may increase the risk of head-on collision if not adequately marked and separated from traffic moving in the opposite direction. However, no systems currently in operation have been noted to increase the frequency of such accidents.

Economic Impacts.—Some temporary dislocation of business activity may accompany the initiation of parking controls, traffic cells, auto-free zones, and changes in land use accompanied by major urban renewal efforts. Long-range improvements in retail trade, value of property, and tax revenues are documented as the experience of urban areas where these programs have been carried out. Parking controls and ride-sharing programs allow both public and private employers to reduce parking facilities and put the reclaimed area to higher economic use. Business activity also tends to be stimulated by transit circulation systems in the CBD and improved mobility in suburban areas.

Road pricing programs, on the other hand, permanently discourage the use of certain routes and can result in economic losses through employee turnover and decreased business activity. The impact may be sufficiently critical to require the relocation of businesses or residences. New Towns may also generate costs to participants in excess of returns. Expenses of relocating families and businesses may not be compensated for by savings in lower land costs, and property taxes in the newly developed area may be very high. Replacing experienced personnel who do not wish to move out of the central city also adds to relocation costs. Finally, roads and public utilities must be extended to the new areas, usually at considerable expense to the state and local governments responsible for providing them.

Economic impacts of the remaining techniques are considered negligible.

Equity Considerations.—The five techniques that provide better and cheaper transit services are of particular benefit to those in the community who are poor, elderly, handicapped, or under driving age, who have no access to private transportation.

Four of the candidate techniques, however, impose unequal penalties on low-income workers, especially those who cannot easily shift to new job locations. Road pricing and parking controls that involve pricing penalties for all-day use work a special hardship on commuters who can least afford to pay but whose limited skills restrict their options for employment at other hours or at different locations. Planned neighborhood developments involving upgrading of residential facilities in city centers frequently result in higher rents and force low-income families to seek housing elsewhere. Communications substitutes for travel to work not only involve substantial user costs that place them beyond the reach of lower-income workers, but also are not applicable to manufacturing and service functions that are generally performed by low-income employees.

Institutional considerations, public.—None of the candidate techniques appears to involve serious disbenefits for public agencies either participating in programs or indirectly affected by them. Staggered work hours, ride sharing, road pricing, and parking controls may result in some employee turnover where the need to change commuting patterns creates problems for certain individuals.

Institutional considerations, private.—Private institutions are affected by traffic reduction techniques in much the same ways as are public agencies. Some immediate employee turnover can be expected from programs that force changes in existing commuter patterns, but reduced tardiness and improved productivity over the long run should outweigh this.

In general, private business profits by programs that discourage the use of private vehicles for commuting. Costs of providing for employee parking are reduced, and access to customers, clients and professional contacts is improved by the greater availability of short-term parking accommodations.

Time Factors

Two aspects of the timing of impacts are important in evaluating techniques of reducing traffic congestion. The first deals with lapse of time that must be expected between the adoption of a technique and the point at which benefits can be realized. Some programs, such as reallocating land uses, can be initiated immediately, but their full development and impacts on congestion will not occur for several years.

The second time factor concerns the duration of benefits that can be derived from applying the various techniques. Some techniques, such as maximizing the use of existing facilities, can be expected to result in immediate improvements in traffic flow, but such benefits will usually disappear as soon as more drivers are attracted to the improved routes.

Four techniques should present immediate benefits: staggered work hours, road pricing, parking controls, and carpooling. Three other techniques—New Towns, planned neighborhoods, and substitution of communications for travel to work—could not be expected to have significant impacts on congestion for at least three years. Similar delays in benefits can be expected where rezoning for multiple land uses is extensive and transit priority systems require new construction of freeway lanes for the exclusive use of buses. The remaining techniques should become effective between one and three years from initial adoption.

Maximizing the use of existing road facilities through engineering improvements and carpooling programs has been observed to provide only short-term benefits. It has also been seen that New Towns can suffer economic dislocations that force residents to commute to work in other communities. Other than these cases, reductions in peak-period congestion resulting from the application of candidate techniques could be expected to be lasting.

Obtaining Essential Institutional Support

Implementation of congestion-reduction programs relies on the support of public agencies for funding and technical assistance. Public support in both these areas is traditionally excellent for efforts to utilize engineering techniques to improve the capacity of existing roadways. Technological development of communications equipment and systems has also received substantial support from government, but no funding program yet exists to assist communities in implementing the large-scale substitution of communications for travel to work. Federal Highway Administration (FHWA) and Urban Mass Transportation Administration (UMTA) funding is available to support local implementation of staggered work hours, parking controls, carpooling, transit improvement, and incentives to mass transit use. Urban renewal and planning programs of the Department of Housing and Urban Development will provide funds to communities for revising zoning and building codes and developing planned neighborhoods and auto-free zones. Technical support in all these areas is evaluated as moderate to good.

Public Acceptance

Public acceptance of programs to reduce peak-period traffic congestion operates on two levels. First, each technique used must be generally approved of as a good thing for the community, carrying with it no serious penalties on any particular segments of the population, such as low-income or elderly. Second, the program must appear sufficiently attractive to gain the active participation of enough individual commuters to have an effect on traffic congestion. General approval often can be gained for programs that are perceived as inflicting only a small degree of inconvenience on the participants, but such programs will fail to be effective because individuals choose not to subject themselves to the inconvenience that they find theoretically tolerable for other people. To be successful, programs must offer the participants more than the satisfaction of contributing to a community effort to reduce traffic congestion. Initial enthusiasm for the scheme can fade rapidly and participation will decline unless the program offers tangible benefits to the individuals to compensate them for the inconvenience they suffer.

Public acceptance of the concept of the candidate techniques was evaluated as excellent or good in 14 cases, but willingness to participate in programs applying these techniques is found to be excellent or good in only 7 cases. Techniques for which general approval and the likelihood of an effective level of participation are both high are staggered work hours, traffic cells, auto-free zones, planned neighborhoods, communications substitutes for work trips, maximizing use of existing road systems, and transit circulation systems.

Public acceptance is evaluated to be most difficult to obtain for road pricing schemes. Public acceptance in specific applications of modifying zoning and building codes is often difficult to assure. Finally, willingness to participate in group riding, taking advantage of incentives to use transit, and tolerating freeway surveillance and control programs, are all evaluated to be only moderate compared to the general approval of these techniques in the abstract.

Acceptance by Private Organizations

Several of the candidate techniques need not only individual acceptance but also the active cooperation of private organizations. The support from private organizations necessary to carrying out congestion-reduction programs should be readily obtainable for ten of the candidate techniques. Programs improving and promoting the use of public transit can be expected to have the strong support of local transit authorities. Cooperation from employers in promoting carpooling and other ride-sharing arrangements has been found to be generally excellent.

Business institutions generally favor revisions in land uses that improve property values and permit more productive uses of space formerly devoted to parking. Some initial negative reactions to proposals for traffic cells and auto-free zones can be expected, especially from retailers who fear that customers may be driven elsewhere by restricting vehicle access to their shopping areas.

Intensive promotion is necessary to gain the cooperation of employers in staggered-hours programs. Support from private organizations is also difficult to obtain for road pricing and parking control schemes. Incentives in the form of relocation grants have been found necessary to obtain an adequate economic base for New Towns. Acceptance and support may be more readily available for programs of substituting communication for travel to work, however, if user costs can be kept to a minimum.

Compatibility with Existing Laws and Regulations

None of the candidate techniques requires major changes in existing laws. Some local regulations may need to be revised and new authority provided to carry out certain programs.

New authority to levy tolls will be necessary if road pricing is to be applied for the first time along a route, and new variable-toll schedules will have to be approved for roadways where user charges are already in force. Implementing parking controls through variable charges may also require a new taxing authority and approval of rates to be applied to privately owned parking lots.

Programs restricting vehicle access to traffic cells and auto-free zones will call for withdrawing certain streets from use by passenger vehicles and establishing regulations on their use by commercial vehicles. All techniques involving changes of road and land use, including the establishment of New Towns, will normally require their conformity to regional or city development plans. In some cases a new land-use plan will have to be approved by local government and zoning and building codes revised. Finally, in the case of New Towns, permission for incorporation must conform to existing state laws and the approval at that level of government.

State of the Art

All of the candidate techniques are technologically ready for implementation in some form. Procedures for implementation are well established for programs of staggered work hours, auto-free zones, ride sharing, improving the vehicle capacity of existing roadways, and providing transit services.

The technology for carrying out road pricing by metering vehicles is theoretically available, but practical application is not feasible at this time. Implementation of road pricing is currently feasible, however, through the simpler method of varying tolls collected from drivers prior to their use of bridges, tunnels, or expressways. Technology for parking control programs is also adequate, although more needs to be known of the effectiveness of different rate schedules.

Programs involving modifications to land use—New Towns, planned neighborhoods, and zoning and building codes—represent a special situation with regard to technological readiness for implementation. Techniques of physical planning are highly developed, but far too little is understood of the social and economic implementation.

Finally, the substitution of communications for travel to work is currently feasible with existing types of equipment. Improvements in equipment to lower costs and increase performance capabilities are needed to improve both consumer acceptance and the attractiveness of system implementation to privately owned communications companies.

PACKAGING TECHNIQUES FOR GREATER EFFECTIVENESS

Seventeen candidate techniques were finally selected as both effective and feasible. However, none was found to offer more than marginal reductions in peak-period traffic congestion when applied individually. Some techniques, such as planned neighborhoods, affect so small a percentage of CBD commuters that reductions in congestion resulting from one of these redevelopment projects would not be discernible in any large city. Other techniques, such as carpooling, present the promise of significant impacts on congestion in theory, but have never realized that promise in practice.

It was noted, however, that many of the techniques could be implemented in combination, with the potential for far greater combined effectiveness than when applied singly. Carrying out packages of compatible techniques under one coördinated program can not only improve the benefits that can be realized from the most promising techniques, but also achieve significant results from techniques that individually are only minimally effective. Carpooling, for example, supported by road pricing programs that selectively penalize single-occupancy vehicles, can promote greater and longer lasting participation in group commuting than without this additional incentive. As another example, the individual techniques of peripheral parking, transit circulation systems, and auto-free zones, none of which in themselves are capable of eliminating more than a small percentage of CBD rush-hour congestion, can be highly effective when implemented in support of one another. Much greater benefits can be obtained if people destined for downtown locations in and around the auto-free zone can leave their cars in outlying parking lots located convenient to their entry routes and be carried by transit vehicles to and from their CBD destinations.

Analysis of the compatibility of the candidate techniques suggested eight "packages" of solutions that could successfully be applied within coordinated congestion-reduction programs. Each of the packages has been specifically selected to treat one or more of the congestion problems commonly found in urban areas. Combinations of congestion-reduction techniques other than the eight described here are also feasible, and may be suggested by local conditions. However, these eight packages were selected as generally applicable to a large number of urban areas.

The selection process, involving analyses of compatibility of techniques and applicability of combinations of techniques to different types of congestion problems, is discussed in the following, followed by descriptions of each of the eight recommended program packages.

Selection of Packages

Packages of effective combinations of congestion-reduction techniques were selected on the basis of two criteria: the compatibility of the individual candidate techniques and the applicability of combinations of techniques to different types of congestion problems.

Compatibility of Techniques

The compatibility analysis was carried out in two stages. First, the impact of combining pairs of techniques was examined by developing a matrix listing all 17 candidates on both axes. Next, the matrix was rearranged according to the relative compatibility of the pairs to suggest whole groupings of techniques that could successfully be combined within a single program package.

Figure 1 shows the first-stage matrix, in which the relative compatibility of pairs of techniques is indicated as mutually supportive (+), neutral (0), or conflicting (—). Mutually supportive combinations range from (a) those where application of the techniques together yields an effect greater than the sum of the two implemented individually to (b) those in which one technique will fail to improve traffic conditions unless it is accompanied by another complementary technique. Conflicting combinations may range from those that can yield somewhat less than the sum of their individual effectiveness when implemented simultaneously to those that can render each other ineffective or even create a further traffic problem.

It will be noted that some of the relationships vary, depending on whether a technique is being considered in a basic or a supportive role. For example, carpooling is supported by a transit circulation system that can provide noon-hour mobility for those who have not driven their own cars to work. But transit circulation, as a link in an integrated regional system carrying commuters to and from their jobs during rush hours, can be negatively affected by a carpooling program that competes for the same rides. Similarly, traffic cells and auto-free zones require the support of engineering techniques on perimeter roads to accommodate vehicles displaced by restricting their entry into these areas. However, efforts to increase the capacity of commuter routes as a solution to peak-period traffic congestion are hampered by creation of new congestion problems that accompany development of vehicle-restricted areas.

In some instances it was difficult for the researchers to select a single indicator of the relationship of a basic technique to others. Certain techniques affect congestion differently in different places. Rezoning suburban residential communities for commercial and industrial development, for example, may relieve congestion in the CBD, but may create new problems in the rezoned area. Controlled entry to freeways may facilitate traffic flow to the extent that it encourages long-distance commuters to drive into the central city and increase congestion there. In addition, certain combinations of solutions can be beneficial under one set of conditions and destructive under a different situation. For example, auto-free zones too large to be covered easily by walking need some form of internal public transit system for circulation, but when the area is very large and heavily used the amount of transit service necessary to provide adequate circulation can prove disruptive to the pedestrian environment.

To solve this dilemma, two guidelines were adopted:

1. Where combinations of techniques impacted differently on different parts of the community, the symbol selected would represent the anticipated effect on congestion in the CBDs of large urban areas.
2. Where impacts would vary according to the conditions under which the techniques were applied, the rating would reflect the effect of combining the techniques under the most common conditions.

Thus, pairs of techniques that relieve congestion on freeways but contribute to CBD congestion are shown as incompatible. Similarly, where combining two techniques improves their performance in CBDs of small cities, but does not affect their impact on CBD congestion in large cities, the relationship is shown as neutral. Finally, where the relationship between pairs of techniques will be modified by attendant circumstances, the rating shown assumes an average urban environment and project size.

Although the symbols represented in the matrix suggest combinations of techniques particularly suited for the CBDs of large cities, the researchers made note of other combinations that were effective in treating other types of congestion problems. These additional evaluations were later brought into the final selection of packages so that they would include recommended programs for reducing peak-period congestion in all the critical problem areas.

In general, it was found that improvements in driving conditions work counter to efforts to shift commuters from their own cars onto public transit or to participate in ride-sharing programs. Penalties associated with driving, on the other hand, support these efforts, as well as attempts to reduce over-all travel by changing land uses and substituting communications for work trips. All transit improvement and incentive techniques are mutually supportive to a high degree. Carpooling, which in itself appears to be a moderately effective and inexpensive approach, does not blend well with many other approaches; efforts to reduce travel demands by changing land use, to spread peak commuting times, to provide transit alternatives, or to improve traffic flow through improvements to roadways all reduce the motivation for participating in prearranged ride-sharing.

Figure 2 shows the second-stage matrix, in which compatible pairs of techniques were rearranged in light of these general observations to suggest larger groupings of techniques that might successfully be combined into program packages. Clusters of mutually supportive techniques were possible to identify, even though the matrix did not present a perfect fit, and some of the values assigned in the earlier matrix had to be adjusted.

Each of the clusters circled on the matrix corresponds generally to one of the eight recommended packages of congestion-reduction techniques. The boundaries of the clusters were drawn in part by subjective judgments based on known characteristics of the individual techniques and the degree to which they were compatible with others.

The packages were each focused on a central technique or combination of highly interrelated ones and assigned the following designations:

1. Work-hour changes.
2. Pricing techniques.
3. Restriction of access.
4. Changes in land uses.
5. Prearranged ride sharing.
6. Communications substitutes for travel.
7. Traffic engineering techniques.
8. Transit treatments.

Applicability to Types of Congestion Problems

The eight packages of techniques suggested by the second-stage matrix were then evaluated for their applicability to different types of congestion problems. When matched against the five major kinds of congestion identified as common to many urban areas, the packages were found to have different degrees of relevance to these problems.

The components of the packages were modified, where necessary, to make them more effective. Four of the packages were designed with slightly different alternative combinations of techniques to make them applicable to different types of congestion problems.

Table 1 gives the applicability of the modified packages of congestion-reduction techniques to the five major problem areas. All of the eight packages would be effective in the CBDs of large cities. Modified forms of pricing techniques, entry restriction, and transit techniques are suggested for application to CBDs of small cities and suburban activity centers, along with the basic traffic engineering package recommended for larger CBDs.

Peak-period congestion on urban freeways and major arterials can be treated with six of the eight packages, with some modifications of traffic engineering and transit techniques from those recommended for CBD implementation. These same modified packages can also be applied to roadways with strong one-directional flows, along with the package of changes in land use. Congestion on roadways presenting limited options for alternative routes, such as bridges and tunnels, can be reduced through road pricing, land-use, and communications packages, and the traffic engineering combination of techniques recommended for freeway congestion.

Components of Recommended Packages

Figure 3 identifies the eight congestion-reduction packages finally selected and indicates the individual techniques each includes. These component techniques are indicated by asterisks (*). Other techniques are indicated as options

BASIC TECHNIQUE \ SUPPLEMENTARY TECHNIQUE	Staggered Work Hours	Road Pricing	Parking Controls	Traffic Cells	Auto-Free Zones	New Towns	Planned Neighborhoods	Zoning and Building Codes	Transit Marketing	Carpooling and other Ride Sharing	Communications in Lieu of Travel	Freeway Surveillance and Control	Maximum use of Existing Facilities	Transit Circulation	Priority Systems: Arterials	Priority Systems: Freeways	Extended-area Transit
Staggered Work Hours		+	+	O	O	O	O	O	+	—	+	—	—	+	+	+	+
Road Pricing	+		+	O	O	+	+	+	+	+	+	—	—	+	+	+	+
Parking Controls	+	+		+	+	O	O	+	+	+	+	—	—	+	+	+	+
Traffic Cells	O	O	+		+	O	+	+	+	O	O	+	+	+	+	+	+
Auto-Free Zones	O	O	+	+		O	+	+	+	O	O	+	+	+	+	+	+
New Towns	O	+	+	O	O		+	+	+	—	+	—	—	—	—	—	+
Planned Neighborhoods	O	+	O	+	+	+		+	+	—	O	O	+	+	—	—	—
Zoning and Building Codes	O	+	+	+	+	+	+		+	O	O	O	O	O	—	—	—
Transit Marketing	+	+	+	+	+	O	O	O		—	—	—	—	+	+	+	+
Carpooling and other Ride Sharing	—	+	+	O	O	—	—	+	—		—	—	—	+	—	—	—
Communications in Lieu of Travel	+	+	+	O	O	+	O	O	—	—		—	—	—	—	—	+
Freeway Surveillance and Control	+	+	—	—	—	+	+	+	—	+	+		—	—	—	—	—
Maximum use of Existing Facilities	—	—	+	+	—	+	+	+	—	+	+	—		—	—	—	—
Transit Circulation	+	+	+	+	+	O	O	+	+	—	—	—	—		+	+	+
Priority Systems: Arterials	+	+	+	+	+	—	—	O	+	—	O	—	—	+		+	+
Priority Systems: Freeways	+	+	+	+	+	—	—	O	+	—	—	—	—	+	+		+
Extended-area Transit	+	+	+	+	+	+	—	O	+	—	+	—	—	+	+	+	

Figure 1. First-stage matrix showing the compatibility of the candidate techniques.

	Carpooling	Zoning and building codes	Planned neighborhoods	New Towns	Communications	Traffic cells	Auto-free zones	Staggered work hours	Parking controls	Road pricing	Circulation	Transit priority: arterials	Transit priority: highways	Extended-area services	Transit incentives	Maximum use of existing facilities	Freeway surveillance and control
Road pricing	+	0	0	0	+	+	0	+	+	+	+	+	+	+	+	-	-
Parking controls	+	+	0	0	+	+	0	+	+	+	+	+	+	+	+	-	-
Staggered work hours	-	0	0	0	0	0	0	+	+	+	+	+	+	+	+	-	-
Auto-free zones	0	+	+	0	0	+	+	0	0	0	+	+	+	+	+	0	0
Traffic cells	0	+	+	0	0	+	+	0	+	+	+	+	+	+	+	+	+
Maximum use of existing facilities	-	+	+	0	-	+	0	-	-	-	-	-	-	-	-	+	+
Freeway surveillance and control	-	0	0	0	0	+	0	-	-	-	-	-	-	-	-	+	+
Zoning and building codes	+	+	+	+	0	+	+	0	+	0	0	0	0	0	0	+	0
Planned neighborhoods	0	+	+	+	0	+	+	0	0	0	+	0	0	0	0	+	0
New Towns	-	+	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0
Communications	-	0	0	+	+	0	0	0	+	+	-	-	-	-	-	-	0
Carpooling	+	+	0	-	-	0	0	-	+	+	+	-	-	-	-	-	-
Transit incentives	-	0	0	0	-	+	+	+	+	+	+	+	+	+	+	-	-
Circulation system	+	+	+	0	-	+	+	+	+	+	+	+	+	+	+	-	-
Transit priority: arterials	-	0	0	0	-	+	+	+	+	+	+	+	+	+	+	-	-
Transit priority: expressways	-	0	0	0	-	+	+	+	+	+	+	+	+	+	+	-	-
Extended-area services	-	0	0	0	-	+	+	+	+	+	+	+	+	+	+	-	-

Figure 2. Second-stage matrix showing mutually supportive techniques arrayed to suggest program packages.

for implementation with the basic packages—those that would improve over-all effectiveness are identified by the plus (+) symbol; those that would simply add another independent increment to the total impact on congestion and not detract from the effectiveness of the basic package are identified by the zero (0); techniques that should be avoided when selecting supplementary activities to combine with recommended packages are identified by the minus (—) symbol.

The techniques of this last group work in conflict with the major thrust of the particular package and, if implemented simultaneously, would lessen its effect in reducing peak-period congestion. As an example, the "work-hour changes" package basically combines five individual techniques:

1. Staggered work hours.
2. Road pricing.
3. Parking controls.
4. Transit marketing.
5. Extended-area transit.

Communities implementing this package can improve its effectiveness if local resources permit addition of programs to develop priority transit services on freeways and arterials and a CBD transit circulation system. Conversely, they are cautioned against simultaneously attempting carpooling and other ride sharing, freeway surveillance and control, or maximizing use of existing facilities in the same location, as these techniques are potentially conflicting. All other techniques may be added as options without reducing the effectiveness of the basic program.

Some communities may wish to undertake a large-scale, intensive program to alleviate peak-period traffic congestion by simultaneously implementing two or more packages of techniques. All of the packages can be safely applied within a coordinated effort as long as conflicting approaches are directed to different problem areas. For example, transit treatments may be utilized for heavily traveled corridors between medium-density suburbs and the CBD while prearranged ride sharing is promoted for commuter trips between lower-density residential areas and large industrial developments outside the city center. However, if both

TABLE 1

APPLICABILITY OF EIGHT PACKAGES OF TECHNIQUES IN TREATING FIVE TYPES OF COMMON PEAK-PERIOD CONGESTION PROBLEMS*

Package of Congestion-Reduction Techniques	Major Problem Areas: CBDs of Large Cities	Major Problem Areas: CBDs of Small Cities and Suburban Activity Centers	Major Problem Areas: Urban Freeways and Major Arterials	Special Problem Areas: Roadways With Strong One-Directional Traffic Flows	Special Problem Areas: Roadways With Limited Options for Alternative Routes
Work-Hour Changes	X		X		
Pricing Techniques	X(1)	X(2)			X(3)
Access Restriction	X(1)	X(2)			
Land-Use Changes	X	X	X	X	X
Prearranged Ride Sharing	X		X		X
Communications Substitutes for Travel	X		X		X
Traffic Engineering Techniques	X(1)	X(1)	X(2)	X(2)	
Transit Treatments	X(1)	X(1)	X(3)	X(3)	X(3)

*Some of the packages are modified for application to different types of peak-period traffic congestion problems and conditions. Most indicate that more than one version of that package of techniques has been designed, and only version 1, 2, or 3 is recommended for treatment of that particular congestion problem.

programs are attempted along the same commuter routes, they will compete for the same riders, and neither program will be as cost-effective as if it had been implemented by itself. The demand densities necessary for the efficient functioning of both modes will be difficult to achieve in the competitive situation.

Difficulties can also arise in attempting to combine these recommended packages because one of the techniques in the first package is in conflict with one technique in the second, even though the principal elements of the packages are compatible. Thus, the packages of changing land uses and traffic engineering approaches should not be applied in the same area, because the transit elements on which the former heavily depends are incompatible with improving freeway capacity through surveillance and control. Improvements to local streets, however, are supportive of the land-use package and should be added as a separate technique rather than attempting to adopt the entire traffic package that is inherently in conflict.

Figure 4 identifies compatible packages of techniques, as well as combinations that should be avoided. Again, supportive, neutral, and conflicting relationships are indicated by +, 0, and — symbols, respectively. The compatibility ratings summarize complex relationships that are discussed in detail in following sections devoted to each of the packages. In some cases the degree of compatibility varies, depending on whether the package is being considered as the focus of the program, indicated in the table as a "basic" package, or functions as a "supplementary" package.

Package No. 1: Changes in Work Hours

This package affects peak-period traffic congestion by redistributing the times at which the largest number of peak-period trips are made. By staggering work start and stop times, work trips are distributed over a longer period and travel demand at any one time in the traditional peak is lessened. In formal staggered-hours programs, new start and stop times are staggered appropriately, reducing the peak demand for a number of travel facilities, including the road network, transit stops and stations, parking lots, PACKAGE

INDIVIDUAL TECHNIQUE	WORK-HOUR CHANGES	PRICING TECHNIQUES	RESTRICTING ACCESS	LAND-USE CHANGES	PREARRANGED RIDE SHARING	COMMUNICATIONS SUBSTITUTE FOR TRAVEL	TRAFFIC ENGINEERING TECHNIQUES	TRANSIT TREATMENTS
Staggered Work Hours	*	+	0	0	-	0	+	+
Road Pricing	*	*	0	+	*	*	-	+
Parking Controls	*	*	+	+	*	*	+	+
Traffic Cells	0	0	*	+	0	0	-	+
Auto-free Zones	0	0	*	+	0	0	-	+
New Towns	0	+	0	*	-	*	+	0
Planned Neighborhoods	0	+	+	*	0	0	+	0
Zoning and Building Codes	0	+	+	*	+	+	+	+
Incentives to Transit	*	*	+	+	-	-	-	*
Carpooling and Other Ridesharing	-	*	-	0	*	-	+	-
Communications in Lieu of Travel	+	+	0	+	-	+	0	-
Freeway Surveillance and Control	-	-	+	-	-	-	*	-
Maximizing Use of Existing Facilities	-	-	*	+	-	-	*	-
Transit Circulation	+	*	*	+	+	-	-	*
Priority Transit: Arterials	+	*	+	-	-	-	-	*
Priority Transit: Expressways	+	*	+	-	-	-	-	*
Extended-Area Transit	*	*	+	+	-	-	-	*

* Component of the Basic Package
\+ Supportive Technique
0 Neutral
\- Conflicting Technique

Figure 3. Matrix showing the relationship of individual techniques to packages.

BASIC PACKAGE \ SUPPLEMENTARY PACKAGE	Work-Hour Changes	Pricing Techniques	Restricting Access	Changing Land Uses	Prearranged Ride Sharing	Communications Substitutes	Traffic Engineering	Transit Treatments
Work-Hour Changes		+	0	0	-	+	-	+
Pricing Techniques	+		0	+	-	0	-	+
Restricting Access	0	0		+	-	0	+	+
Changing Land Uses	0	+	+		0	+	-	-
Prearranged Ride Sharing	-	0	0	0		0	-	-
Communications Substitutes	0	+	0	+	-		-	-
Traffic Engineering	+	0	-	+	-	0		-
Transit Treatments	+	+	+	0	-	0	-	

+ Supportive　　0 Neutral　　- Conflicting

Figure 4. Matrix showing the compatibility of packages.

and elevators in tall buildings. In flexible-work-hours programs, the lack of congestion in off-peak periods induces workers given the choice to reorient their work trips to off-peak periods. A number of other techniques are combined here with both types of work-hours changes to ensure that transit riders do not revert to commuting by auto and to induce other employees to switch to transit use. A schematic of this package, including its individual components and supportive and conflicting techniques and packages is shown in Figure 5.

Staggering of work hours may reduce peak-period congestion by spreading work trips over a longer morning and evening peak. Theoretically these work-hour changes have the potential to either positively or negatively affect transit use. In practice, when coordinated with the needs of an existing transit system, staggered work hours have been able to make significant improvements in transit system operating efficiency and even to increase ridership. This package proposes combining either type of staggered work-hours program, planned in cooperation with the transit system, augmented by inducements to transit use.

Inclusion of road pricing and parking controls in this package is designed to provide incentives to mass transit use by increasing the cost of commuting by auto relative to transit cost during the work-commute period. The road pricing techniques envisioned for use in this package are existing road pricing techniques (i.e., gasoline taxes and tolls) rather than other more exotic or sophisticated approaches. Parking controls could consist of either parking charges or reduction of parking spaces by participating firms or municipal authorities, or both.

Naturally, transit service on both sides of the present peak will need to be increased to accommodate changes in travel times. As an added incentive to transit use during this period, fares on line-haul express bus services would be reduced during underutilized portions of the morning and evening commute periods. Further marketing activities should include an informational campaign and provisions for consumer feedback on the new service. Extended-area transit services (such as park-and-ride programs) should be examined with the idea of establishing or expanding such services. In larger cities of certain geographic configurations, feeder services to express routes may have to be provided; but this option should be carefully studied for financial feasibility and the impact on the current operating practices of the transit system.

The combination of these techniques should create a complex of incentives that would more than offset any tendency for current transit riders to switch to auto driving when work starting times are spread out, and both provide an additional incentive to existing car drivers to switch to transit use. It is important that the incentives to transit use are constructed so as to bring riders to the system during periods when the system has excess capacity; any other option would have dysfunctional consequences for the transit system. If used in the appropriate situation and in the right context, this package can reduce congestion on the transit systems and to a lesser extent the road system in peak periods.

Compatibility with Other Approaches

As shown by Figure 5, several techniques and packages are compatible with this package. The individual supportive techniques in general seek to make transit a more attractive option for commuters. Priority transit treatment can speed the home-to-work trip, making it comparable with travel times by auto. Circulation systems further increase the attractiveness of transit by making it possible to travel in a CBD or large employment concentration without a car. Substitution of communications for travel to work can also be supportive, because the reduced number of trips to the centrally located office that will still be required can be made at off-peak hours. Transit treatments and communications substitutes for travel are compatible packages for the reasons previously discussed. Pricing techniques is also included as a supportive package because its main components are a basic component of this package.

The conflicting techniques and packages in this case can be considered as two separate types of incompatibility. Carpooling as a technique or as the main component of the ride-sharing package is in direct conflict with a change-in-work-hours package. Evaluation of several staggered-work-hours programs has shown inability to form and maintain carpools to be a major disadvantage and a frequent source of employee dissatisfaction. Maximizing use of existing facilities as an individual technique or as one of the main components of the traffic engineering package presents a different type of incompatibility. Because this technique increases traffic capacity, it would encourage auto travel and tend to work against the transit incentives offered by this package.

Applicability

The staggered work hours and entire package of transit services and incentives make this package applicable to cities of any size that have congested downtown areas. It would work best when applied to medium or large cities where the following conditions apply:

1. One or more major employment concentrations in or near the CBD; the fewer the number of employers the better.
2. Existing transit service.
3. Suburban commuter trips of at least 8 miles.
4. Highways that provide direct routing to employment concentrations.

Staggered work hours alone have the potential to relieve peak-period traffic congestion in any dense employment concentration, whether composed of one employer or many. If sufficient workers switch to transit, arterial congestion around the actual employment concentrations will be reduced, as well as traffic delays due to ingress and egress from parking facilities. This package requires that a transit service currently exist that need only be modified slightly, if at all, to provide an attractive alternative to the car to those employees with new work hours. If a major new service is required, or major modifications must be made in existing service patterns, transit systems will be understandably unwilling to cooperate; evidence exists that such changes may lose them substantial sums of money. On the other hand, the transit system is a valuable ally in any plan to stagger work hours when it feels its needs are being well served. If new express bus service is required, a situation must exist where the variable road pricing scheme will ensure sufficient ridership along a given route; as indicated earlier, this usually requires a line-haul trip of at least 8 miles. It is important that the worker see a trade-off between transit service and private auto use on the same trip. A corollary to this requirement is that direct highway routing to major employment concentrations must exist so that express bus service can be provided along a convenient route, and so that a system of variable road pricing can be instituted manually on just a few major highways. If auto travel patterns are too diffuse, a far more sophisticated, and far more expensive, method of road pricing would be required, but probably would not be justified for such a situation.

Costs and Effectiveness

Direct Costs and Benefits.—The costs of this package can be broken down into three categories:

1. Pre-implementation costs for staggered work hours.
2. Transit system expenditures.
3. Road pricing equipment and facilities.

Actual experience has shown that the fewer the number of individual employers involved, the lower the initial staff costs. In addition, some transit operations are willing to cover the entire pre-implementation costs themselves because of the increased operating efficiency they see as the successful result of this technique. It is difficult to generalize about the costs of actually organizing the work schedule changes; the New York system has spent over $50,000, whereas the far more successful Ottawa system reports marginal pre-implementation costs.

If planned properly, costs to the transit system should

Component Techniques of the Basic Package

Staggered work hours	Road pricing
Parking controls	Incentives to transit
Extended-area transit	

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Priority transit, arterials	Traffic cells	Carpooling and other ride sharing
Priority transit, expressways	Auto-free zones	Freeway surveillance and control
Transit circulation	New Towns	Maximizing use of existing facilities
Communications in lieu of travel	Planned neighborhoods	
	Zoning and building codes	

Supportive Packages	Neutral Packages	Conflicting Packages
Transit treatments	Changes in land use	Prearranged ride sharing
Communications substitutes for travel	Restriction of access	Traffic engineering techniques
Pricing techniques		

Figure 5. Schematic of package No. 1: Changes in work hours.

be small and more than offset by increases in ridership. As noted at length earlier, if the staggered work hours plan is not well coordinated with the needs of the transit system, the system may find that it has to increase service at costs far beyond any increased ridership revenue. Because most U.S. transit systems have little means to subsidize such operating losses, the transit system may well refuse to continue its involvement with such a scheme. If the transit system is required to institute a new express bus line-haul service, with or without feeder bus service, it may incur additional expenses because express bus routes often poorly utilize existing equipment. In this case, it may be necessary to use revenues from the road pricing scheme to subsidize the express bus service.

As discussed earlier, the major beneficiaries of most American and Canadian work schedule changes have been transit systems that were able to make use of formerly underutilized capacity by diverting existing transit riders to the slopes of the peak-period curve and, in some cases, by attracting new transit ridership. The effect of such staggered schemes has been felt far less on the arterial and road network; although congestion was reduced in the vicinity of a single plant or parking facility, most schemes have not produced measurable reductions in total traffic congestion. The technique of manual road pricing during peak periods has been added, therefore, to increase auto to transit diversion to a point where traffic flows are noticeably speeded up; again no hard data are available on the amount of transit diversion and ultimate traffic reduction that can be expected from such a measure. To make transit even more attractive vis-a-vis the auto, transit fares have been decreased during underutilized periods (which may be the entire peak period for some transit systems) and provided first-rate transit service—express line-haul bus service. System-wide fare reductions bring increased transit ridership, although the number of former peak-period auto drivers is not known; combined with significant express bus service of more than 8 miles, it is not unlikely that transit ridership could increase by from 12 to 15 percent in the morning and evening peaks. Express bus service in the correct market areas has been entirely successful and, as illustrated in Knoxville, more than pays its own way.

The most significant cost factor in the implementation of this package would be the costs of road pricing and parking controls. Where a toll system already exists on congested expressways, bridges, or tunnels the costs of implementing variable user charges would be minimal. Development and monitoring of a fee schedule and any lane marking could be done for $50,000 or less. Where no such facilities exist, a toll system on a major roadway could be constructed for between $250,000 and $510,000, with annual maintenance and operations costs of between $75,000 and $100,000. In both cases the costs could most probably be met by the revenue generated from the new tolls. The cost of a parking controls program can vary widely, depending on the extent of the program; from a few thousand dollars for a new parking meter system up to $150,000 for a system of parking taxes in privately-owned facilities. Again, the additional revenues generated should be sufficient to cover the costs involved.

It should be noted, therefore, that this package, if properly implemented, would essentially pay for itself. Although this package does not recoup any revenue that might be gained from decreased traffic congestion around concentrated employment sites or the CBD, it does allow the costs of implementing staggered work hours to be assessed against the benefits to the transit system of generating new ridership and revenues with previously unused capacity. At the same time it allows revenues from road pricing and parking controls to offset their cost.

Indirect Impacts.—This package as a whole will have the effect of reducing energy consumption and air pollution to the extent that it reduces travel by automobiles. In addition, staggered work hours have a number of impacts on the firms involved. Several studies have reported that staggered work hours lead to higher employee morale, decreased sick leave, reduced turnover, and increased productivity. An evaluation of the Manhattan program also reported highly favorable effects on home life and evening activities. Road pricing and parking controls have the ability to positively or negatively affect business activity, as discussed later. Finally, the transit techniques included in this package will have varying equity considerations, depending on the programs implemented, and these factors should be considered in the selection of a specific program.

Timing.—Staggered work hours can be implemented very quickly, but it is imperative that the proper pre-implementation studies be made. It is necessary to assess the times and points of greatest traffic and other congestion during the peak period and set up the varying work schedules to act on those types of congestion. It is also crucial that the plan be discussed at length with the transit operator involved *prior* to its implementation. All necessary pre-implementation work can be done in less than six months but, as discussed earlier, there must be a continuing effort after the plan is implemented to make any changes in transit service that are necessary and to continue to work with non-staggered employers. Parking controls and a road-pricing fee schedule require a similar lead-in time. However, should it be necessary to construct toll facilities or create a toll authority, either of these activities would require from one to two years.

Feasibility

Institutional Considerations.—As indicated previously, successful staggered work hours programs have been organized and operated by a variety of groups, ranging from private firms to public agencies. Because this package will probably be adopted by cities, they may choose to place the staggered work hours program under the authority of an existing city agency or create a new agency for this purpose. Regardless, the authority for this program should rest in a single agency, and this agency should be certain to involve all other appropriate agencies, from regional councils of government to local chambers of commerce, in planning and implementing the program. As mentioned previously, the local transit operator, whether a private company or public agency, must also be involved in planning a staggered work hours program. In addition, the transit operator will have the primary responsibility for the marketing and extended-area transit service components of this package. In most cities, it will be necessary to establish a toll authority to implement a road pricing program. It may also be necessary to obtain state or federal approval to impose tolls on roadways built with state or federal funds. Depending on the type or extent of parking controls desired, this component could be operated by a city agency or it may be advisable to create a local parking authority. Funding for both the staggered work hours and transit components of this package is available from UMTA and FHWA.

Public Acceptance.—Staggered work hours and the kinds of transit services used in this package are generally very popular and should face no problems with public acceptance. On the other hand, road pricing and parking controls are relatively untried techniques that may be misunderstood by the public. It will be necessary to educate the public and public officials on the merits of these techniques and their role in this package, in order to assure public support. However, because it would be difficult for individuals to support this program without massive support from the private sector, acceptance by private organizations is the key to successful implementation of this package.

Acceptance by Private Organizations.—The most successful staggered work hours projects have involved a few employers with a significant percentage of the work force in a concentrated area; in Ottawa the federal government, which staggered its work hours, employed 53 percent of the work force in downtown Ottawa. The more individual employers involved, the more difficult the pre-implementation task becomes; the Manhattan experience shows that such public relations and planning efforts must be a continuously on-going function of some responsible agency. The Atlanta experience shows what happens when such effort is not forthcoming. Thus, although the idea is popular, this package requires great energy to overcome initial inertia and some resources to continue the promotional effort.

There may be some initial resistance to the parking control and road pricing components of this package by CBD merchants and owners of private parking lots. However, the experience of London with parking controls has been that short-term parking increases, which should increase business for both groups. Conversely, large employers participating in this program should welcome the opportunity to reduce the number of parking spaces they supply. A system of road pricing by tolls is certain to have negative impacts on CBD business activity. However, its effects can be reduced by graduating tolls according to the time of day or imposing tolls in peak periods only.

It is also imperative that the transit operator either be an active part of the projcct or a willing cooperator, or the transit services necessary will not be forthcoming and the potential benefits of this package for the transit system will be lost. In general, experience shows that the more involved the transit system is in the planning of the program, the more likely it is to be successful and the more likely needed changes in transit service that come to light during the course of the project will be made.

Although transit operators are often public agencies and not private firms, this is no guarantee of their cooperation, especially if the package is not tailored to their specific needs and financial resources. The same is true of public agencies that are large employers; their cooperation is far from automatic, as the Atlanta experience shows. This package requires an active and continuing promotional and informational campaign by some form of permanent staff.

Compatibility with Existing Laws.—There should be no problems with legal restrictions on the staggered work hours or transit components of this package. Legal problems may exist where it is necessary to establish a new toll authority or impose tolls on roadways that were constructed with state or federal funds. However, state and federal cooperation can be expected in this matter. Where parking controls involve taxes in privately owned lots, local laws will probably have to be changed.

Readiness for Implementation.—There are no activities or techniques in this package which are not currently feasible. Although there is need for a pre-implementation study that directly relates the existing techniques to localized conditions and local transit operations, there will be no delay in implementing this package because the techniques themselves are not ready.

It should be noted that although there have been several successful programs of staggered work hours and transit treatments, there is apparently no instance where all five techniques in this package were combined into a single program. This leads to the belief that though pricing techniques would definitely strengthen such a program, it is possible to exclude their use, especially in medium-sized cities. If a city is unsure of pricing techniques, they can be implemented separately.

Package No. 2: Pricing Techniques

This package of approaches is centered around imposing variable charges for the use of congested roadways to discourage peak-period commuting and supporting this disincentive by manipulating the supply and cost of parking in the central city. It assumes that road charges will be imposed by means of tolls collected on entry to the controlled roadways, rather than by complex systems of onboard or off-vehicle sensing devices and metering, which the study team believes to be impractical for current implementation. The package includes transportation alternatives to the individual use of private automobiles for peak-period commuting in the form of transit and carpooling. Figure 6 shows the composition of this package and its relation to other techniques and packages.

Tolls are varied so as to penalize drivers traveling alone in their own vehicles during peak commuting hours. Off-peak travel is encouraged by reducing tolls between rush hours to favor commuters taking part in staggered work-hours programs and to persuade those who shop or visit cultural and recreational facilities in the central city to complete their trips at times when they do not compete with commuters for use of the roadway. To encourage carpooling, tolls also are reduced during commuter peaks for vehicles with multiple riders.

The supply and cost of parking in the central city are manipulated to achieve the same purposes. Parking space in the CBD is reduced by prohibiting on-street parking during peak periods, and limiting it at other times to periods of two hours or less. This allows the customers of retail, service, and other businesses to continue to patronize these establishments, but prevents all-day parking by commuters. Parking fees are graduated so that short-term use is cheap and all-day use is prohibitively expensive. This is implemented in public lots by a system of variable fees, and in privately owned lots by imposing a graduated tax on parking that is passed directly on to the consumer. Special reductions in all-day parking fees can also be allowed to vehicles with extra passengers as an additional inducement to ride sharing.

Selection of effective schedules of variable road and parking prices will probably require some experimentation at the beginning of the program. In general, the more critical the congestion problem, the more severe the penalties must be so as to discourage a significant number of automobile commuters from using overcrowded facilities during peak periods. A small differentiation in peak versus nonpeak road tolls or all-day versus short-term parking fees will discourage only trips of marginal urgency—such as shoppers getting an early start—and have little effect on the major factor in the problem, the daily commuter.

However, if a program of pricing and supply disincentives is to be effective, there must be alternatives to the existing peak-period use of overcrowded facilities to which commuters can turn. It is essential that the capacity of the transit system be improved and ride-sharing programs be promoted prior to the initiation of pricing penalties. If these options are not available the imposition of penalties on individual commuting by private automobile not only will be ineffective in reducing peak-period congestion, but also will create resentment against the concept itself, which may preclude its being attempted again with better preparation.

The transit treatments recommended for this package include priority services on expressways and arterials to make transit even more competitive to automobile use by reducing travel times. Supporting services in the form of downtown circulation systems and local transportation in residential areas will improve ridership of the express service. A CBD circulation system can provide transit riders with greater mobility during the day. Dial-a-ride feeder services to suburban express stops would provide the most attractive form of residential transportation service, but in some areas park-and-ride lots may be a more viable alternative.

The ride-sharing approaches suggested include the entire range of individually organized carpools, employer-sponsored carpooling and vanpooling, and subscription buses, operated as cooperatives by the users or for profit by a commercial transit company.

Compatibility with Other Approaches

This package can benefit from the support of almost all of the remaining candidate techniques with the exception of the two traffic engineering approaches. Both maximizing use of existing facilities and freeway surveillance and control work toward increasing the number of vehicles using the roadways by improving traffic flow, whereas this package seeks to reduce the number of vehicles.

The compatible techniques, however, cannot all be applied simultaneously in the same locations. This is also true of elements in the basic package itself. Transit and carpooling are competitive for the same riders, and therefore are generally held to be conflicting techniques. Their inclusion in the same program is based on the assumption that they will be applied separately to different parts of the total problem. Transit should be promoted for trips that begin and end in relatively high-density areas, whereas carpools will originate and terminate in locations that cannot easily be served by transit.

Similarly, New Towns and planned neighborhoods can all reduce travel demands along the overcrowded route or in the CBD, but do so from different locations.

Efforts to reduce the supply of parking in the CBD can be encouraged by changing building codes with regard to off-street parking where they currently require business and residential structures to accommodate the vehicles driven by customers, employees, and residents. Changes in zoning can encourage the relocation of home and work in closer proximity and increase density of land use to permit efficient transit services. Communications substitutes for travel to work also reduce demands for the use of overcrowded roads and CBDs, and, in turn, become more attractive as costs of commuting increase through pricing policies.

Implementation of staggered or flexible work hours can be supportive to this package if carefully handled. If transit provides the primary alternative mode of commuting, and local transit operators are willing to provide frequent and fast service over an extended peak period, more riders can be comfortably accommodated. This can result in more commuters selecting transit over driving. However, if ride sharing is the principal alternative to private commuting, shifting of work hours should probably be confined to adjusting arrival and departure times for entire institutions. Carpools tend to be made up from people working for the same organization, and can be very difficult to arrange if different sections of the organization or individual employees have different work schedules. Packages of techniques that can be successfully combined with this package are changes in work hours, changes in land use, and transit treatments. Although the prearranged ride-sharing package can be supportive of this package, it does contain some conflicting elements. Therefore, it is difficult to accurately rate the compatibility of these two packages even though the individual technique of carpooling is an essential component of this pricing package. Individual techniques within this package could be used, with special care taken to ensure that the added elements perform a supportive role. The traffic engineering package is in basic conflict with the purpose of discouraging use of facilities through pricing techniques.

Applicability

Two alternative versions of this pricing package are suggested for application to different types of congestion problems. The first combines road pricing through variable tolls with parking controls; the second relies exclusively on manipulating parking supply and user costs to provide disincentives to peak-period use of facilities.

The combination of road pricing and parking controls is especially suited to larger urban areas where congestion problems exist both in the CBD and along limited travel corridors. Road pricing is an effective disincentive to individual use of private vehicles for commuting where access from major residential development is restricted by geographical barriers (such as bodies of water and mountains) to only a few routes. San Francisco is a good example of such an area, inasmuch as its central city lies at the northern tip of a peninsula between the Pacific Ocean and San Francisco Bay. Access to the CBD from residential communities along the peninsula is limited to two major routes, while commuters north and east of the city can reach the CBD only across bridges.

Where access to the CBD is not geographically restricted, road pricing serves only to divert users to other parallel routes and does not discourage commuters from driving into the CBD. Because severe congestion in itself leads rush-hour drivers to seek alternative routes, little added benefit would be derived from instituting a program of road pricing where alternative routes exist. Therefore, the second version of this package, which relies solely on parking controls to provide pricing penalties for individual use of private vehicles for commuting, is recommended for broader application to cities of all sizes where geographical limitation of access routes is not a factor.

This package, in either version, is specifically directed toward inhibiting the use of private vehicles during peak commuting hours, but permitting and even encouraging such use at other times. It should be applied to cities where congestion occurs in the CBD or along certain access routes only at rush hours. If congestion is an all-day problem, other solutions, such as the package of traffic cells and auto-free zones, should be used instead.

The feasibility of either version of this package depends on provision of sufficient attractive alternatives to individual peak-period commuting by private car. In larger cities where the termination of most trips to work is in the CBD, an efficient high-capacity transit system is essential. Where a significant number of work trips is made by commuters passing through the congested CBD to other destinations,

Component Techniques of Basic Package

Road pricing	Priority transit, arterials
Parking controls	Priority transit, expressways
Carpooling and other ride sharing	Transit circulation
Incentives to transit	Extended-area transit

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Staggered work hours	Traffic cells	Freeway surveillance and control
New Towns	Auto-free zones	Maximizing use of existing facilities
Planned neighborhoods		
Zoning and building codes		
Communications in lieu of travel		

Supportive Packages	Neutral Packages	Conflicting Packages
Changes in work hours	Restriction of access	Prearranged ride sharing
Changes in land use	Communications substitutes for travel	Traffic engineering techniques
Transit treatments		

Figure 6. Schematic of package No. 2: Pricing techniques.

a well-developed ride-sharing program may prove more effective than transit in reducing the number of vehicles used for these trips.

Costs and Effectiveness

Direct Costs and Benefits.—Direct costs of implementing the proposed package will vary according to the number of approaches included and characteristics of the road network, existing transit resources, and other elements of the individual city. Where the critical congested roadways are bridges, tunnels, or expressways for which tolls are already being collected, costs of implementing variable user charges are negligible. All that is required is to select and test the effectiveness of a pricing schedule, and to identify one or more toll-collection lanes for high-occupancy vehicles. In the initial year of the program, an investment of $50,000 should cover the original selection, monitoring, and revision of the fee schedule, if necessary, and marking of special lanes. Subsequent expenses could be expected to be absorbed in the normal operation of the facility.

Where access to the congested roadway is not presently controlled, toll collection stations would have to be constructed, or the burden of discouraging automobile commuting would have to be borne entirely by parking controls. If there are no alternatives to the travel corridor, a toll station located at the residential end of the route could be very effective in reducing use by private automobiles without seriously blocking traffic flow along the route and in the CBD. This would prove more satisfactory than attempting to collect tolls in the central city, where the back-up of vehicles passing through the toll facility could create traffic problems. The cost of constructing a toll station on a well-used major route could be expected to be about $500,000. Annual maintenance and operations would probably range between $75,000 and $100,000.

Costs of implementing parking controls will vary according to the size of the area involved and the number and type of ownership of off-street parking facilities. In all cases, costs will be negligible compared to approaches calling for major construction or acquisition of equipment.

On-street parking can be banned by painting curbs or placing signs indicating hours during which parking is permitted. If parking meters are used, their unit cost over the initial 5-year period is approximately $100, including installation, maintenance, and the expenses of collecting and accounting for revenues. This does not include enforcement.

Imposing a variable schedule of parking fees in public off-street parking lots would initially require at least $50,000 to select a schedule, monitor and evaluate it, and possibly modify the rates during the first year of the program. Costs of maintaining the program should add nothing to the normal operating expenses.

Imposing a new system of parking taxes for the use of privately owned facilities could generate initial planning expenses of $25,000 over that involved in setting price schedules for public parking. Assuming a moderately senior civil servant as the program director, with two field people, a secretary, and office space, the program could require an annual operating budget of $150,000.

Costs of improving public transit services could require a major investment and annual operating deficit. It might be possible to allocate existing equipment and personnel to expand the time period of peak service on the express portion of the system without adding to the inventory, but it is more likely that capacity of the system would have to be increased. The additional buses would cost between $500,000 and $1,000,000, for example, but could be acquired under an UMTA capital grant and UMTA is now permitted to assist communities with operating costs. There will be additional costs associated with priority transit service. Transit priority on expressways can be inaugurated for less than $50,000, but features such as ramp modifications can substantially increase this figure. Priority on CBD arterials may prove slightly more expensive if these changes are permanent ones. The costs of park-and-ride programs vary widely according to the type of parking used and the extent of the program. New demand-responsive feeder services in suburban areas can run as high as $20 per vehicle-hour. These services, too, may be partially subsidized through federal transportation programs. CBD circulation systems would probably be the least expensive element of the transit system, as it should be primarily a matter of reallocating existing resources, but it will certainly require subsidization.

The final cost of this package would be for promotion and matching of rides for a carpooling program. The cost of such a program for a single large firm should not exceed $10,000. On the other hand, the initial six months of the carpool program in Portland, Ore., cost $250,000. Again, federal funding is available for such efforts.

The combined effectiveness of road pricing and parking controls with sufficient transit and ride-sharing alternatives could be expected to reduce the number of single-occupancy private vehicles on the controlled corridors by 10 to 20 percent. Experience in San Francisco indicates that variable tolls alone result in shared vehicles increasing to 10 percent of total vehicles using the facility. Impacts on congestion in the CBD will vary, depending on what percentage of total downtown traffic arrives via the controlled roadways. However, imposition of parking taxes alone has been found to reduce use of parking lots by as much as 15 percent. A significant increase in parking fees in Boston has been estimated to reduce vehicle-miles traveled by 7 percent in the CBD. It is possible that the combined impact of the program could reduce the number of private vehicles on CBD streets during peak commuting hours by as much as 10 to 15 percent.

Under the proper circumstances, this program can be highly effective in reducing peak-period congestion both on heavily used roadways and in the CBD at relatively modest cost.

Indirect Impacts.—The main components of this package, road pricing and parking controls, can create a number of indirect impacts, primarily through reduction of CBD traffic. Such a reduction not only would permit CBD traffic to flow more easily and thereby reduce accidents, but the free flow, in turn, also would reduce automobile emissions that are especially high during idling. The impact on air quality should be even greater than on congestion. Noise levels and safety for pedestrians would be improved by this program, but not significantly, because vehicles will still continue to use the CBD streets.

However, the major impact of these techniques would be on CBD business activity. Central cities, and particularly their CBDs, are already suffering from loss of business activity and land values because of existing congestion problems. It is possible that by placing even greater barriers to travel to the CBD in the form of road pricing and parking penalties, business activity in some sectors may decline even further and some establishments may choose to relocate outside of the city center. Over the long run, however, this dispersal of economic activity should improve the livability of the urban areas, but some short-term losses may be felt by individual business concerns and some temporary reduction in the value of CBD property and tax revenues could result.

The indirect impacts of both the transit and carpooling techniques included in this package are not clear. In theory, use of either does contribute to reductions in energy consumption and air pollution, and more importantly, allows better economic use of land retrieved from parking.

Timing.—The major elements of this package can be implemented immediately where a toll authority is already in existence. Should a new authority need to be created and toll facilities constructed, between one and two years might be required. Parking controls for on-street and public facilities can be carried out almost immediately, but at least six months would probably be necessary to create new taxing programs for privately owned facilities.

Public transit improvements that involve reallocation of existing resources can also be implemented immediately, but acquisition of new vehicles can take as long as three years. Establishment of bus priority on expressways and arterials may require up to two years, but normally this can be accomplished in one year or less. Also, development of new suburban feeder systems would require a minimum of two years before they were fully operational.

Promotion of ride sharing and modification of work hours among private organizations could begin immediately, but would probably take six months or more to become effective. In all, this package can be considered a good short-term move to alleviate peak-period congestion.

Feasibility

Institutional Considerations.—Implementation of the major components of this package may require creation of new governmental entities. As previously noted, a road pricing program may require creation of a local toll authority. Also, approval of the state and federal governments may be necessary for imposing tolls on roadways constructed with their aid. Parking controls may require creation of a new parking authority if privately owned lots are to be included in the program. The alternative is for this program to be limited to public parking and managed by the city agency currently responsible for public facilities.

The transit treatments of this package can involve a number of government agencies, including: local transit operators, municipal transportation departments, local transit districts, regional councils of governments, state highway departments, and the U.S. Department of Transportation. Although each group will not be involved in every component of these transit treatments, it will be advisable, in terms of this package, to discuss the techniques with all groups and seek their cooperation and aid. Although carpooling can be implemented without involving government agencies, the effectiveness of this technique in achieving the desired impact on congestion is better ensured by coordination with other agencies involved in the total program, especially the toll and parking authorities. Funding from FHWA is available for carpool programs. The various transit components of this package are eligible for financial aid from FHWA and UMTA.

Public Acceptance.—As long as sufficient transportation alternatives are provided, public acceptance of this program should be possible to obtain. Road pricing has the least political feasibility of the techniques in this package, but this problem can be mitigated by initiating the program with reductions in existing user charges to off-peak users and gradually increasing peak-period charges to the point where they effectively discourage rush-hour driving of private vehicles. Less public opposition has been shown to parking controls, and this can be reduced by publicizing special rates for carpools and the availability of transit services.

Acceptance by Private Organizations.—Private organizations that presently use expensive downtown land area for employee parking should welcome the opportunity to reduce the number of spaces needed and convert the area saved to more profitable use. Large firms also support carpooling for similar reasons and in many cases have sought to institute carpooling, vanpooling, or subscription bus services on their own. This is important, for if carpooling is to play an important role in this package, the support of large employers is crucial.

Owners of private parking lots and CBD retail establishments might object initially through fears of losing business, as was the case in San Francisco, but it should be possible to demonstrate that increased short-term parking capacity and improved CBD circulation improves the attractiveness of the downtown area for customers of these establishments.

Compatibility with Existing Laws.—Legal problems will exist in establishing a new toll authority, if this is necessary, especially as the roadway will generally be controlled by the state rather than the local government. However, most states now are actively seeking solutions to traffic congestion other than construction of additional roadways and their cooperation could be expected. Establishing a new taxing policy for privately owned lots would also involve changes in existing local laws, and may be fought intensely by owners. The remaining techniques of this package would not require any changes in existing laws.

Readiness for Implementation.—All elements of this candidate package have been experimented with and are technologically ready for immediate implementation. It should be noted that road pricing systems requiring complex sensing devices and meters are not suggested as a part of this package.

However, no attempt has yet been made to use all of these elements in a coordinated, mutually supportive program with the specific goals of reducing congestion on limited-travel corridors and the CBD. The effectiveness of these approaches used in conjunction with each other is not known. The limited applicability of road pricing restricts use of the first version of this package to areas with limited-access corridors, but the alternate version, relying on parking controls as the major component, offers a practicable solution for many cities of all sizes and configurations. Therefore, this package is evaluated as ready for implementation on an experimental basis, with intensive monitoring of immediate impacts and periodic evaluation and modification of pricing penalties until the desired results are achieved.

Package No. 3: Restriction of Access

This package of techniques is designed to alleviate severe traffic congestion in selected areas of central cities by restricting the use of private vehicles within these areas. Two different basic approaches may be employed: traffic cells, in which through automobile travel is prohibited, and auto-free zones, which no private vehicles are permitted to enter. In either approach, mobility within the restricted area is ensured by the development of pedestrian facilities, supplemented where necessary by transit circulation systems. Improvements to maximize the capacity of surrounding streets and access roads are essential to ensuring that new congestion problems are not created by traffic diverted from the controlled area. Figure 7 shows the composition of this package and its relation to other congestion-reduction packages and techniques.

Traffic cells prohibit through traffic by dividing an area into cells or zones. Pedestrians and transit vehicles are permitted to cross boundaries between these cells, but private vehicles are prohibited from doing so. Private automobile travel from one cell to another is allowed only via arterial roads on the perimeter of the controlled area. Zonal boundaries within the area are marked with white lines or small raised barriers, and street signs direct drivers destined for locations across these boundaries to the most efficient perimeter route.

In auto-free zones all use of private automobiles is prohibited, and access to the area is permitted only to emergency vehicles (fire trucks, ambulances, etc.) and to delivery trucks at hours of the day when they will not interfere with pedestrian use of the area. Auto-free zones may cover only two or three city blocks or may extend over a much larger area.

Smaller auto-free zones that can be comfortably covered on foot are designed exclusively for pedestrian use, and include benches, planting, fountains, free-standing display cases, and tables and chairs for refreshment service. These facilities may occupy the former roadway, the level of which can be raised so that there is no longer a curb that might serve to inhibit pedestrians from using that section of the street. Larger auto-free zones require some form of transit circulation that will provide easy access to all parts of the restricted area.

Three alternative approaches to restricting vehicle access are possible through use of this package: traffic cells or auto-free zones used separately, or a combination of the two. With the third alternative operation of private vehicles is also restricted within the individual traffic cells (usually to a single, circular, one-way route on the outer edges of each cell) and the interior of the cell is developed for pedestrian use as an auto-free zone.

Options are also available on the extent to which auto-free zones are developed for pedestrian use, as follows:

1. Occasional pedestrian streets, in which temporary barriers close off streets normally used by vehicles on certain days of the week or special seasons of the year (such as Christmas or summer tourist months). Local shops may move display cases, tables and chairs, and potted plants out onto the sidewalk or into the street itself as attractions to pedestrian shoppers, or independent artisans and craftspeople may set up temporary booths or displays on carts, creating an air of a village market day.

2. Regularly scheduled traffic bans, usually prohibiting vehicular use of streets during hours of the day when stores are open. Deliveries to retail establishments in the restricted area are permitted only at hours before or after the traffic ban is in effect. On-street parking is usually permanently removed and sidewalks are extended out into that area, permitting the addition of permanent street furniture, fountains, and planting. Awnings or overhanging sun screens are occasionally extended from restaurants, and tables and chairs are moved out onto the sidewalk for outdoor lunch and refreshment service.

3. Permanent pedestrian areas, in which private vehicles are banned at all times. Streets are totally repaved, with road surfaces raised to the level of the sidewalks so that any psychological barrier to pedestrian use of the former roadway is eliminated. Benches, fountains, and gardens are introduced, and if transit circulation is provided these facilities are placed so as to route foot traffic in safe separation from transit vehicles.

It is also feasible to stage the development of auto-free zones through these three levels of pedestrian accommodation so that gradual changes are made in the status of the area. Costs associated with the initial level—occasionally closing the street to vehicular traffic—are very low, and no permanent barriers or pedestrian facilities are required. It is possible to experiment with such auto-free zones with limited funding, observe impacts on local traffic patterns and business in the area, and modify the location or extent of the restricted area where necessary before investing more substantially in extending sidewalks, repaving streets, or making other permanent changes. If the initial experiment is successful, public support may be generated for more ambitious developments and increased funds may be made available.

Although the long-range purpose of restricting access is to discourage use of private automobiles in congested downtown areas, it is essential to the viability of the controlled area to provide parking accommodations for those who cannot or who do not wish to ride public transit. However, if transit services are improved, more commuters may be persuaded to leave their cars at home, and the capacity of these facilities can eventually be reduced. For traffic cells, parking is best located within the boundaries of each zone so as not to further burden the heavily used perimeter roads. Where the interiors of the traffic cells are established as auto-free zones, parking accommodations should be located on the routes designated for vehicle use at points within comfortable walking distance of destinations within the pedestrian area.

Parking facilities for auto-free zones independent of a system of traffic cells may be located immediately adjacent to the restricted area or in dispersed locations with transit shuttle service between the parking area and the auto-free zone. Lower land costs for dispersed parking accommodations will compensate in part for the additional costs of providing the shuttle service. More visitors and shoppers will be attracted to the pedestrian area if parking and shuttle services are provided at no charge; costs can be met by the city budget, but more often they will be covered by contributions from business establishments within the restricted area who profit from the increased patronage.

An efficient and attractive transit circulation system is essential to successful functioning of both traffic cells and auto-free zones, unless the area is so small that it can be easily covered on foot. Service should be frequent and reach all parts of the area. There should be accommodation for shoppers' packages, and vehicles should be easy to enter and exit. Again, more users will be attracted to the pedestrian area if the transit service is provided at no charge. Where this is the case, the city should consider use of innovative transit vehicles that allow riders to board and leave at several points along the sides, rather than traditional buses that require passengers to enter only at the front so that the driver may collect their fares. Local weather conditions also will influence the selection of transit vehicles. In rainy cities of the Pacific Northwest, for example, vehicles will be completely enclosed, may have drip-free holders for wet umbrellas at each seat and upholstery and floor coverings that will be safe and sturdy when wet. Marquees over boarding areas would also probably be provided. In the milder climates of Florida and the Southwest canopy-covered, open, articulated buses, such as those serving the Disneyland parking lot and the Atlantic City boardwalk, may be the most suited to the purpose.

The circulation system should not only provide access to parking facilities, but also connect with regional transit routes that can bring people into the area without their having to drive. This would extend the benefits of reduced congestion to other parts of the city beyond the restricted area. Transit use would be promoted by constructing a transfer facility with seating, lockers for checking packages, and change machines. A highly developed public information system—displayed route maps and schedules, directional signs, and either direct telephone connections to a

Component Techniques of Basic Package

Traffic cells	Maximizing use of existing facilities
Auto-free zones	Transit circulation

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Incentives to transit	Staggered work hours	Carpooling and other ride sharing
Priority transit, arterials	Road pricing	
Priority transit, highways	New Towns	
Extended-area transit	Communications in lieu of travel	
Parking controls		
Planned neighborhoods		
Zoning and building codes		
Freeway surveillance and control		

Supportive Packages	Neutral Packages	Conflicting Packages
Transit treatments	Changes in work hours	Prearranged ride sharing
Traffic engineering	Pricing techniques	
Changes in land uses	Communications substitutes for travel	

Figure 7. Schematic of package No. 3: Restriction of access.

centralized transit information service or a manned station within the facility that would also sell transit tickets—would be desirable. Merchants in the area might also use this facility as an information center to guide visitors to shops and restaurants. The combined services would be especially attractive to tourists.

Traffic engineering techniques that maximize the use of existing facilities must be applied to peripheral roadways to avoid inadvertently shifting congestion from the controlled area to another location. The full range of techniques available for improved lane separation, directional signs, signalization, etc., are described in detail earlier and discussed later in Package No. 7: Traffic Engineering.

Special attention must be given to selection and design of access points to traffic cells and parking facilities adjacent to auto-free zones to prevent congestion as cars slowly enter and leave these locations. Pairs of one-way streets flowing in opposite directions around the controlled area can better accommodate a slow turn-in lane without interrupting the flow of other traffic, and should reduce the potential for accidents. Prohibiting on-street parking on these perimeter streets, either permanently or at peak commuting hours, would also improve flow and reduce accidents.

In larger cities the existing urban freeway system is often superimposed over the older street pattern of the CBD, rather than circling around it. Traffic cells developed in such areas can use these overhead freeways in place of a peripheral road system by limiting access to the freeway to only one point in each cell. The right-hand lane must be strictly reserved for slower-moving vehicles entering and exiting the freeway at these points to reduce the potential for accidents when vehicles traveling at high speeds suddenly come upon those waiting to turn off or just coming onto the freeway. In many cases it probably will be necessary to prohibit through traffic from using this lane throughout its entire route through the downtown area.

Compatibility with Other Approaches

This package of techniques restricting vehicle access is compatible or neutral with regard to all but one of the other candidate techniques, carpooling, which represents a competitive alternative to transit for trips to the CBD, and works counter to obtaining sufficient ridership to justify frequent and easily accessible transit service. If the decision is made to provide transit service as the alternative to private auto use, carpooling programs will interfere with the efficiency and viability of that transit service. Improvements to transit through priority systems on arterials and freeways, feeder services in outlying areas, and marketing, on the other hand, are considered to be the most important of the supportive techniques. An integrated transit system can connect these restricted areas to major residential areas, providing an alternative to driving and reducing the need for parking. Marketing incentives to off-peak travel, in the form of free transit fares or short-term parking coupons provided by retailers, can be effective in attracting tourists and shoppers to these areas.

Parking controls and freeway surveillance and control systems can be useful in preventing new congestion problems outside of restricted areas. Zoning and building codes can be modified to promote the type of new development that will make areas more attractive and may be necessary in some cities to eliminate requirements for off-street parking accommodations within individual office buildings and large retail establishments. Planned neighborhoods may add residential developments to existing commercial land uses within these areas, contributing to the long-range goal of bringing places where people live and work closer together. Changes in land use and redevelopment of downtown structures can also be carried out in areas adjacent to those where vehicle access is restricted, under the encouragement of improvements taking place there and extending its positive impact on the CBD environment.

Other packages of techniques that can be combined in their entirety with this basic package of restricting vehicle access are transit treatments, traffic engineering, and changes in land use.

Applicability

Traffic cells are particularly applicable to larger cities where the downtown area is old, and widening streets or superimposing a new freeway system would destroy much of the charm and historical value of the old central city. It is also an especially useful technique where downtown roadways carry considerable through traffic because alternative routes are lacking. Seattle is an example of this type of problem; Puget Sound to the west and mountains and lakes to the east of the city make the north-south route the only possible one in the region.

Auto-free zones are applicable to CBDs of both large and small urban areas. In smaller cities, access to the auto-free zone will continue to be primarily by private automobile because the relatively low population densities cannot support intensive transit operations. In larger cities much of the travel to the controlled area can be made by transit, and parking facilities will become relatively less important.

Care should be taken, regardless of the size of the city, that any one auto-free zone remains small enough to provide an attractive pedestrian environment and a neighborhood identity. Too large an area will require a level of transit circulation services that may interfere with freedom of pedestrian movement. If a widespread banning of private vehicles in the central city is being attempted, a system of traffic cells, each developed with a central auto-free zone, would function more effectively.

Costs and Effectiveness

Direct Costs and Benefits.—Experience in Europe indicates that basic costs of establishing traffic cells are moderate. In Gothenburg, $30,000 was spent for a public information program prior to introduction of the new system, and an additional $50,000 was spent on marking zonal borders and placing road signs. Approximately $2,000,000 was spent in Bremen for a similar project, but these costs included provision of underground and multiple-story parking facilities and improvements to existing streets, including pedestrian facilities.

The costs of developing auto-free zones can vary widely, depending on the amount of new construction desired and support facilities and services required. First-stage, occasional pedestrian streets will involve public expenditures only for placing and removing barriers and enforcing vehicle restrictions by the city police department. Other optional costs would be incurred by participating local business establishments and independent craftsmen. Experience in U.S. cities for second- and third-stage developments involving some construction presents a range of $75,000 to several million dollars. If no major land acquisition, clearance, and redevelopment is involved, and no additional transit service is required, costs will lie at the lower end of the scale and cover primarily the repaving of streets and sidewalks and the provision of street furniture, lighting, and planting to enhance pedestrian use. At the other end of the spectrum is a complete redevelopment program where new streets, parks, underground parking facilities, public transit, and high-rise office and apartment buildings may cost as much as $25 million.

Assistance in funding such projects is available to local government under a number of federal programs through the Departments of the Interior, Housing and Urban Development, and Transportation.

The costs of a downtown circulation system will vary according to local requirements. However, that cost can easily be determined in advance. It will consist of any necessary capital expenditures (generally new, smaller buses, and signs and schedules) and 100 percent of the operating and maintenance costs. Although operating costs vary slightly with passenger load and average speed, it should be possible to predict both ridership and average operating speeds within a satisfactory range.

The capital expenditures involved in a circulation system are eligible for funding from both FHWA and UMTA. As noted earlier, downtown merchants and large employers are often willing to pay part or all of the operating costs of downtown circulation services because of either increased revenue or increased employee mobility.

The costs of techniques that make maximum use of existing facilities are also difficult to predict. One-way street conversion and on-street parking restrictions are low-cost measures that may cost as little as $2,000 to $5,000. Channelization and design modifications will vary significantly in cost according to the amount of construction involved. Funds for these engineering techniques are often available through various state highway programs, as well as TOPICS and other federal road construction programs.

Traffic cells are extremely effective in reducing traffic congestion. In Gothenburg traffic volume has been reduced by 70 percent, and air pollution and traffic accidents have been reduced. Retail trade in the city has increased.

Traffic congestion within the auto-free zones can be completely eliminated under this program, because only emergency vehicles and off-hour delivery vans are permitted to enter the area. Adequate provision of public transit access and proper location of major parking facilities should also prevent creating new congestion problems outside the area. On the whole, experience with restricting automobile traffic in selected areas has demonstrated reduced congestion in the area itself and no serious increases in congestion elsewhere.

Combining traffic cells and auto-free zones with a high level of transit service can remove traffic entirely within central portions of zones, and may reduce over-all congestion in the controlled area by as much as 80 percent.

Indirect Impacts.—Some dislocation of the downtown economy should be expected during the initial phases of a program restricting vehicle access while people become accustomed to new travel patterns. However, experience indicates that business in the controlled area will benefit in the long run. Some traffic problems may be created initially along the border streets and at the entrances to the cells, but these can be eliminated with the application of traffic engineering techniques and greater use of transit.

The major indirect cost of extensive redevelopment programs that may be undertaken in connection with the creation of new auto-free zones is the dislocation of businesses and loss in local property tax revenues when existing structures are torn down to make room for new uses. These should also be evaluated carefully by the local authority when estimating project costs.

Air and noise pollution associated with automobile traffic will be significantly reduced by this package. Sharp reductions in vehicle and vehicle-pedestrian accident rates can also be expected as a result of restricting access of private automobiles.

Timing.—Steps necessary to physically closing off streets to vehicular traffic can be carried out immediately; an auto-free zone can be created simply by placing temporary, moveable barriers at either end of block-long shopping streets. No more than a few weeks would be necessary to provide the road markings and directional signs for a system of traffic cells.

However, no attempt should be made to institute extensive changes in vehicle access in CBDs until adequate provisions have been made for transit circulation and parking, and the peripheral road system and entry points have been improved as necessary to accommodate increased demands. It is also wise to conduct a public information program prior to the initiation of the controls so that former users of the central area road system can plan travel alternatives.

Techniques of closing zones to private vehicles and developing a pedestrian environment on former streets have been successfully demonstrated and can be applied immediately by other cities. There is also considerable experience both in the U.S. and abroad in providing related parking facilities and internal transit systems, as well as in major redevelopment of downtown properties.

Auto-free zones can be developed in stages, as previously indicated. Initially, streets may be closed off for selected periods of the day. Unfixed benches and potted plants can be brought in and street entertainments provided to emphasize the special quality of the area. Later, should the experiment prove successful, streets can be permanently closed to private vehicles and repaved for pedestrian use. Finally, selected structures can be replaced with new buildings more in keeping with the revised character of the area and long-range goals for the development of the city.

Feasibility

Institutional Considerations.—Creation of a system of traffic cells can be undertaken solely by a local government. However, the city may wish to consult with FHWA or the state transportation agency in this process. This technique has never been attempted in the United States, but funding for a traffic cells experiment may be made available under either an UMTA demonstration grant or the FHWA traffic improvements program.

Auto-free zones may also be undertaken solely by cities, but funding for various aspects of these developments is available from the federal departments of the Interior, Housing and Urban Development, and Transportation. Coordination of activities under several federal assistance programs can pose difficult problems, and city governments not familiar with these programs may find it helpful to obtain the services of an experienced project manager.

A downtown circulation system can be developed by the city and local transit operator, with federal support. The necessary traffic engineering modifications can be made by the city with financial aid from the TOPICS program.

Public Acceptance.—Experience in Europe indicates that public response to traffic cells should be favorable. Some initial objections to this package may be voiced when people are not yet used to the system, or details of operating the program have yet to be adjusted. Reaction in the long run should be positive as improvements in the environment of the controlled area become apparent. Where the city center includes structures of historic and cultural value that are preserved and made more accessible by a system of traffic cells, public support of the program should be especially strong.

Acceptance by users of auto-free zones has been found to be readily obtained. Shoppers and tourists are attracted to the area and local residents are proud of the improvements to a formerly deteriorated neighborhood.

Acceptance by Private Organizations.—Active participation of private business in the controlled area will contribute to the success of such programs. There may be some initial criticism of the scheme because of concern over losing customers or employees, or proposed assessments for street improvements and support of transit. Local shopkeepers in Bremen, for example, were sharply critical because strangers found it difficult to find their way through the restricted area, but improvements in signs and distribution of guide maps solved this problem. Initial fears of loss of business have proved not to be justified: in Tokyo, 219 of 274 shops surveyed reported increased sales; increases in retail sales of 15 to 35 percent were reported in Rouen, France; and increases of between 10 and 30 percent have been recorded on Nicollet Avenue in Minneapolis. Support for the program can be expected to grow as local firms see the benefits of increased business activity.

Compatibility with Existing Laws.—There should be no difficulty in carrying out these programs under the existing authority of local governments. Changes in the designation of public roads to restrict vehicle access would be necessary. Some changes in zoning ordinances and building codes might be necessary if new types of structures were to be added to those presently in the proposed auto-free zone.

Readiness for Implementation.—Because all of the techniques described have been implemented previously, they are available for immediate application. Careful evaluation of existing travel demands should be made to determine needs for parking and public transit before these facilities and services are designed.

In addition, there is a need to carry out periodic evaluation of the impacts of the new development, not only within the restricted area itself, but also in areas outside the zone that may be affected. This information not only will help the individual city to improve its program where necessary, but also will provide valuable data for other cities considering this package of approaches as a possible solution to their own congestion problems.

Although the technique of reducing CBD congestion through traffic cells has not yet been tried in the United States, models exist in Gothenburg and Bremen. Implementation techniques have been designed and have proved feasible, and are available for use in U.S. urban areas. Techniques of improving pedestrian facilities, constructing underground and multi-story parking structures, and developing supporting transit systems are well known in the U.S. and are accessible to cities selecting this program. Modifications would have to be designed to accommodate the unique characteristics of individual urban areas, but the basic technology for all segments of the program is ready for application.

Package No. 4: Changes in Land Use

This package combines techniques for changing existing patterns of land use in urban areas so that places of residence and work, shopping and recreation are brought closer together. Traffic congestion is alleviated by reducing basic demands for travel, especially at peak commuting hours, as many work trips become short enough to be accomplished by walking and bicycling instead of driving.

Techniques are included in the package for modifying land use throughout all parts of metropolitan areas: CBDs and central cities, suburbs, and currently undeveloped lands. Changes in zoning and building codes permit the new construction of apartment houses in CBDs within convenient walking distance of downtown offices and stores. Planned neighborhood projects upgrade older residential areas in central cities, from which people employed in the CBD can commute by short transit or pedestrian trips. Changes in zoning ordinances can also introduce new employment opportunities into suburban areas formerly reserved exclusively for residential use, reducing needs for long commuter trips to work in other locations. New Towns can be constructed in dispersed locations providing a balanced development of housing, employment, and recreation facilities in close proximity; trips between home and work are accomplished within the self-sufficient New Towns, often by walking or bicycling, and do not contribute to peak-period congestion in and around the central city.

Figure 8 shows the composition of this package and its relation to other packages and techniques.

It was suggested earlier that lasting solutions to peak-period traffic congestion will ultimately depend on changing the form of urban areas so that needs for travel, especially for daily commuting trips, are reduced. This package is designed to achieve that goal. However, the changes in allocation of land use that it proposes can be implemented only slowly. Government action in providing a regulatory environment that permits more efficient urban design can be taken immediately, but carrying out these changes rests largely with the private sector, which must rehabilitate or construct new facilities, develop new sites, and relocate businesses and homes.

Government can supply some impetus to private action through funding assistance for construction, tax relief for relocating commercial and industrial firms and families, and developing public facilities and services that enhance the desirability of certain locations. However, even with these incentives it will be many years before a new, efficient urban environment can be created and the full benefits of reduced congestion can be realized.

This package is strongly recommended as a long-term solution to peak-period traffic problems. It can be initiated at the same time as other programs aimed at the immediate relief of congestion, lending increasingly effective support to these short-term efforts and ultimately providing a lasting solution to the problem.

Of the approaches to more efficient urban design included in this package, the most important is modifying current zoning practices to permit mixed land uses. Residential units can then be added to the CBD within walking distance of downtown jobs and industry can be brought out to residential suburbs closer to those who would otherwise need to commute long distances to the central city.

Care must be taken to ensure the insulation of residential development from the noise and air pollution and traffic hazards that can be generated by commercial and industrial activities. CBD apartment complexes should be provided with safe pedestrian access to offices, shops, restaurants, and theaters, perhaps by a system of underground or overhead walkways. Rehabilitated city residential streets should be

Component Techniques of Basic Package

New Towns

Planned neighborhoods

Zoning and building codes

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Road pricing	Staggered work hours	Freeway surveillance
Parking controls	Carpooling and other ride sharing	Priority transit, arterials
Traffic cells		Priority transit, expressways
Auto-free zones		
Communications in lieu of travel		
Maximizing use of existing facilities		
Transit circulation		
Extended-area transit		
Incentives to transit		

Supportive Packages	Neutral Packages	Conflicting Packages
Pricing techniques	Changes in work hours	Traffic engineering
Restriction of access	Prearranged ride sharing	Transit treatments
Communications substitutes for travel		

Figure 8. Schematic of package No. 4: Changes in land use.

closed to through traffic. New commercial and industrial developments in suburban areas should be located at natural divisions between residential neighborhoods and provided with sufficient access road capacity to avoid traffic use of residential streets.

New Towns can also play an important role in improving the distribution of different activities so as to reduce needs to travel, especially at peak commuting hours. These self-sufficient communities can offer housing, shopping, recreation, and jobs within short distances of each other. Special facilities can be designed to enhance pedestrian and cycling travel within the community. The most successful New Towns appear to be those constructed as satellites around existing urban centers, connected to them by high-speed transit that permits residents of these communities to take occasional advantage of the greater shopping, entertainment, and cultural opportunities of the central city. However, these satellite towns must be provided with a sufficient number and range of employment opportunities and be located far enough away from the central city to discourage daily commuting trips to the city.

Redevelopment of deteriorated residential areas in older sections of urban centers can also contribute to bringing more people closer to their places of employment, shopping, and recreation. As in-town residential properties are upgraded they become more desirable to middle- and upper-income families whose livelihood is derived in the CBD. Some of the original lower-income residents may find it necessary to seek new housing as rents in the rehabilitated area rise. If wisely planned, this dislocation of low-income city families can be turned from a hardship to an advantage. The development of low-cost, possibly subsidized, housing in suburban areas closer to industrial and agricultural jobs can open up new employment opportunities that were impossible to take advantage of because of difficulties in commuting from the central city.

The basic concept underlying all of these techniques is to reallocate urban land uses so as to create new complete "communities" inside and around existing cities within which most day-to-day activities can be carried out. Not only does this offer a long-range solution to peak-period traffic congestion in and out of the city center, but it also holds the promise of a more satisfying way of life for the urban population.

Compatibility with Other Approaches

Modification of land uses in the city center may include creation of auto-free zones and traffic cells, which enhance the pedestrian environment and discourage commuting by private automobile. New high-rise apartment buildings can be constructed within a pedestrian complex of commercial structures as part of a major CBD clearance and redevelopment project. Where neighborhoods of historic or architectural value are being preserved through rehabilitation, new residential units can be created by subdividing former city mansions. Special care in maintaining the unique architectural features of such structures can make these units highly desirable, especially if traffic is diverted away from the area and the original narrow streets are reserved for pedestrian use.

Road pricing and parking controls support efforts to move places of residence and work closer together by placing penalties on commuting. Road pricing can be especially effective in discouraging daily commuting to the central city from new satellite developments. Parking policies that penalize all-day users of CBD accommodations will reinforce the road pricing sanctions.

The substitution of communications for travel to work provides an opportunity to those who live in suburbs or New Towns to carry on business activities with concerns located in the CBD without daily commuting to the central city. Such trips as may be necessary can be made at off-peak hours.

Where travel to work, shopping, and other activities cannot conveniently be made by walking or bicycling, local transit services should be provided. These may be transit circulation systems in higher-density areas or some form of demand-responsive services where housing and other facilities are more dispersed. Use of transit should be promoted by public information services and other marketing techniques.

The availability of public transit will reduce the need to use private vehicles for these trips. Many families may find it possible to function without owning their own car, by walking, bicycling, or using transit for local trips, and renting cars only for vacation trips or other special occasions. An additional advantage to this scheme is that different types of cars may be selected for different purposes: a camper or station wagon for vacation trips, a small sports car for an afternoon in the country, or a large passenger car for taking visitors on a tour of local points of interest. The aim of these measures is not to eliminate all use of private automobiles but to relieve urban dwellers of their dependence on cars for day-to-day transportation, especially commuting to work.

Applicability

There is probably no city in the United States that would not profit by reexamining its current land-use controls and modifying its existing development pattern to bring places of residence, commercial and industrial activity, and cultural and recreational facilities within easier reach of one another. The combined influences of traditional planning theory that advocated the separation of urban functions and the growing ownership and use of private cars have generated peak-period congestion problems even in small cities.

However, this package of techniques to modify land use is designed primarily for large metropolitan areas where residential development is largely confined to suburbs, and severe peak-period congestion problems result from daily commuting between these residential areas and the central city. These concepts might also be useful to clusters of small communities seeking ways to achieve the benefits of a larger urban complex, but avoid its disadvantages.

Costs and Effectiveness

Direct Costs and Benefits.—Rebuilding existing cities so that they can become stimulating and friendly environments for the people who live there generates costs so large as to be meaningless in the context of local programs to alleviate traffic congestion. Local government can, however, provide a regulatory environment to promote these changes by revising existing land-use plans and zoning and building codes. Costs of these activities will vary according to the size of the area involved and the degree of planning detail. At the lower end of the scale, single-purpose zones can simply be redesignated for multiple-use development at no costs beyond those normally budgeted for the agencies and commissions involved. Detailed plans for planned neighborhood redevelopment may range between $50,000 and $250,000. Long-range master plans for the realignment of entire urban areas, including specific designs and implementation schedules for large-scale redevelopment, can cost upwards of $500,000.

Because the major burden of urban redevelopment must be borne by private investors, changes in response to revised land-use controls will be made only gradually. Years may elapse between the drawing up of new land-use plans and their implementation. Local governments are cautioned not to invest too heavily in costly detailed planning for projects that cannot be carried out immediately.

Urban environments are volatile, planning concepts change, and proposals that appear practical now may later prove to be unworkable or inappropriate; when the opportunity for implementation finally arrives, the detailed planning will have to be done again. Opportunities will arise from time to time, however, to redevelop a few blocks in the CBD or an old downtown residential area, or to relocate job opportunities in a suburban area or a New Town. With the appropriate land-use policies each of these opportunities can be utilized as a small step toward achieving the over-all goal of creating livable communities within large urban complexes.

The Federal Government was very active in assisting in the development of planned neighborhoods and New Towns during the 1960's. Planned neighborhoods were eligible for funding under the Urban Renewal or Model Cities programs. Although many of these programs were successful, others fell short of producing the benefits anticipated. These programs have recently been curtailed. Sources of future federal assistance are not yet known, but it is generally expected that they will come from Community Development Grants.

The extent of benefits that can be realized from better allocations of land use can only be speculated upon. It is believed, however, that even limited efforts in relocating employment centers and residential facilities close to each other can bring significant improvement to peak-period traffic problems. It has been estimated that by arranging land use so that apartment house development and high-density employment areas are closely tied together and housing developed for a wide range of income groups within 10 minutes of large employment centers, auto trips in the Washington-Baltimore area could be reduced by as much as 20 percent.

Indirect Impacts.—Poor planning that fails to protect the residential environment can result in costs to the community or air and noise pollution and traffic hazards in neighborhoods devoted to residential use. Addition of new economic activity in suburban areas may result in through traffic on residential streets if not properly located and provided with other means of access.

Indirect benefits to the community from this program will be not only alleviation of traffic-generated accidents and noise and air pollution, but also less tangible advantages in easing the strains of current urban life and reducing the time devoted to commuting and traveling to shopping and recreation facilities. It can also generate greater feelings of community and identity for residents of large cities who now feel alienated.

Timing.—This package of approaches requires a number of years before its effects on alleviating traffic congestion can be felt. Redevelopment of CBD properties can take between 5 and 10 years, whereas development of a New Town can require 20 to 25 years. The program is recommended as a long-term scheme for achieving a lasting solution to traffic congestion rather than as a package of immediately effective techniques.

Feasibility

Institutional Considerations.—As previously mentioned, funding and technical assistance for the development of planned neighborhoods and New Towns can be obtained from agencies of the Federal Government. Development of planned neighborhoods can be undertaken solely by a city, but the creation of a New Town will involve a county or regional planning commission. Zoning and building codes can be modified by local planning departments with no outside involvement at other levels of government. Where counties maintain zoning authority over unincorporated areas, their cooperation is essential to the success of adding commercial and industrial development to residential suburbs located beyond city limits.

Public Considerations.—Considerable effort may be necessary to inform the public of the benefits of mixed land uses and to overcome fears that the mixture will result in deterioration of residential amenities and a lowering of land values and property tax revenues.

Introducing industry and low-income housing to existing suburban areas has been observed to meet initially with considerable local opposition. Lower-income city residents often fear being relocated to suburbs away from familiar shops and old friends. A good public information program and sensitive response to individual needs and concerns can make the difference between acceptance of proposed programs and their being delayed or even completely abandoned.

Acceptance by Private Organizations.—The cooperation of private organizations is essential where industry and commercial businesses are to be relocated in suburban areas or in New Towns. It is also necessary for the redevelopment of both commercial and residential land uses within the central city. Fortunately, it often is possible to find some private organizations that see benefits to themselves in participating in these schemes. Their cooperation is essential to the success of the undertakings, and these programs should not be attempted until participation by private sector investors is assured.

Compatibility with Existing Laws.—Redevelopment of property in the central city may involve condemnation of land and forced relocation of businesses and residents. Although precedents for such actions exist, court proceedings may be involved, causing considerable delays. If counties do not presently possess zoning powers, the state should be encouraged to grant these.

Attempts to bring industry and low-cost housing to established suburban residential communities may be in opposition to existing zoning and building restrictions. Unless the community is willing to see these changed, implementation will not be possible.

Readiness for Implementation.—All of the approaches described in this program have been implemented individually and techniques for planning and carrying them out are established. However, each of these techniques must be adapted to the specific characteristics of the area in which it is to be used, and considerable planning and evaluation of potential impacts should be carried out prior to implementation.

Package No. 5: Prearranged Ride Sharing

This group of approaches to alleviating peak-period congestion is centered around the sharing of rides to work by prearranged carpools, vanpools, subscription buses, and sharing of taxis. This measure reduces congestion by increasing vehicle occupancy and consequently reducing the number of vehicles used for commuting. Parking controls and road pricing are included in this package to provide economic incentives for creation and continued use of carpools and other forms of ride sharing. Figure 9 shows the composition of this package and its relation to other packages and techniques.

Carpooling and ride sharing provide commuters with an alternative to driving themselves to work individually in the form of group use of a single vehicle. Usually, some route deviations at the beginning and the end of the trip provide riders with pick-up at their own homes and delivery at their specific places of work.

Ride sharing is most commonly carried out where a long trip is involved and public transit is either inconvenient or not available. Both origins and destinations are usually concentrated within relatively small areas, and arrival and departure times of the participants are similar.

Arrangements for ride sharing can be made independently by the participants, or can be sponsored by large concerns and government agencies, or even as a city-wide program. Costs are normally shared by participants of carpools and taxi-pools, but employers may subsidize all or part of the costs of subscription vans and buses. Often, employers will provide the information service for matching individuals to others with whom they can share a ride; sometimes they will permit an employee-organizer of ride sharing to spend part of his regular work hours on this task.

Ride sharing can be carried out as an isolated technique, but will be more effective in achieving widespread participation if it is supported by parking and road pricing policies. Use of parking controls and road pricing in this package is in a narrower context than the applications previously discussed. In other applications the goal is to discourage use of privately owned vehicles in general; in this context a system of selective penalties is employed to favor private vehicles used for ride sharing. The effect desired for this package can be obtained by imposing limited parking policies. These selective policies may include reduced rates or free parking in publicly owned lots and the reservation of close-in, convenient spaces in company lots for carpools. Some carpooling programs (such as in Portland, Ore.) provide park-and-ride spaces at centralized pick-up points in residential areas, so that door-to-door pick-up can be eliminated.

Road pricing can be designed to penalize drivers traveling alone in their own vehicles during peak commuting hours while offering reduced rates for carpools using the same facilities. An example of this is toll-free use of bridges, tunnels, or expressways for private vehicles carrying three or more persons. This package does not advocate creation of new toll facilities, but rather the use of such facilities already in existence.

Compatibility with Other Approaches

Ride sharing to points in the CBD may also be encouraged by the presence of a downtown transit circulation system that can take riders between the parking lot and their places of work and provide additional mobility during the noon hour. These systems have been successful in many U.S. cities where employment is concentrated in the CBD. Changes in building codes that permit employers to reduce the amount of parking provided for employees can serve as an additional incentive for business firms to participate in ride-sharing programs.

As previously noted, staggered work hours and the package of work-hour changes are highly conflicting with this package. Attempts to institute staggered or flexible work hours within an organization sponsoring ride sharing can make it more difficult to match riders with the same travel needs. The Pueblo (Colo.) Army Depot was forced to reduce its staggered work hours to encourage carpooling during the recent (1974) energy crisis.

The relationship between this package and the remaining transit techniques is more complex. Some experiments have been made in allowing shared vehicles to use reserved bus lanes on freeways and arterials. Theoretically the greater utilization of the exclusive lanes better justifies implementation costs; in practice, however, permitting private vehicles access to these lanes increases the difficulties of enforcement. Also, it is believed that transit and carpools are potentially competitive; if both modes are developed along the same commuter route, implementation costs will be greater but ridership will be much the same as if only one new mode had been offered.

Traffic engineering approaches are considered incompatible with this package because their implementation may encourage drivers to continue or revert to single-occupancy commuting.

Applicability

Unlike many of the other packages, this package has wide applicability. It can be used to reduce congestion without regard to city size or form. However, prearranged ride sharing functions best when the following conditions prevail:

1. Both origins and destinations are concentrated within relatively small areas with a long trip in between.
2. Arrival and departure times are concentrated within a fairly short interval.
3. Disincentives to travel are present, either personal (inability to drive, no car available) or general (long commute route, severe roadway congestion, or parking restricted by lack of space or high cost).

Ride sharing is particularly applicable to large business and government organizations located outside of existing transit routes. Many of the most successful programs have been developed by single, large employers located in relatively isolated situations and drawing their labor force from residential communities some distance away.

However, carpools and subscription buses have also been successfully used in bringing commuters to the downtown areas of large cities (such as Washington, D.C., and Los Angeles) that are served by public transit. All that is required to attract riders is that the service have some of the following attributes: more direct, more easily accessible, more comfortable, and not significantly more expensive than the available public transit.

Costs and Effectiveness

Direct Costs and Benefits.—Carpools can be organized and operated by private individuals at savings to participants over their former travel to work in separate cars. Organization-wide programs will involve an initial expense promoting participation and matching riders, but because of the current availability of both computer and manual matching techniques this will probably not exceed $10,000 even for a very large organization.

Sponsoring organizations may also purchase vans or buses to transport groups of employees. The best known and most successful example of this approach is the vanpool operated by the 3M Company in St. Paul, Minn. Costs of maintenance and operation are paid by the riders.

Buspools are often operated by private transit companies on a profit-making basis. However, the residents of Reston, Va., have organized a nonprofit bus club for daily commuting to Washington, D.C., in which costs are shared by users.

Community-wide ride-sharing programs are more difficult to promote and implement because so many separate organizations are involved. For the initial six-month period of the Portland, Ore., program, a budget of $250,000 was allocated from an UMTA grant. The major expense of this program has been for personnel, but $58,000 was allocated for advertising and $60,000 for the provision of incentives. As experience with this technique grows, it is expected that the costs of a community-wide ride-sharing program can be reduced.

Federal assistance for promotion of group riding programs is available to local governments from both UMTA and FHWA. FHWA 90/10 matching grants can be obtained through Federal Aid Urban Assistance funds. Federal funds are also available for constructing fringe parking lots for carpools and buspools and carpool-only mini-parking lots within the right-of-way of Interstate System interchanges.

No accurate measures of the impact of ride-sharing programs on congestion have been made. Data show that average vehicle occupancy for employees of organizations strongly promoting carpooling can be as high as 4.1 persons per car. If over-all vehicle occupancy in congested cities could be increased to one-half that amount, theoretically a 25 percent reduction in the number of vehicles on the road could be realized. However, it is more realistic to expect 5 to 10 percent reductions in congestion from implementation of this package.

Indirect Impacts.—Indirect benefits of carpooling and

<u>Component Techniques of Basic Package</u>

Carpooling and ride sharing

Road pricing

Parking controls

<u>Supportive Techniques</u>	<u>Neutral Techniques</u>	<u>Conflicting Techniques</u>
Zoning and building codes	Traffic cells	Staggered work hours
Transit circulation	Auto-free zones	New Towns
	Planned neighborhoods	Incentives to transit
		Communications in lieu of travel
		Freeway surveillance and control
		Maximizing use of existing facilities
		Priority transit, arterials
		Priority transit, expressways
		Extended-area transit

<u>Supportive Packages</u>	<u>Neutral Packages</u>	<u>Conflicting Packages</u>
None	Pricing techniques	Changes in work hours
	Restricting entry	Traffic engineering
	Changes in land use	Transit treatments
	Communications substitutes for travel	

Figure 9. Schematic of package No. 5: Prearranged ride sharing.

other ride-sharing schemes accrue mainly to employers and consist primarily of being able to reduce parking accommodations and use the freed land for other, more profitable, purposes. Some employers also find that problems with late arrival at work are reduced when ride sharing is instituted. The public in general should benefit from reductions in fuel consumption and air and noise pollution. No disbenefits should be experienced by any particular socioeconomic group under this package.

Timing.—Ride sharing programs can be implemented very quickly, especially when the vehicles to be used are the employees' own cars. If vans or buses must be acquired, delays of a few months may be experienced. Large-scale matching programs may also take several weeks to complete, but both computer programs and manual techniques have been developed and may be obtained from FHWA.

However, ride-sharing arrangements are often short-lived. Brought about by intense promotion at the time of the 1974 gasoline shortage, many new carpools were abandoned when gasoline became more easily available. Subscription buses and vanpools on the other hand, which are usually driven by a single employee-organizer who makes a small profit if his vehicle is filled, tend to retain riders better than carpools do.

Feasibility

Institutional Considerations.—Funding and technical assistance for ride-sharing programs are available from FHWA and UMTA. Where preferential tolls are to be offered as an incentive, the local toll authority must be involved in the program. Other than these considerations, communities and employers have the ability to institute and operate ride-sharing programs on their own.

Public Acceptance.—Public approval of ride-sharing schemes is readily obtained, but this approval commonly represents a general acceptance of the idea for the community as a whole rather than a personal commitment to participate. Efforts must be made to provide sufficient rewards in the form of preferred-location and reduced-fee parking and special low or free tolls. Participation can be stimulated by fuel supply crises or sharp increases in fuel costs, but may disappear when the crisis situation is over or the cost increase is accepted as normal.

Acceptance by Private Organizations.—Private organizations must also be motivated to participate in ride-sharing programs. Savings in the costs of providing parking and the opportunity to put parking areas no longer necessary to higher economic use, are common motives. Ride-sharing programs may also permit the organization to obtain and hold a higher quality of personnel, especially if the facility is located where public transit service is adequate. Major auto insurance companies contacted by the study team indicated that carpooling would not interfere with insurance in force *if* no money transactions were involved. Problems might arise if nondriver members became part of a carpool and sought to pay their share of the expenses. However, such arrangements are common in a number of areas and several insurance agents indicated that payment would not be withheld on claims or insurance cancelled unless it became obvious that the driver was operating a transport business. In practice, insurance companies have been very flexible and have cooperated with large-scale carpooling projects such as the one in the Dallas area.

Compatibility with Existing Laws.—No legal difficulties are encountered in the implementation of ride-sharing programs. Some changes in existing regulation of toll facilities and public parking lots may be involved in setting special reduced rates for shared vehicles.

Readiness for Implementation.—The one technological problem associated with carpooling and other ride-sharing approaches was the development of usable computer and manual matching techniques. Several such programs are now available for use by both individual organizations and city agencies. In addition, there has been a great deal of experience with ride sharing in recent years, and information on these programs is now becoming available. Therefore, all elements of this package can be implemented immediately.

Knowledge of actual impacts of ride-sharing programs, however, is not known, and it is essential that the sponsoring agency or department monitor the program to measure its effectiveness and value to participating institutions and to the community. Such data would also be helpful to other urban areas considering the application of this package to their own congestion problems.

Package No. 6: Communications Substitutes for Travel

This package is centered around the technique of using communications in place of travel to work. It supplements this basic technique with road pricing and parking controls that attach penalties to commuting and with the development of New Towns, which provide dispersed locations for new communications centers and work at home that might otherwise be carried out in the overcrowded CBDs of central cities.

Although individual business organizations, especially those whose product is information (e.g., finance, insurance, research), can undertake an independent program of substituting communications for work trips, a significant reduction in peak-period congestion can only be realized through a communitywide effort that includes supportive techniques. Figure 10 shows the composition of this package and its relation to other packages and techniques.

Commercial communication services designed for interoffice or intraoffice communications could be used to (1) develop new locations for employment and residence and (2) move urban workplace destinations closer to employees' homes. These are the two operations examined for this package. They may be understood as representing two major stages on the scale of communications-assisted changes in the locational pattern of office employment.

Individual approaches likely to enhance the communications substitution process are road use and parking pricing measures, which would tend to raise the price of travel relative to that of communications, making the latter alternative economically more attractive. These techniques, like communications, can result in changes in urban form, and by their economic sanctions against daily commuting by autos, encourage workers to seek residential proximity to

Component Techniques of Basic Package

Communications in lieu of travel	Parking controls
Road pricing	New Towns

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Zoning and building codes	Staggered work hours	Incentives to transit
Extended-area transit	Traffic cells	Carpooling and other ride sharing
	Auto-free zones	Planned neighborhoods
		Maximizing use of existing facilities
		Freeway surveillance and control
		Priority transit, arterials
		Priority transit, expressways
		Transit circulation

Supportive Packages	Neutral Packages	Conflicting Packages
Pricing techniques	Restriction of access	Prearranged ride sharing
Changes in land use	Changes in work hours	Traffic engineering
		Transit treatments

Figure 10. Schematic of package No. 6: Communications substitutes for travel.

their employment locations. This package envisions communications substitutes providing the same kind of alternatives to auto use as are demanded by commuters in the pricing package, but provided in that case by transit services and carpooling techniques. Here the communications alternatives would be offered initially and the pricing techniques introduced to discourage the daily commuter from using crowded highway facilities during peak periods.

Also compatible is the development of New Towns, as both techniques encompass two steps or stages. Developing new home-work locations includes developing growth centers both inside and outside existing urban areas, while moving work closer to home can be accomplished by dispersion of individual firms or diffusion of office-type work.

The communications networks required for the different urban forms would vary in structure and in geographical coverage. The terminal hardware components and system capabilities would cover the full range of existing equipment and new types of components would be added as they are developed. This equipment would serve the following functions.

1. Audio conferencing with recording.
2. Numerical information (data bank) access with copying.
3. Written information (library) access with copying.
4. Computation and programming (computer).
5. Facsimile transmission and reception.
6. Video conferencing with taping.

Some of these capabilities may be unnecessary for certain types of industries, whereas other specialized procedures or systems may need to be designed for other industries, such as the airlines reservation system or remote word processing (secretarial and editorial services). All but the last of these capabilities could be effected using existing telephone bandwidth capacities, and so these functions are, strictly speaking, within the current state of the art.

Compatibility with Other Approaches

This package can be considered to be compatible with the technique of mixed zoning and the changing land uses package, because all of these techniques also act to change urban form and would allow development of new home-work locations within existing urban areas.

Transit and traffic engineering techniques conflict with this package, because they encourage commuting to centrally located employment areas (such as CBDs) while this package encourages dispersal. Carpooling and ride sharing are similarly incompatible because they depend on high levels of travel demand. All of the packages except for changing land use contain some incompatible elements although the pricing package is generally supportive.

Applicability

Both approaches (develop new locations and move work closer to home) could be adopted as long-range measures to prevent congestion in any size city where a congestion problem exists. There is no reason to think that only large cities are structured such that small outlying nonurban activity centers or urban satellite centers could not be developed to hold a larger proportion of the city's jobs. Large cities in particular might profit most in the long run from a policy to encourage location of new employment outside the center city. The small and medium-sized cities to which growth might be shifted could experience an increase in congestion, unless they also followed a policy of dispersing location of new employment to several activity centers. Towns on the low end of the city-size scale (below 50,000) should not be excluded if rural development or New Town development is considered as an option.

Because in the long run a successful dispersion policy would fundamentally alter work-trip patterns by shortening trips and taking them away from the CBD, it should be seen as impacting primarily on CBD congestion. There would be positive impact on freeway traffic if trips are shortened sufficiently. Depending on the size of the areas defined as satellite centers, some work traffic that at present uses freeways could shift back to arterials for the shorter trips, and intersatellite freeway trips could also be reduced as more work trips would be within satellites rather than between them. Congestion on arterials could increase to the extent that trips are diverted from freeway to arterial networks, but would decrease to the extent that fewer trips originating outside a satellite center would terminate within it.

Development of new locations, on the other hand, would be likely to affect equally all types of congestion in the area of traffic to the extent that the new centers turn out to be largely self-sufficient with regard to employment. New traffic obviously would be created on the routes connecting the new location with the nearest metropolitan area as people drive in to make use of the facilities and service which it is not economical to provide in a smaller city (entertainment, specialized health services, some retail purchases), but these types of trips do not typically contribute to peak-period congestion.

Costs and Effectiveness

Direct Costs and Benefits.—The direct and indirect costs of implementing a program of new location development or of bringing workplaces closer to homes are nearly impossible to estimate with assurance. However, some indications are given in the following.

Information on the additional direct costs due to communications for new location development requirements may be forthcoming or inferable from the final results of the New Rural Society project. Most existing estimates of the cost of moving are for a future cable-based system and its hardware components, with capital investment requirements ranging from $1 to 2 billion per 100 million subscribers (or $1 to 2 billion per year) up to $30 to 50 billion by 1985-90, and user charges of $1,000 for hookup, plus $200 to $700 for equipment purchase and about $20 per month for home subscription services. On a local level, per subscriber costs for installation of a limited 2-way cable system are estimated at from $100 to $1,200, the latter being equivalent to telephone installation. However, cable-based systems are likely to be used only for home services, such as remote shopping; it is the phone-based network that will be the basis for meaningful business applications. Dispersion to a number of urban satellite centers, made possible by greater application of communications techniques, can save both the company and the employee money.

Both road pricing and parking controls could add significantly to the implementation costs of this package. If there was an existing toll system on affected expressways and bridges or tunnels, the costs of implementing variable tolls would be small. If a new toll system was required, initial capital costs would range from $250,000 to $500,000 and annual maintenance and operating costs would fall between $75,000 and $100,000. As detailed in previous packages, the costs of implementing a coordinated downtown parking scheme can range from a few thousand dollars for a new parking meter system to well over $150,000 for a system of parking taxes in privately owned facilities. It is expected, however, that the revenues generated from both types of pricing systems would more than offset their initial costs.

Detailed discussion of the costs involved in implementing a New Town was presented earlier under "Package No. 4: Changes in Land Use." The Federal Government, through HUD, has previously been very active in providing support in this area, but future funding is uncertain.

The long-term effects of bringing workplaces closer to homes and development of new locations could be very important. The literature lends support to the view that dispersal of workplaces within the metropolitan area can result in shorter commutes, whereas further dispersal outside the metropolitan area may not increase congestion but probably will result in longer work trips.

Regarding the relocation of jobs to smaller urban areas or to rural areas, this approach should result primarily in a simple transfer of traffic from more- to less-congested facilities. Principal surface arterials and minor arterials in small urban areas are congested far less than those in urbanized areas, and freeways in small urban areas, although only slightly less congested than those in urbanized areas, can more easily be avoided by peak-hour motorists.

Indirect Impacts.—Although there are benefits in energy savings and transportation cost savings, no one has investigated possible indirect social costs. One possible effect that has been suggested is that the new urban forms would hasten the deterioration of existing CBDs. But it is more probable that relieving downtown congestion through this package of techniques would improve economic wealth of the CBD.

Experts in this field claim that there would be energy use savings from implementing a communications-relocation policy; none have looked specifically at the pollution or safety issues, but obviously a reduction in the gallons of gasoline consumed implies a reduction in air pollutants emitted by cars. Nille's modeling exercise, designed to determine the effects of dispersing the employees of a Los Angeles insurance company to 18 small locations in existing commercial centers close to workers' residence, shows that the energy operating cost of "commuting with telecommunications" is less than 5 percent of that of commuting by private auto, and less than 10 percent of commuting by mass transit at normal load factors. An offhand estimate is that if 10 percent of the nation's urban commuter population were to be transferred to dispersed work centers, roughly 150 billion kilowatt-hours a year would be saved on a national basis.

In spite of the many potential benefits of this package, several important equity considerations arise. Communications substitutes are less likely to be viable travel alternatives for lower-income workers and those in professions with little choice of work patterns. These types of workers and income groups are often unable or unwilling to move to New Towns. At the same time, the pricing and parking mechanisms incorporated in this package would pose tremendous hardships on those very people, who often have little choice but to drive to work in congested areas during peak periods. Consideration should be given to providing these special groups with other more practicable travel alternatives, such as specialized transit.

Timing.—Timing is a difficult parameter to estimate for this package. Although the systems and equipment required are currently available, the combination of communications technology and land-use changes is a significant new step for any government to consider. Again, although such an approach can be begun tomorrow, major pre-implementation feasibility studies would be required to estimate the impact of the implementation of this package on a number of significant variables.

Implementation of an experimental or pilot project to substitute communications for travel by relocating jobs could probably require a year or two of initial detailed planning. The results of this experimental stage would provide valuable guidance, and perhaps stimulus, to adoption of communications work patterns by certain types of information-oriented industries. Even so, it may be at least ten years before these organizations would be able to evaluate the pilot example, and if it is a success and shows potential for cost-cutting, five more years before significant impacts on congestion and other measures could be detected. However, the attractiveness of this approach, despite its uncertainties and unknowns, is its promise of a permanent reduction in over-all travel to work.

Feasibility

Institutional Considerations.—The institutional considerations of this package are not fully known at the present time. However, it is expected that the role of federal, state, and local governments will be primarily in regulation (FCC, POCs), granting CATV franchises and funding research and development demonstrations (HUD, NSF, DOT). It does not seem likely that the impetus for this approach will come from institutions.

Public Acceptance.—To the extent that consumers attach no positive value to travel to work as a good in itself, there is no reason why the working public should not accept the idea of working closer to home within the urban area as long as their job opportunities are not constrained. Public acceptance of developing new employment centers, however, may be encouraged by the opportunity to find just the home, neighborhood, schools, and amenities in a city or town with limited employment opportunities.

Acceptance by Private Organizations.—Private sector motivation to invest in dispersal was discussed earlier. There is little motivation for a developer to trouble with recruiting employers for a New Town if he can make just as much or more of a profit by building a planned community of residential structures alone. The key to the decision to adopt communications applications to change work location patterns is private profitability. Unless an innovative approach either (a) can make or save money for someone or (b) falls within what is broadly agreed to be the domain of public responsibility (as traffic control and public transit service), theoretical evaluations of their potential benefits to society in terms of reducing peak-period congestion will not be effective. Because the communications and land development industries are clearly in the private sector, it is their private profitability and not the social benefits which should be the focus of further work in this area.

Compatibility with Existing Laws.—No legal or regulatory barriers exist at present to hold back use of communications in dispersed workplace locations. Some cities or towns might object to being developed if the citizens think the community has reached the optimum size and that further development is undesirable. Development of new satellite developments must conform to local land-use policies.

Readiness for Implementation.—Although existing technology is more than adequate for implementation of the communications systems needed under this package, improvements in equipment could be made that would lower user costs and increase the capacity of these systems. More importantly, however, the greatest barrier to implementation is simply lack of real-life evidence of a business firm or community that has undertaken to apply communications facilities to reduce home-to-work—not intraoffice—

trips and has followed through by monitoring the results. The success of this first application may in turn depend on the adequacy of the local telephone infrastructure to handle the increased load. A research team is currently working with the telephone company serving an insurance company, to determine the impacts of the required communications facilities on the local telephone network and the associated costs.

Package No. 7: Traffic Engineering

This package combines a number of individual traffic engineering approaches that maximize the service level of a given system facility. The combination of approaches reduces congestion by controlling or removing impediments to traffic flows while at the same time increasing the level of service of an existing traffic network. The thrust of this package is on coordinating the planning, joint implementation, and monitoring of a comprehensive engineering approach to traffic congestion. The packaging of these individual engineering techniques stresses to public decision-makers the need to identify the total system impacts of their implementation, including social, environmental, and institutional benefits and disbenefits. The applicability of the package and its components is primarily determined by the incidence and location of congestion, which in turn is largely a function of city size. For this reason, the package is divided into two basic approaches, which are discussed collectively as well as independently. Figure 11 shows the composition of this package and its relation to other packages and techniques.

Maximum use of existing facilities actually involves a combination of several practical traffic engineering techniques, including signalization, land-use and directional control, channelization, and other capacity optimization schemes. Many of these concepts may be used individually to enhance the effectiveness of the existing facility system; others, when combined, may prove to further their impact on peak-hour congestion. Arterial traffic congestion is heavily influenced by unexpected or erratic disruptions in traffic flows. Some of these techniques attempt to remove impediments such as drivers entering or leaving parking facilities or the congestion caused by traffic accidents, by reducing the incidence of these activities. Others, such as channelization, increase the actual capacity of the arterial. Most of the elements comprising this technique are low in cost, thereby making their use very cost effective.

The installation of traffic signals has the inherent characteristic of increasing delay, and thus congestion, through their stop-and-go format. This can be offset by decreasing accident experience or severity and by increasing travel speeds. A system of interconnected signalized intersections, for example, can provide better traffic progression during peak periods.

Reversible lanes are an accepted technique used to provide additional directional capacity during morning and evening peaking. Experience in Chicago, Los Angeles, and Milwaukee has shown a significant increase in directional volume without a significant change in accident experience.

Use of one-way streets operated in directional pairs has proven very successful in increasing the volume of traffic funneled through a corridor. Implementation of a system of one-way streets has had a corresponding impact on accident experience. The success of this procedure can be partially attributed to elimination of possible traffic conflicts.

On-street parking restrictions implemented during peak periods are most effective in increasing volume throughput and in reducing potential conflicts, which cause accidents and more congestion. This technique can be a very effective low-cost element in this package.

Other techniques, such as channelization and prohibition of turning movements, are designed to physically separate the vehicles and reduce conflicting vehicular movements. As expected, accident experience is greatly reduced. Lighting of streets and intersections is another technique that can be used in areas where driver visibility may be impaired due to adjacent land-use activities or the design of the facility. This has been effectively used in reducing nighttime accidents or accidents on those winter days where a portion of the morning and evening peaks may occur during darkness.

There are numerous cases where the geometric design features have been altered to decrease traffic congestion. These modifications are made or sponsored by all levels of government and are not restricted to a single jurisdiction. This approach to spot improvements has been very effectively implemented.

In urban areas containing an access-controlled, high-design highway facility that experiences traffic congestion at one or more time periods, these techniques of maximizing use of existing facilities should be combined with freeway surveillance and control. There are variations of freeway surveillance and control measures which can be used to increase the effectiveness of this technique. Within the specific technical approach a subset of measures can be added to solve an array of specific problems. As discussed earlier, ramp metering to control entering traffic at fixed or predetermined rates can be a very effective technique for specific congested locations. However, for an entire freeway corridor or the inclusion of the CBD, the system may require signs or other real-time driver information systems, interconnected arterial intersections, real-time control of the ramp, and special-vehicle priority systems. The more complex the traffic congestion the larger the array of potential solution options and the relative initial cost.

Practical approaches to increasing the capability of the existing street systems to facilitate movement of traffic in the vicinity of the freeway are essential to effective implementation of this package. The freeway must be considered as an integral component of the surface transportation system. Any changes, modifications, or alterations in one subcomponent may have an adverse effect on the corridor, adjacent streets, and the origin-destination patterns of the trip-maker. It is therefore imperative that where freeway surveillance and control is used, techniques that maximize the use of existing facilities are also included.

Compatibility with Other Approaches

Many other techniques can have a significant impact on peak-hour traffic congestion and can be considered as an optimal addition to this package. The benefits to be derived from their implementation may be marginal but generally are not considered to be counterproductive or conflicting in their effectiveness. One example of such a technique is the use of parking controls. Elimination of on-street parking during periods of traffic congestion can be most effective in reducing the number of conflicts associated with vehicle maneuvers, and it essentially adds an additional traffic lane. In addition, parking controls may cause a shift in travel mode, which may have a positive effect on freeway traffic volume. This is most effective when there are few major activity centers, thereby reducing the number of work-trip origin-and-destination pairs needed to be served by radial transit systems.

The arterial network of a city is likely to experience a high degree of traffic congestion, largely due to its dual functions of facilitating through traffic movement and providing access to adjacent land-use activities. These two functions are often in conflict in an operational situation, a conflict best seen in the degree of traffic congestion that arterials experience in peak periods. An approach to controlling this conflict is to discourage access to adjacent land-use activities. This can be done through parking restrictions as previously mentioned (and discussed in detail elsewhere in this report) and by controlling land-use activities. Use of mixed zoning, New Towns, planned neighborhoods, and building codes can be an effective way to control trip generation and attractions associated with any particular land-use activity; and these techniques can also be used to restrict accessibility to the land use or facility in question. Furthermore, they can be used to guard against significant unplanned or unprogrammed changes in land use, which can cause a shift in travel pattern and travel demand, creat-

Component Techniques of Basic Package

Freeway surveillance and control

Maximizing use of existing facilities

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Parking controls	Communications in lieu of travel	Road pricing
New Towns		Traffic cells
Planned neighborhoods		Auto-free zones
Zoning and building codes		Incentives to transit
Staggered work hours		Extended-area service
		Priority transit; arterials

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Carpooling and ride sharing		Transit circulation

Supportive Packages	Neutral Packages	Conflicting Packages
Changes in land use	Pricing techniques	Transit techniques
Changes in work hours	Communications substitutes for travel	Restriction of access
		Prearranged ride sharing

Figure 11. Schematic of package No. 7: Traffic engineering.

ing major traffic problems on the existing freeway and adjacent street network. For these reasons, these techniques and the changes-in-land-use package are considered to be complementary or supportive.

Another compatible option could be the institution of a staggered work-hours program. A staggered work-hours program among major employers can have a significant influence on reducing localized congestion on arterials serving that location. However, to be effective in reducing freeway congestion and increase the opportunity for this package to be successful, the program must be coordinated among those major employers to insure that their staggering plans are complementary to one another and not counterproductive. Indeed, an uncoordinated program by major individual employers may create traffic congestion rather than relieve it. Finally, carpooling programs combined with parking privileges can enhance a traffic modification designed to increase the use of the existing arterial system. Some techniques may be dysfunctional if used with this package. Road pricing techniques, for example, can be counterproductive if the delay incurred in daily implementation of the collection mechanism creates congestion or a corresponding decrease in the service level. Road pricing would also have the effect of creating congestion on alternate routes, which is noncompatible with this package. It should be noted, however, that although road pricing is in conflict with the maximum use of existing facilities, and therefore is in conflict with this package, it is somewhat compatible with the technique of freeway surveillance and control. The use of tolls or fees collected at ramp entrances is a way to restrict traffic and a simple scheme of ramp metering. In addition, this technique is effective in reducing the demand for travel by private automobile on the freeway, thereby enhancing the level of service.

Traffic cells and auto-free zones, which comprise the restricting entry package, are conflicting techniques because their implementation may automatically create serious congestion on surrounding arterials and streets.

There are important contingencies associated with these two techniques. There are cases where use of traffic cells and auto-free zones may be applied to enhance the maximum use of existing facilities. Through reduction of signalized intersections and channelization of traffic flow along designated corridors, the flow of traffic may be significantly facilitated. However, if sufficient street facilities required to handle the additional diverted traffic cannot be obtained, increased congestion and delay will result. Therefore, caution is advised when a package of traffic engineering techniques augmented by these techniques is proposed.

The transit techniques package and its various components are considered to be in conflict with this package. This is due to the tendency of all transit treatments to reduce the level of service of an existing arterial and may cause a traffic shift to local streets.

These examples tend to focus on how misuse of, or lack of coordination among, the various techniques presented in this report can create conflicts that lead to increased traffic congestion. As previously stated, the combined package must be considered in light of its effect on traffic congestion in particular areas.

Applicability

As previously indicated, maximum use of existing facilities is well suited for use in any type of city, whereas freeway surveillance and control is appropriate for larger urban areas only. Because maximum use of existing facilities is actually a combination of several traffic engineering techniques, their applicability is discussed in terms of the general type and location of congestion they are designed to alleviate. In implementing this package, a city should use any or all of the following approaches that are appropriate to the types of congestion it faces.

Signalization is effective in reducing bottlenecks at intersections, usually the most demanding point in a traffic network. On-street parking restrictions are appropriate where congestion is being created by friction with the traffic flow caused by parking maneuvers. One-way street operations have proven successful in reducing congestion caused by friction between opposing traffic streams or where intersection operations need to be simplified. These conditions are generally found on narrow streets in older sections of a CBD, but this technique is applicable only where one-way pairs can be provided (a single one-way street is normally inappropriate). A reversible-lane operation is very useful where there is a definite directional peak in the morning which is reversed in the afternoon. Channelization and prohibition of turning movements are appropriate where congestion is caused by a number of conflict points between crossing traffic movements at intersections. Lighting of streets and intersections should be used where, for any reason, driver visibility is impaired.

Freeway surveillance and control should be considered where congestion may be caused by the geometric design of the facility, freeway incidents that restrict traffic movement, and ramp operations. The degree to which the entire technique or particular elements of it are implemented is related to the problems that exist. In urban areas with freeways that are beginning to experience traffic congestion during the traditional peak periods, a simple fixed-rate ramp-metering program combined with practical traffic engineering techniques to increase the efficiency of the existing street systems may be the optimum solution. In other uses, surveillance systems with ramp metering have been installed in Houston, Tex.; Los Angeles, Calif.; and Chicago, Ill. Although attempts have been made to use helicopter surveillance techniques, television surveillance has been more successful.

A good example of this technique's application is the system currently being installed in Dallas. For areas such as Dallas, with extensive freeways and a multitude of major activity centers, a comprehensive system combining many of the elements may be required. The Dallas case is a full application of the two techniques in this section and an extension of the surveillance and traffic signal control systems to the freeway corridor. This includes computer control of the freeway frontage roads and other selected arterial streets.

Costs and Effectiveness

Direct Costs and Benefits.—Most of the maximum use techniques presented are inexpensive to implement and have been shown to be very cost effective. These spot-type improvements are made at the local level, with existing staff ability, and through normal budget limitations; cooperation and support may be available through the highway transportation agencies at the state and federal levels. Many of the applications may not require special budgetary provisions. Direct costs of implementation vary with the magnitude of the problem and the solution concept to be used. The direct benefits to be realized are usually measured in terms of savings in travel time and delay, traffic volume change, level of service provided, and decrease in accident costs.

In the area of traffic signal modifications, average initial costs can vary from $200 to $550,000 as shown in the Sunnyvale and Tallahassee cases, respectively. The high cost in the Tallahassee case was for installation of a central computer to handle traffic signals at 25 intersections. Only 5 percent of the cost was paid by the city and county. The costs of the Sunnyvale case involved both a survey and a change in the signal timing program to affect periodic traffic progression on preferred routes. However, the costs for updating a traffic signal with fully actuated or semi-actuated equipment are approximately $35,000 per intersection.

Traffic signals are intended to control traffic movements and cause traffic delay by their stop-and-go routine, but use of this technique can be justified on the basis of accident experience. Although a system of interconnected signalized intersections can be effective in increasing travel speeds on preferred routes, the costs associated with delay and stops may be increased. Therefore, an analysis of total delay and other direct costs may be desired prior to solution alternatives selection.

Use of reversible lanes required an initial cost of from $2,000 per lane in Los Angeles, to a total cost of $72, 000 in a Chicago experiment. This technique has been effective in reducing peak-period congestion by allowing a 20 to 50 percent increase in two-way traffic volume and a 20 percent reduction in travel times. No cases were found which showed an increase in accidents, with a decrease in accidents reported in some projects.

One-way street conversion is another low-cost measure that may cost as low as a few thousand dollars, depending on the degree of implementation. The potential effectiveness of this technique was discussed earlier. Average travel speeds have been increased approximately 5 mph with a significant one-third increase in traffic volume in some cities that have implemented this technique. Another significant factor is the reduction in accident experience recorded in the cases reviewed.

Channelization and other design modifications vary significantly in costs because of the variation in application. As in the previous cases there have been significant reductions in total accidents and the severity of accidents. Traffic speeds were increased by as much as 10 mph in some cases. In other cases the annual delay cost was reduced from $24,000 to $38,000 despite significant increases in traffic volume.

With the use of parking restrictions, documented case experience has shown that the direct cost of implementation is very low and the benefits to be anticipated are significant. For example, traffic speeds have showed a 5-mph increase with a corresponding peak-hour travel time reduction of approximately 25 percent for automobiles and 10 percent for local buses. Delays and stops were reduced by as much as 50 percent without a change in accident experience.

The costs associated with implementation of freeway surveillance and control can be high, depending on the degree of implementation and local conditions. Generally, it is not considered a low-cost capital improvement but is incremental in that the system can be made operational in phases. In addition, the initial capital costs are quite variable.

Current ramp metering systems similar to those installed in Milwaukee and Los Angeles County cost approximately $6,000 per ramp. The usual annual operating and maintenance costs are approximately $1,000 per ramp.

The Chicago Area Freeway Surveillance Project, which electronically monitors 90 miles of freeway and controls 48 on-ramps, cost approximately $4.5 million for implementation, not including $359,000 for the central computer. In addition to the annual operation and maintenance cost the emergency traffic patrol that handles freeway incidents has an annual budget of approximately $1.5 million.

The North Central Expressway project in Dallas initially comprised the mainline of the freeway and 35 ramps controlled by a central computer at an initial cost of $450,000 exclusive of the computer. A system of eight television cameras was installed later at a cost of $10,000 per camera installation. The system was later expanded to include the frontage road control systems, which cost approximately $800,000 including the computer system.

Other costable items include the installation of changeable-message signs on the Los Angeles area freeway for a total cost of $1.2 million with an option for additional signs at $20,000 to $25,000 each.

The cost-effectiveness of these programs can be measured by their impact on traffic flow. For example, the Chicago expressway ramp control systems have reduced travel time over a 10-mile section by 45 percent, accidents by 17 percent, and congestion by 60 percent.

The effectiveness of the Milwaukee freeway ramp control program can be seen in the peak-hour volume increase of 4 percent and a vehicle speed increase of approximately 20 percent. Implementation of this technique on the Detroit Lodge Expressway considerably improved traffic flow conditions and reduced accidents. While in operation the program's annual benefits were estimated to be approximately $675,000.

The Los Angeles expressway program of ramp control of six ramps on the Harbor Freeway has enhanced the traffic flow. For example, travel time has been reduced by 32 percent and estimated annual public savings amount to $325,000. Similar experience has been recorded on the

Houston Gulf Freeway project; traffic volume has increased 9 percent, travel time has been reduced by 25 percent, and estimated annual public savings amount to $262,000.

Indirect Impacts.—Many of the techniques that maximize use of existing facilities may have some impacts on adjacent land-use activities. For example, restriction of parking on arterials in commercially zoned areas during peak periods may cause changes in consumer activities. Prohibition of turning movements and conversion of CBD streets to one-way pairs may have a similar impact. In general, the greater the number of controls instituted to program traffic movements, the less flexibility the driver has in operating the vehicle. Although these controls are aimed at reducing peak-hour traffic congestion, actual travel patterns may be altered, which can lead to an increase in distance traveled. In the cases previously cited, the benefits measured were in terms of traffic volume increase, accident reduction, and delay costs along a route or at a specific location. To determine the over-all effect of these measures requires consideration of the entire area. There may be an increase in the travel distance required to satisfy origin-and-destination pairs. This would be reflected in some tradeoff of travel times, speeds, and distances, as well as corridor or route impacts if any.

A program of freeway surveillance and control will aid in moving traffic at controllable service volumes, thereby enhancing the drivers' attitudes toward continuing their travel habits. Only when traffic congestion, travel time, or travel cost reach unacceptable levels and feasible alternative travel modes are made available will travel patterns and habits change. This technique provides a short-term solution to freeway traffic congestion, thereby continuing to foster auto travel. This will have the effect of increasing congestion elsewhere, which can be alleviated by the maximum use of existing facilities; but regardless, increased auto travel will result in increases in energy consumption and air pollution.

Timing.—Most of the maximum use techniques can be implemented in a very short time frame and do not require extensive programming or budgetary requirements. The more complex alternatives involving a major design modification (such as construction of a grade-separated interchange) in the past have required a one- to three-year planning-to-implementation period. Today this time period for major changes involving heavy construction may take eight years, including public hearings, environmental impact statements, and other pre-construction requirements. However, most of the techniques considered here are immediately implementable.

From the experience to date, installation of a freeway surveillance and control system requires approximately three years from the planning phase to implementation. This includes ramp metering projects and installation of electronic surveillance on the freeway.

Feasibility

Institutional Considerations.—The institutional considerations of this particular package are minimal. Traffic engineering solutions can be carried out entirely by local governments, although state and federal technical aid and support is available. Freeway surveillance and control systems are generally operated and maintained by state highway agencies or by the city; but because of the high costs involved, research, development, capital investments, installation, and construction have been funded by the state and federal governments.

Public Acceptance.—There is general acceptance by the public of the implementation of these techniques. Maximum use of existing facilities requires a short-term "phasing in" of the modifications to ensure compliance and to overcome any difficulties that may initially develop. Because of the past experience of the public in the use of these techniques, general compliance can be expected. When freeway surveillance and control has been implemented, some difficulties have developed when ramps are closed during certain time periods. For this reason, an educational program may be required to inform the public of the intent of the project. For example, it may be important to provide information on how to interpret the signs and signals when driving on an entrance ramp that is metering the flow of vehicles onto the freeway. This aids in implementing the package and increases its immediate impact.

Acceptance by Private Organizations.—Experience has shown that acceptance of engineering techniques and the over-all package may vary. In specific locations, particularly where land-use activities may be adversely effected, the approach can cause conflicts with private organizations; e.g., the removal of on-street parking from in front of shopping stores. Another example of a potential conflict is an improvement that creates more traffic volume and higher speeds in a residential area. Again, implementation of these techniques requires consideration of the impact on areas adjacent to the actual target arterials.

Generally, private organizations are receptive to freeway surveillance and control because it provides for greater accessibility throughout the area. Again, conflicts may develop when use of the private automobile is restricted or access to the freeway is restricted or denied in certain locations during peak periods. This is discussed in more detail elsewhere in this report.

Compatibility with Existing Laws.—The implementation of this package or a variation of techniques does not appear to be hindered by any legal obstacles. Most areas have experience in implementing several of the maximum use techniques presented in this package; consequently, no difficulty is anticipated. Although experience with freeway surveillance and control is not as common, it has been demonstrated throughout the United States, thereby providing precedent for its use.

Readiness for Implementation.—The procedures and technology currently exist to readily implement this package. The degree of sophistication desired in the control and response mode of the freeway surveillance and control package may require some hardware and software development. However, it is expected that most applications will center around the current state-of-the-art programs.

Package No. 8: Transit Treatment

This package of techniques is aimed at making transit more competitive with the private auto along the major urban travel corridors and in the congested downtown and major activity centers of larger urban areas. This is accomplished by providing priority for express transit systems along freeways and arterials and making these services accessible at both ends of the communter route by extended-area transit in residential areas and circulation systems in the CBD. Marketing techniques, such as reduced fares and park-and-ride facilities, provide additional incentives to transit use. Figure 12 shows the composition of this package and its relation to other packages and techniques.

Effectiveness of this package in reducing peak-period traffic congestion is dependent not on the number of travelers carried in the peak period by the transit system, but on improved traffic flows along streets, arterials, or highways. This in turn is dependent on the number of peak-period drivers diverted to transit treatments. To be effective this package must create a situation along certain major travel corridors that not only diverts a sufficient number of travelers to transit to decrease traffic congestion, but also does so in a manner that tends to inhibit the redevelopment of congestion.

This package is designed to capture the cumulative impact of as many individual transit approaches and incentives as possible. Express buses, even in mixed traffic, offer an improved transit service that is as fast as private cars on the line-haul portion of a trip and may be sufficiently attractive to divert a number of travelers to transit. Giving priority to express bus services along major urban travel corridors offers an even more attractive transit package by providing transit service that is faster than private cars along the line-haul portion of the trip. In addition, the priority given to express buses in congested downtown streets ensures that the time gained over the auto on the line-haul portion of the trip is not lost. Priority given to both express buses and the "local" downtown circulation system increases the attractiveness of transit commuting to work. Moreover, the downtown circulation service removes some of the fears that auto drivers may have about easy midday mobility if they do not drive their cars to work; it also reduces the number of short noon-hour auto trips that add to midday congestion in the CBD. A no-fare downtown circulation system can offer additional incentives; combined with the arterial priority system, special circulation buses offer an attractive service to a number of different users, including peak-period auto drivers. When such a system is implemented, advertising and promotional programs and improved public information services are required, and these marketing techniques can contribute to increases in ridership.

Component Techniques of the Basic Package

Incentives to transit

Priority transit, expressways

Priority transit, arterials

Transit circulation

Extended-area transit

Supportive Techniques	Neutral Techniques	Conflicting Techniques
Staggered work hours	New Towns	Communications in lieu of travel
Road pricing		Carpooling and other ride sharing
Parking controls		Freeway surveillance and control
Traffic cells		Maximizing use of existing facilities
Auto-free zones		
Zoning and building codes		

Supportive Packages	Neutral Packages	Conflicting Packages
Changes in work hours	Changes in land use	Prearranged ride sharing
Pricing techniques	Communications substitutes for travel	Traffic engineering
Restriction of access		

Figure 12. Schematic of package No. 8: Transit treatment.

Three types of express bus treatment along highways and expressways are recommended for use in this package:

1. Express buses in mixed traffic on existing major freeways.
2. At-grade contra-flow priority lanes on existing expressways and freeways during peak periods.
3. At-grade with-flow priority lanes on existing expressways and freeways during peak periods.

Busways, additional lanes constructed for exclusive bus rights-of-way, are not proposed because of their high costs.

The most successful express bus systems offer service along relatively long corridors from residential districts to well-defined and fairly concentrated employment sites; most utilize a park-and-ride service rather than transit feeder service. However, transit feeder service may be required in some communities. When express bus service is considered for initial service or expansion as part of this package, the need for feeder services should be investigated, preferably by being offered for some time as a test run.

Although it is no longer thought necessary that a bus priority lane carry as many passengers per hour as private autos would if they were using that lane, ridership may be substantially below that number in some areas. Along travel corridors with sufficient ridership to warrant an express service but insufficient ridership to warrant priority treatment, express bus services can still be very attractive in mixed traffic, especially if they are given priority treatment on downtown arterials as envisioned by this package.

If sufficient ridership exists to warrant granting higher-occupancy vehicles priority over autos traveling along the same expressways and freeways, this package provides for selection of the least costly and most immediately implementable method—a system of manually placed barriers during peak periods. Both with- and contra-flow priority lanes can make use of underutilized lanes of traffic in the off-peak direction; thus they become relatively cheap to implement and they impose the least burden on auto traffic in adjacent lanes. Although most planned bus priority systems call for construction of at-grade or grade-separated right-of-way on the expressway, that solution is far from the most cost-effective for the majority of American cities. Contra-flow lanes are by far the cheapest and easiest priority treatment of express buses because they require the fewest ramp alterations.

However, this technique cannot be applied on freeways where peak-hour flow is equally heavy in both directions. In such cases a lane of traffic in the with-flow direction would have to be removed from auto availability to create a priority lane.

Where this occurs planners and decision-makers must make a policy decision: does the greater potential capacity of the bus justify the heavy imposition on existing auto traffic that would occur if a full lane (or two) were removed from auto availability? The decision would be based in part on the number of auto drivers that would be expected to switch to transit if auto traffic significantly increased due to imposition of the bus-priority lane.

It is more difficult to determine whether a with-flow or a contra-flow lane would be more efficient in the downtown area of most cities. Such decisions depend on local conditions, including the number and extent of the one-way street system as well as the routing of both the express buses performing their distribution function and the special downtown circulation system. This package envisions both types of buses using the same reserved curbside lane. Regardless, inclusion of preferential treatment for transit vehicles on downtown streets is necessary in order to maintain or increase any gains in travel time brought about by express or priority transit services on freeways. In areas that are heavily congested for long periods of the day, it may be feasible to allow transit travel priority at the expense of auto traffic, because the downtown circulation system, by providing mobility for all travelers, offers a service competitive to that of the auto in congested areas while reducing the need for parking facilities. Some cities have found that the presence of both express and local buses in the same priority lane did cause a slight delay in the express service. Part of this problem may be handled by better scheduling, but most cities just accepted this delay because the priority concept still brought about marked increases in both types of bus service.

Free downtown circulation systems have had a record of success in both increasing transit ridership and decreasing downtown traffic congestion. Peripheral-area parking services will attract more users if offered in conjunction with a free circulation system.

Downtown circulation systems often show fairly heavy ridership throughout the day. Some of this ridership represents an increase in discretionary riding, but it also represents substitution of some short auto trips for those who drive their cars to work. Making such circulation systems free is designed to attract as many substitutions for auto travel in downtown congested areas as possible.

Free off-peak service has been shown to be an effective means to divert transit ridership from peak to off-peak hours. In addition, such fare reductions have been associated with slight increases in over-all system ridership. This diversion of travelers to off-peak periods is designed to accomplish two objectives. The first is to reduce peak use of transit facilities, thus making transit more attractive to the traveler who must travel in peak periods and increasing peak-period system operating efficiency. The second objective is to increase the over-all operating efficiency of the transit system by encouraging use of generally underutilized equipment in off-peak periods.

Compatibility with Other Approaches

This particular package is compatible with many other techniques and packages; primarily because these techniques and packages, whether social or socioeconomic approaches, incorporate some transit component in their operation. Staggered work hours, when implemented efficiently, allow the transit system to better utilize its excess capacity on both sides of the morning and evening peaks. Moreover, staggered work hours programs can be successfully combined with express bus service, especially when large employment concentrations are being served. The pricing techniques (road pricing and parking controls) encourage use of transit by creating economic sanctions against commuting by auto and thereby increasing the attractiveness of transit. Auto-free zones and traffic cells also increase transit ridership by limiting or prohibiting the use of autos. Furthermore, these techniques offer the opportunity to redesign transit facilities and impose priority transit in certain areas. Finally, zoning and building codes can be used to limit the supply of off-street parking and encourage drivers to turn to transit for trips to congested areas.

Traffic engineering techniques, maximum use of existing facilities, and freeway surveillance and control are not appropriate for use with this package. Because the primary goal of these techniques is to increase road capacity, they are in direct conflict with the creation of bus priority lanes. More importantly, the impact of these techniques is to encourage increased use of private vehicles, which is directly opposed to the aims of this transit technique package. Communications techniques, which have a neutral relation to most techniques and packages, are considered conflicting with transit treatments as their widespread use would lead to declines in transit use. The effect of carpooling and ride sharing on this package is uncertain. Priority lanes may be opened up to carpools, increasing the effective capacity of the lane and further justifying their creation. Care must be taken, however, to assure that this does not interfere with transit vehicles, especially on entrance and exit ramps. This report takes the position that these techniques are conflicting because they compete for the same riders, and evidence from experiments in California seems to support this view.

Applicability

The thrust of this package is on two problem areas at the same time; downtown area congestion and, to a lesser degree, arterial and highway congestion outside the downtown area, especially along corridors of heavy travel demand. This package would be applicable to medium or large cities with residential suburbs and concentrated downtown or other central areas that are heavily congested for most of the day. The package promises a measurable reduction in downtown traffic congestion but is less optimistic about the impact of these measures on expressway corridor traffic flows.

Express bus service is appropriate for cities with fairly fixed travel corridors of between 8 and 14 miles with either a common CBD or central area destination; these are the conditions that are most conducive to successful express bus services. The package also envisions a city with fairly substantial transit ridership but not operating at or near potential capacity; it assumes that an increase in transit ridership during the peak period would be beneficial to both the road and transit systems.

The decision to attempt a priority treatment for express bus services depends on both the number of vehicles and the number of passengers actually carried in each vehicle in the priority lane. If the expressway priority lane were open to only buses, it would have to carry in excess of 3,000 passengers per hour to equal the auto-carrying capacity of that lane, assuming an average occupancy of 1.5 persons per auto. This passenger volume is equivalent to 60 full 53-passenger buses running on 1-minute headways. Of course, the carrying capacity of the lane could be increased by opening it to carpools, but this may create operational difficulties; allowing carpools to use the lane would require policing, as exemplified by the Bay Bridge (San Francisco) experience. Special exit ramps for carpools would be necessary inasmuch as the priority lanes envisioned in the downtown area in this package would exit onto downtown "bus only" lanes.

Priority treatment is most applicable in cities with high-density corridors and high potential transit ridership where traffic flows are heavily weighted in one direction during the peak period. This condition implies that there are opportunities for using underutilized lanes of traffic in the non-peak direction for bus priority lanes. It is worthwhile to note that the four most significant contra-flow expressway projects so far operate only in the AM peak when the flows are extremely weighted in one direction; the flows in the evening peak are also heavily weighted in one direction, but are not considered intense enough to justify use of a transit priority lane. If there is not an existing lane that is currently underutilized, some cities may nonetheless choose to remove one or more lanes of traffic from auto use in the peak direction in order to provide greater transit incentives through the ensuing increase in traffic congestion. Such a policy would convert existing heavily utilized lanes of auto traffic to transit priority lanes as a purposeful public policy of discouraging auto travel to downtown areas. This could, in effect, create prohibitive sanctions against auto use on specific heavily traveled routes and could effectively be applied in older, densely populated cities where roadway facilities were built several decades ago or where natural bottlenecks like bridges and tunnels create congestion in both directions in the peak period.

Applicability of the remaining techniques in this package (circulation systems and marketing) is not restricted by urban size or form; the techniques have been successfully used to reduce congestion in many CBDs and central areas. Their only requirement is an existing transit system. Their impact as part of this package, however, will be significantly greater than if they were used alone.

Costs and Effectiveness

Direct Costs and Benefits.—The capital costs of this entire package are generally low, although operating costs may be high. In general, capital costs are limited to five areas:

1. Transit system capital expenditures, if any, for new rolling stock for either express or circulation service.
2. Costs involved in modifying expressways for peak-hour priority lanes.
3. Costs involved in constructing or modifying exit and entrance ramps to give priority to transit.
4. Costs involved in converting arterial curb lanes into priority transit lanes.
5. Costs of providing and maintaining peripheral parking lots.

These costs will vary from city to city; most of the capital expenditures involved are eligible for both FHWA and UMTA funding under the Highway Act of 1973 and the Transit Assistance Act of 1974. If new transit vehicles are required, a substantial time delay should be anticipated, because most manufacturers are significantly behind in their production.

Costs of the modifications to be made to the highways and arterials in question should be small. On expressways these will involve some reworking of the median strip, re-striping of lanes, a system of signing, and adjustments in entry ramps for the transit vehicles; most of the projects analyzed earlier spent less than $50,000 on these changes. Reworking of ramp entrances may prove to be the most expensive part of expressway alterations, but this can also vary from city to city.

Modifications to the arterial system in the downtown area may prove somewhat more expensive because these will be permanent installations; again they will require re-striping of lanes and a system of traffic signs. On streets where curb parking has been permitted, a simple solution is simply to ban such parking and use the additional space for the priority lane. On streets where this lane is already committed to vehicular traffic, it will be necessary to reduce the lanes available for automobile use in order to create a lane for the exclusive use of transit vehicles.

If peripheral parking facilities are not currently owned by either the transit system or the municipality, they must be purchased or leased. If the city or transit operator currently owns a parking facility and operates it for a fee, revenues lost by instituting free parking must be assessed against this package as a cost. However, parking areas of public facilities not normally used during working hours, such as stadiums, may be available; the only cost of using them for commuter park-and-ride facilities is then for surveillance and maintenance.

The major operating expenses will be borne by both the transit authority and the agency responsible for manually converting traffic lanes to transit priority lanes during peak periods.

Costs to the transit authority will consist of additional operating losses occasioned by increasing services on the line-haul express routes, providing new or improved feeder services, and operating the CBD circulation system at no fare. These additional costs will vary from city to city, depending on the existing level of service and the increased efficiency of operation of the new level of service, but can be assumed to range between $0.75 and $1.10 per vehicle-mile. It is possible that improved travel speeds on the line-haul portion of the service and increases in ridership may compensate for additional operating costs of the new express services.

As indicated earlier, feeder services to line-haul facilities have only been self-supporting when they have had significant nonfeeder ridership that continues through non-peak hours of the days. This may indicate that it is more useful to simply reroute local buses to intersect with express routes. The viability of conventional feeder services to the express line-haul services is unknown and will vary from community to community; it may be more cost-effective in some cities to provide expanded park-and-ride facilities. The costs of the no-fare downtown circulation system will consist of any necessary capital expenditures (generally new, smaller buses, and signs and schedules) and 100 percent of the operating and maintenance costs.

Although operating costs vary slightly with passenger load and average speed, it should be possible to predict both ridership and average operating speeds within a satisfactory range for improvements to existing routes. It is more difficult to predict ridership on any additional express routes; it probably would be wise to assume low ridership or, alternatively, high subsidy requirements for a pre-established but adequate time period. At the end of that period a decision should be made, based on actual ridership at the time, whether to continue the service, modify it in some way, or abandon it because it is too costly. (This is recommended over the more common practice of assuming large initial ridership and then being forced to seek adequate subsidy when the ridership does not materialize.

The major operating costs that must be carried by the traffic agency are (a) the manual change-over to priority lanes during different peak periods and (b) policing of downtown priority lanes. In Boston the cost of manually placing barriers and traffic cones was more than $500 per day. Some experts feel that the addition of more permanent signing mechanisms and other devices will reduce operating costs significantly. However, for all the contra-flow projects investigated, long-term operating costs exceed implementation costs.

The success of this group of techniques in reducing actual peak-period traffic congestion depends in large measure on the number of auto drivers diverted to transit in peak periods; even dramatic increases in transit ridership along major arteries and expressways have not been accompanied by decreases in traffic congestion. There appears to be a number of reasons for this; express transit riders may be former transit riders who have switched to a more efficient routing. They may also be new travelers or former carpool members. In addition, there is evidence that auto drivers who normally traveled in the slopes of the peak period switch to more traditional peak times to take advantage of the decrease in traffic brought about by the bus priority system; thus, a new peaking phenomenon occurs.

Congestion on freeways and arterials may also be increased where former automobile lanes have been allocated to the exclusive use of transit vehicles. This congestion may be created deliberately to discourage commuters from driving their cars into the CBD. This package relies on the greater attractiveness of transit vehicles, both on expressways and downtown arterials, to divert a significant number of former auto drivers to transit—only in this way can this package justify both preemption of one or more lanes of traffic for transit use and the daily operating costs involved in manually changing priority lanes.

When priority treatments are applied to freeways with no excess capacity, a different impact is expected: this approach aims at first producing traffic congestion, which is then used to produce a sizeable diversion to transit. This is done to limit the number of private vehicles entering the CBD because of CBD congestion or to reduce air pollution and energy consumption. Theoretically, this diversion to transit should ultimately decrease traffic congestion along these travel corridors. Of course, the greater decrease in downtown or central area congestion is expected because of the dual reinforcement of superior line-haul service and local transit priority combined with a no-fare policy. Unfortunately there is not much actual experience with the conscious preemption of heavily utilized lanes of traffic; both California and New York are planning to implement demonstrations of the feasibility of this concept.

Both priority approaches promise sizeable diversion of travelers to transit; it is not known if the traffic congestion created by the second approach along expressway travel corridors will ultimately abate as more and more travelers change to transit. It is possible to be more optimistic about the result of both approaches on downtown congestion; the fare incentives to transit and the availability of service that may be superior to the auto in a congested area have brought about measurable decreases in traffic congestion in a number of areas. Many cities are quite enthusiastic about the concept of free downtown transit service, even without priority treatment.

Downtown circulation systems have been very successful in attracting ridership in the last five years; recent experiments with downtown systems show dramatic increases in ridership and some measurable decreases in traffic congestion. Peripheral parking facilities used as downtown park-and-ride services, either in conjunction with specialized transit services or in conjunction with regular transit service, have not been equally successful. This is thought to be due to the reluctance of commuters who have already driven part of the way to work to change modes so close to their destination. As part of this package, however, peripheral parking can be expected to be more effective. This technique is recommended because most cities can create peripheral parking facilities at very small cost, and the minor deviation that might be required for routing of the downtown circulation system may well be justified in terms of reduced numbers of private cars in the CBD. If parking costs were a significant factor in such a package for any individual city, however, that city might well reexamine the need for the peripheral parking feature of this package.

This package of techniques promises more significant traffic reduction in congested downtown areas than along travel corridors into that downtown area. The package is envisioned as a good test of the effectiveness of mixtures of techniques with both primary and secondary impacts on traffic congestion.

Both priority treatments, but particularly those that impose significant restrictions on autos in adjacent lanes, may never be advanced solely as a tool to control traffic congestion; they generally will be invoked to deal with environmental and energy concerns, perhaps in line with recent EPA requirements. If so, use of this package could and may be justified on a number of independent grounds; these should be borne in mind when discussing both costs and political feasibility.

The success of this package, then, depends in large measure on its correct application to a relevant situation. Even then, there may be additional problems. The return of off-peak drivers to peak times when a transit priority system brings about increased traffic flows may indicate that most drivers are willing to tolerate current levels of traffic congestion and only techniques which penalize them further, such as road pricing, can prevent this recurrence of traffic congestion.

Indirect Impacts.—Priority transit treatments have the potential to create additional imposition on adjoining lanes of auto traffic. If this increase in congestion is tolerated by current drivers, and they do not relieve the situation by switching to transit, a number of serious problems arise. Total trip time will increase for all auto travelers while gasoline consumption and pollution will also rise. Even if auto drivers are finally forced to switch to transit, the other impacts in the interim period may have created serious health and energy problems.

In addition, this package centers on existing downtown and heavily built-up employment concentrations. This has two major implications. First, it may act to revitalize and strengthen the downtown of cities at the expense of suburban and other urban complexes. In this regard, downtown merchants and large downtown employers are often willing to pay part or all of the costs of downtown circulation services either because of increased revenue or increased employee mobility. This potential source of revenue should not be forgotten; it is one way to capture some of the increases in commercial profits generated by both the system itself and any reduction in traffic congestion it produces. Second, by addressing travel problems only in existing employment concentrations it fails to capture transit workers in new or developing employment centers, particularly in the suburbs. These new employees' travel habits will grow up around use of the private car and not around transit.

Timing.—Technically, this package of techniques is implementable immediately, especially if most of the transit options can be undertaken without purchase of new equipment. Should the transit authority need to provide new buses there is now a substantial wait before these vehicles can be delivered by manufacturers. However, the downtown circulation or feeder systems can utilize more readily available smaller vehicles. The expressway lanes are easily implemented in most areas; the longest time would be required for provision of special freeway access and egress ramps. These changes generally require a year or less. The same is true for installation of downtown arterial markings, barriers, and signs. However, before any of these activities are begun, six months to a year should be devoted to studying the feasibility, application, and possible impacts of this package.

Feasibility

Institutional Considerations.—Because all of the techniques in this package are transit treatments, the institutional considerations of this package are minimal. Bus priority on expressways involves the greatest number of agencies, primarily because it is a relatively new transit technique. These programs have previously involved the following agencies: FHWA, UMTA, state departments of transportation, regional councils of government, transit authorities, counties, and cities. The other techniques in this package typically require only the cooperation of local governments and local transit operators. As previously mentioned, some funding for all five techniques is available from UMTA and FHWA.

Public Acceptance.—This entire package requires the acceptance of the general public in two ways. First, the public must approve of the policy of granting priority to transit vehicles; this has been the case with most of the operations discussed previously. Second, the public must, by and large, honor the temporary barriers and stay out of priority lanes. It is precisely because people will use the lane if not stopped that contra-flow lanes are often suggested for priority treatments, inasmuch as they tend to be self-regulating. Policing and enforcement will be necessary for with-flow reserved lanes even if physical barriers are provided, but the need for policing should decrease over time, especially where permanent physical barriers to auto travel are constructed. If transit priority lanes take over some existing heavily utilized traffic lanes, there may be a great deal of public opposition from drivers who are accustomed to using that route. Their initial response will be to protest the reduction in automobile lanes, and diversion to transit will come only after they have accepted the additional congestion of their particular routes as a permanent change. In general, the other components of this package have been well received. If public officials feel they have over-all community support for such a package, they may feel safe in implementing it; other officials may seek such solutions only under the type of duress provided by the EPA.

Acceptance by Private Organizations.—Businesses in downtown commercial areas tend to profit from the over-all impact of downtown priority transit and circulation systems. However, because priority transit often removes parking from immediately in front of their entrances, and delivery and service calls to downtown commercial and business enterprises along the route of the arterial bus-only lane may be hampered, merchants may initially pose difficult problems. Downtown merchants often are unwilling to consider any alterations in existing parking or traffic patterns because they fear these changes will reduce their revenues. These commercial enterprises must be provided with alternate service entrances and delivery times; in Los Angeles a downtown bus lane was disrupted by delivery vehicles parking in what was formerly the curb lane because no alternative delivery entrances were available.

Because this package is aimed at improving travel into and within the central city, suburban merchants and other business establishments may oppose the subsidization of transit operations that will exclusively benefit the CBD. Revitalization of downtown activities may take place at the expense of suburban shopping centers, and this package should not be implemented without recognizing this as a possible side effect. Over-all urban development policies should be consulted to determine whether such shifts in economic activity are desired by the community, and whether additional efforts, such as improving suburban transit circulation, should be made to maintain suburban businesses.

Compatibility with Existing Laws.—None of the individual techniques or the package of techniques would require any change in existing laws.

Readiness for Implementation.—All of the individual techniques that comprise this package have been tested and are considered ready for immediate implementation. Aside from delays in purchase of new transit equipment, implementation of this package should meet with no serious obstacles. The most critical factor in its implementation may be the willingness of the public agency involved to either absorb the costs as payment for the external benefits to the community (such as decreased traffic congestion and enhanced environmental factors) or the agency's ability to recoup some of the costs from the community.

CHAPTER THREE

INTERPRETATION, APPRAISAL, AND APPLICATION

To assist local agencies in selecting effective and workable solutions to their particular peak-period traffic congestion problems, the eight packages of congestion-reduction techniques were evaluated in terms of anticipated benefits and costs, and feasibility. Because none of the combinations of techniques has yet been implemented as a package, the conclusions presented here reflect subjective judgments. They are drawn largely from the evaluations of the individual techniques reviewed in Chapter Two. However, they have been modified to incorporate changes in effectiveness, costs, indirect impacts, and feasibility that are expected to result from the application of these techniques within a coordinated program.

Summary ratings of each of the packages with regard to separate elements of benefits and costs and feasibility are first presented. This is then followed by a composite ranking of the eight program options as solutions to the five types of peak-period congestion problems found to be common to many urban areas.

BENEFITS AND COSTS

Direct Costs and Effectiveness on Congestion

Table 2 compares the effectiveness in alleviating traffic congestion and direct costs of implementation of the proposed packages. Impact on congestion in each of the five problem areas ranges from 0 (not effective) through 3 (highly effective). Direct costs range from 0 (none) to 3 (over $1 million), and distinguish those that would be borne by local government and others for both basic and additional or optional costs. In an attempt to suggest an over-all guide to the relative cost-effectiveness of the different packages,

TABLE 2

RATINGS OF EFFECTIVENESS AND DIRECT COSTS OF PROPOSED PACKAGES OF CONGESTION-REDUCTION TECHNIQUES

	Effectiveness on Congestion *					Cost of Implementation **				
	Major Problem Areas			Special Problem Areas		Basic		Additional		
Package	CBDs of Large Cities	CBDs of Small Cities	Urban Freeways and Arterials	Roadways with Strong One-Directional Flow	Roadways with Limited Options for Alternative Routes	Local Gov't	Others	Local Gov't	Others	Generalized Ratio of Effectiveness and Direct Cost to Local Government
Work-Hour Changes	2	1	1	2	2	1	1	1	3	2/1
Pricing Techniques	3	3	1	1	3	1	2	1	3	3/1
Access Restriction	3	3	1	1	2	1	2	2	3	3/1
Land-Use Changes	3	1	2	2	3	2	3	1	3	3/2
Prearranged Ride Sharing	2	1	2	2	3	1	1	1	1	2/1
Communications Substitutes for Travel	1	0	2	2	2	1	3	1	3	2/1
Traffic Engineering Techniques	2	2	3	3	1	2	3	1	3	2/2
Transit Treatments	3	1	3	3	3	2	3	3	1	3/2

* 0 = Not effective, 1 = Slightly effective, 2 = Moderately effective, 3 = Significantly effective.

** 0 = None, 1 = Under $300,000, 2 = $300,000-$1 million, 3 = Over $1 million.

generalized ratings of effectiveness and direct cost to local government are presented as ratios.

The transit treatment package is judged to be highly effective in four of the five congestion problem areas, and represents probably the best all-around solution to an urban area with a broad range of peak-period traffic difficulties. Pricing techniques function well on roadways with limited options for alternative routes as well as in CBDs, whereas the restriction of access package is particularly suited to problems of CBD congestion in both large and small cities. Traffic engineering techniques are best applied to freeway and arterial congestion, especially those burdened by strong one-directional commuter traffic. Impacts of work hours changes, prearranged ride-sharing, and communications substitutes packages on peak-period congestion are found to be only moderately beneficial because only a relatively small percentage of commuters is affected.

Basic costs to local government of all of the packages would not exceed $1 million, although heavy investment by state and federal government is necessary to the traffic engineering and transit packages and by private entities for land-use changes and communications substitutes. Five of the eight packages could be basically implemented by local government for less than $300,000: work hours changes, pricing techniques, restriction of access, ride sharing, and communications substitutes. Additional costs that may be incurred generally fall on others than local government. In most cases they represent federal grants for major improvements to transit and for urban redevelopment that may be undertaken in support of the basic programs.

Packages of pricing techniques and restriction of access appear to be the most generally effective measures for their costs. Costs of the work hours changes, the communications substitutes, and the prearranged ride-sharing packages are also low, but are not rated as effective as those mentioned above. Packages of land-use changes and transit treatments require an investment of $300,000 to $1 million on the part of local government, but are rated as significantly effective. The traffic engineering techniques package involves substantial costs to local government, as well as to other levels of government, but is generally not as effective in reducing traffic congestion as many of the other packages.

Indirect Impacts

Table 3 summarizes the indirect benefits and disbenefits expected as a result of implementing the eight congestion-reduction packages. Net benefits are indicated by plus (+) symbols and net disbenefits by minus (—) symbols. Where benefits and disbenefits are considered as balancing each other out, a zero (0) is shown. In another attempt to provide an over-all evaluation of the various packages, a generalized rating of the combined indirect impacts is suggested for each potential program.

In only two instances can potential disbenefits be expected to accompany implementation of the proposed congestion-reduction packages. Restriction of access will place additional traffic burdens on peripheral roadways and will interrupt the flow of vehicles at entry points to traffic cells and parking facilities. Although these undesirable effects can be mitigated by improving the capacity of peripheral roads and reserving slow lanes for entering and exiting facilities, some congestion problems should be expected during the initial phases of the project. Eventually, however, this problem should disappear as drivers find alternative routes and more commuters are persuaded to use the improved transit facilities.

Equity problems cannot be avoided in pricing schemes. Low-income workers, whose limited skills offer them fewer options in selecting work locations and hours, will feel the penalties of the system to a larger extent than the labor force in general. Sufficient options in transit and ride sharing can help to relieve some of this inequity.

In the remaining cases benefits either outweight or equalize disbenefits that would result indirectly from applying the proposed packages of congestion-reduction techniques. All of the packages hold the promise of reduced environmental pollution, either by decreasing the number of vehicles used for commuting or by improving traffic flow. All but two of the packages (work hours changes and traffic engineering techniques) would result in energy savings through reduced consumption of automotive fuels. Decreases in accident rates could be expected to result from all but one of the packages (restricting access), where congestion problems at entry points to controlled areas and parking facilities may balance out those eliminated within the restricted zones.

Beneficial changes in long-range travel demands and patterns are anticipated from six of the eight proposed packages, especially in response to modifications in land use that reduce the needs for long commuting trips. Area-wide reductions in peak-period traffic congestion could be expected from implementing the packages of work-hours changes, land-use changes, prearranged ride sharing, communications substitutes, and transit treatments. Economic benefits are associated with pricing techniques, restriction of access, and prearranged ride sharing, whereas transit improvements would provide increased urban mobility for those who are now restricted by their inability to drive or lack of access to private cars.

Both public and private institutions could anticipate some tangible benefits from programs involving restricted access, land-use changes, ride sharing, and communications substitutes for travel to work. The over-all evaluation of the packages of congestion-reduction techniques indicates that six of the eight proposed programs would result in greater indirect benefits to the community than disbenefits, and the remaining two packages would yield an acceptable balance of positive and negative impacts.

Time Factors

Table 4 compares the eight congestion-reduction packages with regard to two important time factors: the lapse of time that should be expected between initiation of each of the proposed programs and the realization of benefits in reduced congestion; and the lasting quality of these benefits. Three of the packages of techniques could bring immediate relief to peak-period traffic congestion: work-hours changes, pricing techniques, and prearranged ride

TABLE 3

RATINGS OF INDIRECT BENEFITS AND DISBENEFITS ASSOCIATED WITH THE PROPOSED PACKAGES OF CONGESTION-REDUCTION TECHNIQUES *

Package	Other System Traffic Congestion	Long-Range Travel Demands and Patterns	Energy Conservation	Environmental Pollution	Public Safety	Economic Impacts	Equity Considerations	Institutional Considerations: Public	Institutional Considerations: Private	Generalized Summation of Net Benefits and Disbenefits
Work-Hour Changes	+	+	0	+	+	0	0	0	0	0
Pricing Techniques	0	+	+	+	+	+	-	0	0	+
Access Restriction	-	+	+	+	0	+	0	+	+	+
Land-Use Changes	+	+	+	+	+	0	0	+	+	+
Prearranged Ride Sharing	+	0	+	+	+	+	0	+	+	+
Communications Substutes for Travel	+	+	+	+	+	0	0	+	+	+
Traffic Engineering Techniques	0	0	0	+	+	0	0	0	0	0
Transit Treatments	+	+	+	+	+	0	+	0	0	+

* + = Net benefits, - = Net disbenefits, 0 = Benefits and disbenefits balance.

sharing. These benefits could also be expected to be lasting under the first two, but there is still some risk that ride sharing, even with the support of compatible techniques, will tend to lose its original impetus over time.

Three other packages offer midterm solutions to peak-period traffic congestion, requiring between one and three years before their potential benefits can be realized. These are programs for restriction of access, traffic engineering techniques, and transit treatments. Improvements in traffic flow brought about by application of the traffic engineering package, however, are evaluated as short-lived, because none of the elements in the program is directed at modifying basic travel demands and patterns. It is expected that reduced travel times and alleviation of congestion problems will eventually attract commuters to the improved route and recreate the original crowded conditions.

Packages of techniques to change land uses and substitute communications for work trips offer lasting solutions to peak-period congestion, but their full benefits cannot be expected for at least three years after the program is ini-

TABLE 4

RATINGS OF TIME FACTORS ASSOCIATED WITH THE PROPOSED PACKAGES OF CONGESTION-REDUCTION TECHNIQUES

Package	Time Lapse Before Benefits are Realized	Duration of Benefits
Work-Hour Changes	1 year	Lasting
Pricing Techniques	1 year	Lasting
Access Restriction	1-3 years	Lasting
Land-Use Changes	3 years	Lasting
Prearranged Ride Sharing	1 year	Short-lived
Communications Substitutes for Travel	3 years	Lasting
Traffic Engineering Techniques	1-3 years	Short-lived
Transit Treatments	1-3 years	Lasting

tiated. Local government can readily take action in modifying land-use designations and providing the opportunities for use of dispersal communications facilities, but significant impacts on commuter travel will only be realized through adoption of these measures by large segments of the private sector. Communities may find it desirable to undertake two different programs, one with short-term effectiveness to bring immediate relief to pressing congestion problems and a second directed toward achieving a lasting solution.

FEASIBILITY

Table 5 rates the feasibility of implementing each of the eight packages of congestion-reduction techniques. The program utilizing traffic engineering techniques to improve road capacity shows the highest potential for implementation, being rated as excellent under all categories of feasibility criteria. Prearranged ride-sharing programs are rated as excellent except in the area of public relations.

Packages of changes in work hours, restriction of access, and transit treatments are also considered to be highly acceptable for current implementation, although feasibility ratings with regard to certain criteria are less than excellent. Availability of essential funding and technical support is estimated to be only fair for the work-hours changes packages, and the cooperation of private organizations must rely on intensive public relations efforts. Techniques of handling restricted access so that the economy of the controlled area is not disrupted and new congestion problems are not created are not so highly developed as would be wished; this is reflected in the lower ratings for technical assistance and state of the art, and accounts for some anticipated difficulties in obtaining acceptance for these programs from private organizations. Problem areas with the transit treatments package are deficiencies in the availability of services for low-density transit markets, and in persuading drivers to adopt this new mode of commuting.

The over-all feasibility of the three remaining packages is rated as moderate. At present, funding for development of communications systems is difficult to find, and costs of equipment are high. Although the state of the art is sufficiently advanced to permit such operations, better and less expensive equipment is needed to gain the support of enough private organizations to have a significant impact on peak-period congestion. The package of techniques for changes in land use is rated as excellent with regard to two feasibility criteria—technical assistance and public acceptance of the concept. However, some problems may be experienced in obtaining funding and the active participation of both individuals and business organizations in carry-

TABLE 5

RATINGS OF THE FEASIBILITY OF IMPLEMENTING THE PROPOSED PACKAGES OF CONGESTION-REDUCTION TECHNIQUES *

Package	Essential Institutional Support: Funding	Essential Institutional Support: Technical Assistance	Public Acceptance: Concept	Public Acceptance: Participation	Acceptance by Private Organization	Compatibility with Existing Laws	State of the Art	Generalized Summation of Feasibility for Implementation
Work-Hour Changes	2	2	3	3	2	3	3	3
Pricing Techniques	2	2	2	1	1	2	2	2
Access Restriction	3	2	3	3	2	3	2	3
Land-Use Changes	2	3	3	2	2	2	2	2
Prearranged Ride Sharing	3	3	3	1	3	3	3	3
Communications Substitutes for Travel	1	2	3	2	3	3	2	2
Traffic Engineering Techniques	3	3	3	3	3	3	3	3
Transit Treatments	3	2	3	1	3	3	3	3

* 0 = Unacceptable, 1 = Poor, 2 = Moderate, 3 = Excellent.

ing out the goals of such programs. Existing land-use and zoning regulations can be changed, but lack of actual experience in large-scale reallocations of urban land leaves only theoretical rather than proven guidelines as to the optimum size and location of new multi-activity urban communities.

The pricing techniques package is evaluated as having the lowest feasibility for current implementation, with particular problems in obtaining the support of private organizations and the approval and participation of private individuals. It should be noted, however, that none of the eight proposed packages is found to be less than moderately feasible over all. No unacceptable feasibility ratings were thought to be justified, because critical problems inherent in certain individual techniques have been reduced by packaging them with other supportive measures. Similarly, in the five instances where poor ratings were given for individual feasibility criteria, these are outweighed by the larger number of higher ratings for other criteria. In short, five of the proposed packages are evaluated as excellent and the remaining three as moderate with regard to over-all feasibility for current implementation.

Although packaging of congestion-reduction techniques improves the feasibility of the individual approaches in general, it may generate new problems in the area of essential institutional support where several public and private entities become involved in the program. Some of the most important and difficult tasks of the local agency responsible for its implementation will be to select from the many federal and state assistance programs available those that will be compatible and appropriate to the goals of the local program, and to coordinate the efforts of these various agencies. Special care must be taken to prevent inadvertent working at cross-purposes, or the imposition of general, nationwide, or statewide objectives where they are not appropriate to the local situation.

RECOMMENDATIONS FOR APPLICATION OF PROPOSED PACKAGES

Five common types of peak-period traffic congestion have been identified.

Table 6 ranks the eight proposed packages of techniques for their relative suitability as solutions to each of these congestion problems. This ranking represents a summation of the preceding evaluations of effectiveness, cost, indirect impacts, and feasibility of the packages.

Before presenting and discussing the recommendations, however, four caveats should be noted. First, the evaluations are based on very few firm data and largely represent estimates of the study team, supported by informed opinion. Second, the process of summarizing requires that the overriding characteristic be identified and complexities and contradictions of the real situation be momentarily ignored. Third, the packages presented do not represent the only possible combinations of techniques that could be applied to these congestion problems; others might be designed that could be highly effective in different urban areas. And, finally, these programs are evaluated with reference to theoretical problem settings; the unique characteristics of individual urban areas may affect the cost, effectiveness, indirect impacts, and feasibility in ways that cannot be represented in these general recommendations.

CBDs of Large Cities

The optimum solution to peak-period congestion in CBDs of large cities is believed to be the package of transit treatments, followed closely by the packages of pricing techniques and restriction of access. Changes in land use offer substantial long-range benefits, whereas changes in work hours and prearranged ride-sharing packages are recommended as moderately effective short-term solutions. Traffic engineering techniques and communications substitutes packages are evaluated as least effective in dealing with the severe congestion conditions that occur in large CBDs.

CBDs of Small Cities

Congestion in CBDs of small cities responds best to the pricing techniques package designed for small cities, which is focused on parking controls. Restriction of access is believed to be the second most effective solution. Traffic engineering techniques that improve the capacity of the road system are found to be beneficial in small cities; the relatively limited economic activity of the community sets the upper limits of the number of commuters traveling to work, and improved routes are not so likely to become recongested as in large cities.

Transit treatments and land-use changes are rated as moderately effective mid-range and long-range packages of techniques, whereas programs of ride sharing and work-hours changes are thought to be only marginally useful in small cities. The package of communications substitutes is rated as ineffective in this problem area.

Urban Freeways and Arterials

Peak-period congestion on urban freeways and arterials can best be alleviated by major shifts in mode of commuting to public transit that can be achieved with the development of the integrated suburb-to-CBD system called for in the transit treatments package. The traffic engineering package, combining freeway surveillance and control with improvements in the capacity of existing roadways, can also be highly effective, but is rated below transit because of the tendency for congestion to reappear on routes where driving conditions have been improved.

Land-use changes that eliminate needs for long commuter trips to work are believed to offer long-lasting solutions to the problem of overcrowded urban road systems, but the benefits from implementing this package of techniques cannot be expected to be felt for some years. More immediate solutions can be provided by the prearranged ride-sharing or work-hours changes packages, although the percentage of total users of the road system participating in such programs will be relatively small and benefits will be limited.

Commuters traveling to the CBD can also be discouraged from using the overcrowded road system during peak periods by programs that restrict vehicle access to downtown areas and penalize all-day parking. Communications substitutes for travel to work can also reduce the number of rush-hour automobile commuters. The effectiveness of these three packages of techniques, however, is highly dependent on the share of total work trips that terminate in the CBD. Most urban areas have major employment centers outside of the CBD that generate peak-period congestion on freeways and arterials, and these trips will not be affected by programs focused on the city center. For this reason, these three packages were rated as less effective in reducing congestion on the urban freeway and arterial system.

Roadways with Strong One-Directional Flow

Roadways that exhibit strong one-directional flow in the morning rush hours and comparable flow in the reverse direction during evening peaks can best be relieved of congestion by the traffic engineering package. Techniques of utilizing lightly traveled lanes in directions opposing the heavy flow which are part of this package particularly offer low-cost, readily implemented solutions. The transit package offers the next best solution by significantly reducing the number of vehicles required to transport commuters over these routes.

Prearranged ride-sharing programs serve the same purpose and are rated as the third most effective option, primarily on the basis of their potential for immediate ef-

TABLE 6

RANKING OF THE PROPOSED PACKAGES AS SOLUTIONS TO FIVE COMMON TYPES OF CONGESTION PROBLEMS *

Package	Major Problem Areas			Special Problem Areas	
	CBDs of Large Cities	CBDs of Small Cities	Urban Freeways and Arterials	Roadways with Strong One-Directional Flow	Roadways with Limited Options for Alternative Routes
Work-Hour Changes	5	7	5	5	5
Pricing Techniques	2	1	8	7	1
Access Restriction	4	2	6	8	6
Land-Use Changes	3	5	3	4	3
Prearranged Ride Sharing	6	6	4	3	4
Communications Substitutes for Travel	8	8	7	6	8
Traffic Engineering Techniques	7	3	2	1	7
Transit Treatments	1	4	1	2	2

* 1 = Most effective, 8 = Least effective.

fectiveness. Changes in land use, however, promise more lasting benefits by reducing basic needs to travel along these routes, and communities may wish to consider implementing both of these packages, the first to provide near-term improvements in traffic flow and the second to achieve a more satisfactory long-range solution.

The package of work-hours changes can be used to spread the peak demand over a longer period. Techniques of providing communications substitutes for travel may also be effective where the congested roadway provides access to concentrations of financial, research, and similar activities that lend themselves well to independent work at dispersed locations. The packages of restriction of access and pricing techniques may also be effective if the congested route leads into the CBD, where these disincentives to peak-period automobile commuting can be applied. However, these packages are useful only under these prescribed conditions, and are rated lower on the scale for not being universally applicable to the problem.

Roadways with Limited Options for Alternative Routes

The package of pricing techniques appears to offer the optimum solution to peak-period congestion on bridges, tunnels, and other roadways for which options in alternative routes are limited. Not only can the penalties for peak-period commuting by individual drivers deter the use of these crowded facilities, but additional benefits also can be realized elsewhere in the urban transportation system by the reduction in vehicles entering the central city.

Improving transit services to accommodate former drivers is a part of the pricing techniques program, but good results could also be expected from application of the transit treatments package, even without the benefits of pricing penalties. Congestion in itself on these restricted routes may generate changes of mode if transit services are of high quality.

Changes in land use are seen as the primary long-range solution to congestion problems created by geographical limitations of access to the central city. Such solutions can be much more cost-effective than continuing to accommodate masses of commuters over or under bodies of water or through mountain passes.

Some relief to the peak-period congestion of limited-option routes can be obtained through the packages of prearranged ride sharing and work-hours changes. Programs of restriction of access may also be of benefit if the destinations of many of the commuters lie in the city center. Traffic engineering techniques and communications substitutes are rated as having the lowest potential for dealing with this problem.

Over-All Application of Proposed Packages

The package of transit treatments is rated as having the highest over-all applicability to the full range of common peak-period congestion problems of urban areas, and offers a mid-term (1 to 3 years) effectiveness at moderate cost to local government. Its indirect impacts on the community are generally beneficial, reducing congestion in other parts of the total urban transportation system, consumption of automotive fuel, air pollution, and accident rates. It is also unique among the proposed packages in offering benefits in improved mobility for those who do not drive or cannot afford to own a car, and has an over-all high feasibility rating.

Short-term benefits throughout the entire urban transportation system can be realized at relatively low cost through application of the packages of work-hours changes, prearranged ride sharing, and the more modest versions of pricing techniques and restriction of access. Portions of the traffic engineering package can also be implemented rapidly and at low cost, but impacts of these programs tend to be more localized and do not yield over-all reductions in peak-period traffic congestion throughout the system.

The package of techniques for changes in land use has been rated throughout this analysis as only moderately useful as a congestion-reduction treatment, primarily because benefits from this program cannot be expected for some time after its initiation. In recognition of the urgency of existing congestion problems in so many urban areas, this negative feature of land-use programs was given considerable weight when its over-all effectiveness and feasibility were compared to those of other packages.

However, the study team believes that modifying urban land uses represents the best long-range solution to peak-period traffic congestion. Lasting improvements in the balance of travel demands and system capacity can be realized through bringing work and home locations closer together, thus permitting substitution of pedestrian, bicycle, or short auto travel for the lengthy commuter trips that are now required. Other social and economic benefits associated with improved allocation of land in and around cities may also provide solutions to other critical urban problems in addition to that of peak-period traffic congestion.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

MAJOR CONCLUSIONS

Several important conclusions can be drawn from this research into solutions to peak-period traffic congestion that should be of particular concern to designers of local congestion-reduction programs. These are:

1. *Traffic congestion is basically a supply-and-demand problem.* Because congestion conditions exist when demand for roadway is greater than can be efficiently accommodated by the existing road system, the problem must be treated by increasing the capacity of the system to meet the demand or by reducing demand so that it can be handled effectively within the existing capacity.

2. *In general, solutions aimed at reducing demand are preferable to those aimed at the supply side of the equation.* Techniques that work toward decreasing the numbers of vehicles attempting to use overcrowded roads during peak commuting hours tend to provide more lasting solutions to congestion than those that attempt to increase the capacity of the system to meet the continually growing needs for more commuter room.

3. *Congestion is to a certain extent a self-regulating phenomenon.* Congestion in itself acts as a deterrent to drivers choosing to add their vehicles to an already overcrowded roadway. When road capacity is increased, this deterrent is weakened, and although, for a time, traffic flows more smoothly, new users are soon attracted to the improved route until congestion conditions reappear.

4. *The self-regulating phenomenon is more pronounced in large urban areas than in smaller ones.* The smaller economic base in less-populated urban areas places limits on needs to commute to work, and techniques directed toward increasing road capacity may be relatively long-lasting, especially if supported by other techniques aimed at reducing travel demands in critical locations. However, the larger, more volatile economy of major urban areas produces an almost endless supply of commuters, who quickly adjust their travel-to-work patterns to take advantage of improved traffic conditions.

5. *None of the individual techniques studied demonstrates a potential for significant reduction of traffic congestion.* The application of individual congestion-reduction tech-

niques offers the promise, at best, of only marginal improvements to the movement of traffic throughout urban areas. Certain restrictive techniques may be highly effective within limited controlled areas, but may increase congestion in other parts of the total system.

6. *Joint implementation of compatible techniques can be significantly more effective in reducing peak-period traffic congestion.* Many techniques are mutually supportive and work better in combination than singly. In some cases, one technique is essential to the successful application of another to the point that the latter will not function effectively without simultaneous implementation of the former. Packages of mutually supportive techniques are recommended as the most effective congestion-reduction programs.

7. *Different types of congestion problems require different solutions.* No simple program can be expected to provide an equally effective solution to all types of congestion problems. Even the eight packages recommended in this study for their broad applicability are not suggested as treatments for all five kinds of peak-period traffic problems; some are relevant to only two or three congestion situations, whereas others depend on some modification of component techniques to make them suitable for use in a wider range of problem areas.

8. *Many options are available for designing packages of compatible techniques.* Eight proposed packages of congestion-reduction techniques are described in this report. Although they are believed to be among the most broadly beneficial, they do not represent the only feasible combinations of techniques that can be applied successfully to local congestion problems. Program designers should look for combinations of approaches that are particularly suited to their unique local situations. So long as care is taken to avoid the simultaneous implementation of incompatible techniques in ways that they will function counterproductively, other highly effective combinations can be utilized.

9. *The optimum solution to peak-period traffic congestion lies in reshaping urban areas.* Although the package of transit treatments is evaluated as presenting the greatest over-all applicability to current congestion problems, the ultimate solution, not only to traffic congestion, but also many other urban problems, lies in changing land use so that places of residence and work are brought closer together and needs for long commuter trips are eliminated. Basic costs to local government of initiating such changes by modifying existing land-use plans and zoning ordinances are small, but major investments over a number of years from federal government and the private sector are necessary to translate the revised plans and ordinances into physical realities.

10. *A program combining short-range and long-range solutions is recommended.* The optimum plan for alleviating peak-period traffic congestion is believed to be the adoption by local government of a dual program. Immediately effective packages of techniques that will produce short-term improvements can be implemented simultaneously with long-range packages of techniques, such as changes in land use and substituting communications for travel to work, that will provide lasting solutions to the problem.

RESEARCH NEEDS

Extent of Current Knowledge

It has frequently been stated throughout this report, particularly where it has been necessary to evaluate and compare congestion-reduction techniques and packages, that remarkably few reliable data are available on the effectiveness and costs of these measures, and almost no information exists on the indirect social, economic, and environmental impacts that might result from their implementation. Many of the individual techniques have been applied in various locations both in this country and abroad, and these experiences have been observed and reported. Often, however, these activities have been undertaken for purposes other than specifically reducing peak-period traffic congestion, and their utility in this particular problem area has largely been ignored.

The packages of techniques present an even greater information problem, because they are inventions of the study team and have never, so far as is known, been implemented as coordinated, mutually supportive programs. The scarcity of information on the individual techniques is compounded for the packages; the effects of interaction of the techniques can only be speculated about.

Needs for further research in this entire subject area are urgent. Problems of peak-period traffic congestion are widespread and are contributing significantly to urban blight and the deterioration of city centers, to environmental pollution and excessive consumption of automotive fuel, to the frequency of automobile-related accidents, and to the increase in the stresses of urban living that are now characteristic of cities.

As a guide to designing further NCHRP research programs on potential solutions to peak-period traffic congestion, the eight packages of congestion-reduction techniques were evaluated as to (a) the extent of current knowledge of their effectiveness, (b) costs, and (c) indirect impacts. Special attention was directed toward the social, economic, and environmental benefits and disbenefits that might be generated indirectly by implementation of the packages, because it was recognized that this area was the least understood and was urgently in need of further study.

Once these detailed evaluations were made, each package was rated for its over-all potential for current application that reflected both its estimated effectiveness and feasibility and the extent to which these factors were reliably established. This analysis was to assist in determining the relative urgency of research needs; packages of high potential usefulness, but lacking in some area of essential information would lend priority to research in that area over that exercised by packages of lesser potential subject to many unknowns. Similarly, an information need common to a number of packages would take precedence over one applicable to only a single package.

In the companion publication to this document (see "Foreword"), specific recommendations for research studies were selected on the basis of their relative urgency among a number of potential studies of congestion-reduction measures. These recommendations represent the study team's selection of the most critical information needs within a subject area that in its entirety should be given priority attention.

Effectiveness and Cost Data

The analysis undertaken indicated the extent of existing knowledge on the eight packages of congestion-reduction techniques with regard to their effectiveness in reducing congestion and their direct costs of implementation. In general, more information is available on costs of implementation than on the effectiveness of these measures in reducing peak-period congestion, inasmuch as they have been used more frequently for other purposes than alleviating peak-period congestion. Costs have been recorded where no measures have been taken in changes in traffic flow. Also, data on effectiveness suffer from lack of a standard measure of congestion.

Current knowledge of the effectiveness of entire packages of techniques is rated as insufficient for even rough estimates, except in the case of the traffic engineering package where data on the two component techniques is of relatively high reliability. The best of the data on freeway surveillance and control and maximizing use of existing facilities are apparently derived from monitoring actual applications of these techniques. None of the information currently obtainable on the remaining individual techniques is adequate for more than developing rough estimates of their potential effect on peak-period congestion. Data are particularly unsatisfactory on central city congestion impacts of road pricing, extended-area transit, New Towns, and planned neighborhoods.

Cost data for implementing staggered work hours, carpooling, changing zoning and building codes, and the traffic engineering techniques are sufficient for arriving at reliable estimates for new applications. They are least satisfactory for special-area transit, much of which is in the development stage; traffic cells, of which only two European examples are known; and New Towns, which have involved such large numbers of unrelated public and private entities to achieve such widely divergent development goals that it is impossible without further study to estimate total investment required for the type of development postulated in the land-use package.

Indirect Impacts Data

The extent of current knowledge of the indirect benefits and disbenefits that could be generated by application of congestion-reduction techniques and packages was also analyzed. Nine impact areas were identified; in none of these areas are existing data considered sufficient to provide reliable guides to the effect of implementing any of the eight packages of techniques. In nearly 40 percent of the cases, information is considered insufficient even for arriving at rough estimates.

Certain of the individual techniques have been implemented and observed to the degree that reliable estimates can be drawn from existing data in some impact areas. These techniques include staggered work hours, carpooling, transit circulation systems, and traffic engineering techniques to maximize use of existing roadways. Least is known about the indirect social, economic, and environmental effects of road pricing, communications substitutes for travel, New Towns, transit marketing, and extended-area services. In one case (planned neighborhoods) indirect impacts are better known than direct effects on congestion, because these programs have often been carried on for social purposes and monitored for their effectiveness in those areas.

Information needs exist in all nine impact areas, but they appear to be most critical in the areas of long-range travel demands and patterns, environmental pollution, public safety, and both public and private institutional considerations. Economic impacts appear to be the most adequately researched, and equity considerations are nearly as well understood. These distinctions, however, are minor; needs for further research in all areas are acute, especially with regard to the implementation of packages of congestion-reduction techniques.

Potential for Immediate Application

All of the proposed packages of congestion-reduction techniques presented in this report were designed as effective and feasible solutions to peak-period congestion problems. None of the packages has yet been implemented to test these assumptions or to be sure of the indirect impacts on the community that might result from their implementation. In short, all are believed potentially beneficial, but none has yet been proven to be.

Earlier in the study, before the concept of packaging mutually supportive groups of techniques was developed, it was assumed that an effective research program could be designed on the basis of the state of the art of the several candidate techniques: those proven effective would be recommended for implementation; those apparently effective and currently feasible, but not yet tried, would be recommended for demonstrations; and those needing technological or conceptual development would be identified as subjects for analysis and design research.

Subsequent study revealed that none of the candidate techniques qualified under the first category, because no satisfactory assessments had even been made of their specific impacts on peak-period traffic congestion and their indirect effects on the functioning of the total urban transportation system or their social, economic, and environmental impacts on the community. Nor are any of the 17 candidate techniques in need of basic technological or conceptual development, because approaches evaluated as not effective and feasible were eliminated from further consideration. Current needs for research on individual techniques lie entirely within the demonstration category, in testing the actual effectiveness of these approaches and evaluating their indirect benefits and disbenefits.

Within this narrow range of readiness for immediate implementation, however, the study team attempted to rank the eight proposed packages of congestion-reduction techniques. The following order represents a combined evaluation of their presumed effectiveness and feasibility to the degree to which these factors are known:

1. Transit treatments.
2. Changes in work hours.
3. Carpooling.
4. Restriction of access.
5. Traffic engineering techniques.
6. Changes in land use.
7. Pricing techniques.
8. Communications substitutes.

Proposed Research Topics

Potential research topics identified by the preceding analyses and the state-of-the-art analysis of individual techniques were then evaluated in terms of four criteria:

1. Readiness of the relevant package or packages for implementation.
2. Comprehensiveness of the topic to be researched.
3. Over-all social significance of the research topic.
4. Relevance of the research topic to NCHRP concerns.

Ten research topics emerged as recommendations for further NCHRP-sponsored studies in the area of solutions to peak-period traffic congestion. Evaluation of potential research topics and recommended research is reported in "Peak-Period Traffic Congestion: State-of-the-Art Analysis and Recommended Research" (see "Foreword" for availability). These topics were presented in the appendix to that report in the format of individual second-stage problem submittals used by AASHTO in designing annual research programs, each introduced by a review of the rationale behind its selection.

The ten specific research efforts proposed for future NCHRP programs are:

1. Development of a Standardized Monitoring System for Evaluating Congestion-Reduction Programs.
2. Impacts of Congestion Solutions on Long-Range Travel Demands and Patterns.
3. Impacts on Congestion of Increased Transit Ridership.
4. Institutional Impacts of Joint Implementation of Restrictive Congestion-Reduction Techniques.
5. Design of Demonstrations of Restricting Vehicle Access.
6. Warrants for Priority Vehicle Lanes and Exclusive Vehicle Ways.
7. Universal Guideway Concept.
8. Reassessment of Freeway and Arterial Geometric Design Criteria.
9. Economic Impacts and Equity Considerations of Pricing Techniques.
10. Demonstration of a Neighborhood Work Communications Center.

The most urgent research need in this area is represented by the initial proposal, which would provide a widely applicable standardized monitoring system for evaluating and comparing alternative approaches to alleviating peak-period traffic congestion. The proposed system would not only supply information on direct effectiveness in treating congestion, but would also examine associated costs of implementation, feasibility factors, and the indirect social, economic, and environmental impacts that occur as a result of utilizing alternative congestion-reduction packages and individual techniques.

Of the remaining nine research proposals, six are focused primarily on the least understood elements of congestion-reduction efforts—the indirect benefits and disbenefits to the local environment, economy, and social structure, and institutions. Another study seeks to assess the direct effectiveness of improving transit services, considered by the study team as potentially the most broadly applicable of the alternative treatments. One looks for a reassessment of currently used freeway and arterial design criteria in light of recent changes in vehicle design and regulation of speed limits. Finally, a demonstration of the most innovative of the treatments is recommended—a neighborhood communications work center—in which the effectiveness, feasibility, and indirect impacts of substituting communications for travel to work can be observed and evaluated.

Each individual research statement is preceded by justification of its utility in terms of the four evaluation criteria previously given. These criteria and the selection of the ten research topics reflect the study team's emphasis on research that will lead to the development of implementable congestion-reduction strategy.

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