

SUMMARY OF THE CURRENT STATUS OF KNOWLEDGE
ON TRAFFIC RESTRAINT

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INTRODUCTION

Traditionally, the success of a transportation system has been measured by the degree or level of mobility that is provided to society. Improvements to the system have been justified on the basis of reduced travel time or costs, improved accessibility, and increased travel demands. In most cases, the objective in transportation planning and design was to maximize mobility within the constraints of available resources. Certainly, this approach to transportation has proven to be a major contributing factor in the development of the United States and its transportation system.

The emergence of such issues as energy, environmental awareness, natural resource conservation, and urbanization has placed new considerations on the development and selection of transportation plans. It is now recognized that in some cases the maximization of mobility may no longer be in the overall best interests of society as a whole. Currently, there is a trend towards greater emphasis on traffic and transportation management with special emphasis on the development of management policies which are compatible with broader development goals.

This emphasis on societal goals and increased control of traffic growth is placing a new dimension on traffic and transportation planning which involves possible constraints on mobility and the demand for mobility. In essence, transportation planners are now faced with seeking means of reducing demand or controlling traffic growth for a particular area. This means that new planning methods and techniques must be explored which yield solutions to this type of a transportation planning problem.

More specifically, there is an increasing concern about the use of the automobile especially in areas which are already experiencing congestion. An alternative to providing improved facilities is to apply a constraint on the use of the automobile. This is not to be construed as a ban on the automobile, but it is a restraint or control on its use. The motives for using traffic restraint are generally associated with the need to alleviate congestion or to discourage the trend towards an increasing number of automobiles in an area. While the concern has focused on the automobile, the impact of restraint certainly affects all modes of transport. Furthermore, in order to control the use of the automobile, it may be necessary to take steps which will give priority to the movement of other transport modes.

Beginning in 1974, a study was undertaken for the purpose of exploring the possible application of traffic restraint to transportation problems in Connecticut. The study consisted of two phases. The first phase was to be a documentation of the state-of-the-art with respect to traffic restraint, while the second phase was associated with the possible application in Connecticut.

This report covers the first phase of the project and serves to document the current status of knowledge on traffic restraint as of the fall of 1975. In the sections that follow, a historical review of traffic restraint is presented along with a documentation of the methods and techniques that may be utilized or considered in the solution of a traffic or urban development problem.

II

HISTORICAL OVERVIEW

The use of the term traffic restraint is a relatively recent occurrence in traffic and transportation. It should be recognized, however, that concept of reducing traffic as a means of alleviating congestion and conflict has been utilized at various times in the past. A classic historical example of traffic restraint was the prohibition of vehicles in the business districts of large cities in the Roman Empire during certain hours of the day. (63)* More recent examples might be associated with charges for parking, restrictions on vehicle use on particular roadways, and turn restrictions at intersections.

While these isolated examples can be readily found in the literature, the general philosophy which has been followed in traffic and transportation planning has been to continually improve facilities to meet the projected transport demands of society and maintain or improve a given level of transport service. It must be recognized that this philosophy has generally provided excellent overall transport facilities. Traffic restraint represents an alternate philosophy or policy in that efforts are made to decrease the demand rather than expand the transport facilities.

There has been evidence in recent years of more widespread application and consideration of traffic restraint concepts particularly in Europe. In contrast, there has been little effort in this area in the United States even though more recent discussions have alluded to the concept. This lag or difference in the state-of-the-art may be due to the fact that Europe,

* Numbers in parenthesis refer to publications in List of References

with its older cities, has been faced with development issues which are just now becoming critical in this country.

The restraint concept as it is now known is in a state of relative infancy. There is little, if any, literature published on the topic prior to the mid 1960's. Possibly one of the earlier efforts in this country associated with restraint was the development of pedestrian malls. A report (58) in 1966 by a committee of the Institute of Traffic Engineers examined the planning of pedestrian malls.

The earliest effort to deal with the state-of-the-art of this concept was undertaken in 1971 at a conference sponsored by the Organization for Economic Cooperation and Development (OECD). (56) The conference addressed the subject directly and served to bring together the state-of-the-art of that time. The publication which resulted from that meeting provides a good preliminary introduction, even though the emphasis is placed on European cities. At that time, it was concluded that the following techniques were worthy of consideration for either local or system wide restraint applications:

- a) traffic cells,
- b) priority public transport lanes,
- c) parking charges and controls, and
- d) road pricing.

As the awareness of more comprehensive planning issues has emerged in urban and regional areas, the need for the consideration of traffic restraint has been more emphasized as an alternate planning strategy. The motivation to retard environmental, aesthetic, and economic deterioration of an area through the use of traffic restraint has offset the sometimes adverse consequences to the motoring public.

III

THE THEORY OF TRAFFIC RESTRAINT

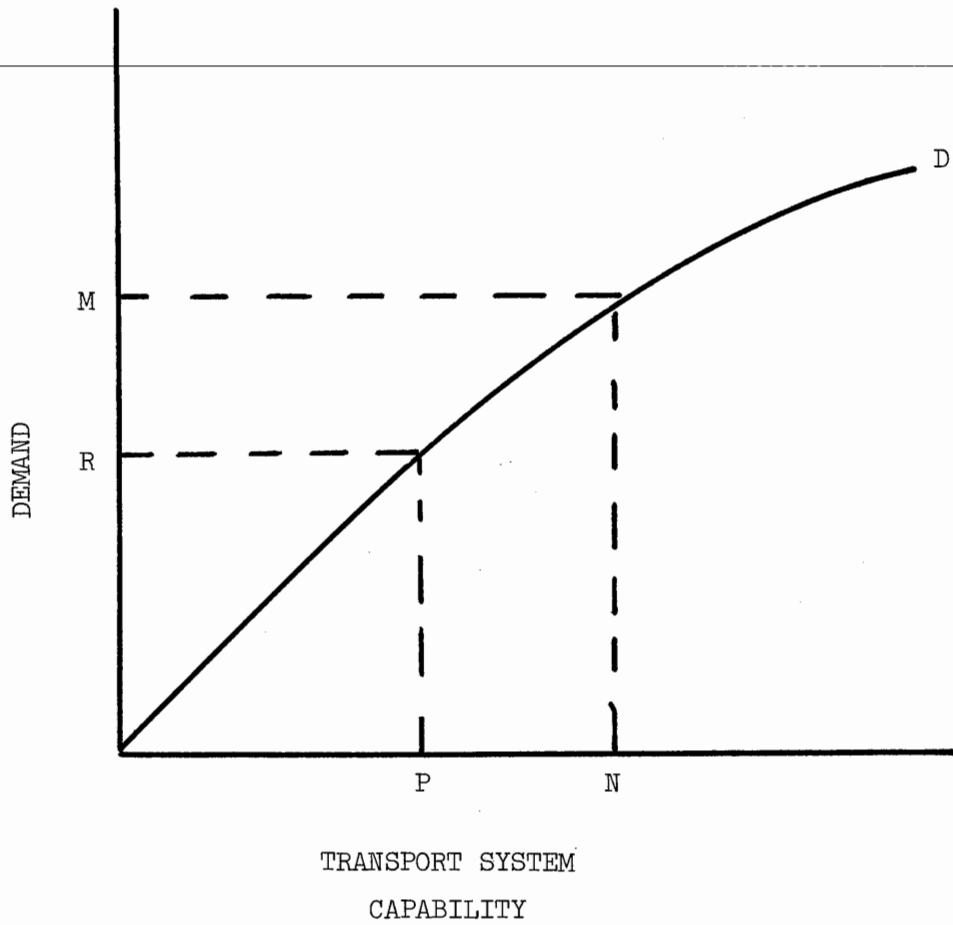
The underlying theory of traffic restraint is based on the concept that the adequacy or the inadequacy of the transportation system or its components can affect the total level of transport demand. In the case of traffic restraint, however, the planning problem is associated with controlling the adequacy of the transport system which results in the control of the demand on the system. For example, Figure 1 illustrates a hypothetical relationship between the transport system capabilities and the demand on the system. This relationship is represented by curve D. Assume that point N represents the units of transport system capability required for a given demand level M. However, if only P units of capability were provided, the demand for use of the system would be lowered to the level indicated by R.

This supply-demand type of relationship has been known to traffic and transportation engineers and planners for a number of years. For example, the term "induced traffic" has been associated with increases in traffic not attributable to normal growth, but resulting from improvements in the facility or the operation. (1)

Diversion curves have been used to express fluctuations in traffic demand with reference to variations in travel characteristics such as time, cost, or distance. (47,59) Primarily, the diversion curve has been utilized when comparing two routes or two modes of transportation for the determination of the amount of estimated traffic that would utilize each route or mode. Generally, this supply-demand relationship must be derived for the particular situation or location that is involved. For example, diversion curves vary from city to city or even with different parts of a city.

FIGURE 1

HYPOTHETICAL RELATIONSHIP
BETWEEN DEMAND AND TRANSPORT SYSTEM
CAPABILITY



The application of the supply-demand concept to the control or restraint of transport demand has not been as evident primarily due to the historical emphasis on the improvement of transportation. If the restraint is to be considered, such a factor must be integrated into the total planning process because of the consequences to transportation as well as society as a whole.

IV

TRAFFIC RESTRAINT METHODS & TECHNIQUES

A number of methods or techniques have evolved which can be considered in attempting to reduce traffic demand. The following discussion provides a summary of the state-of-the-art of each of the methods or techniques which may be currently considered used in the restraint of traffic.

PARKING

Control of parking is just one of the methods that can be implemented to achieve traffic restraint; however, it can prove to be effective if utilized under appropriate circumstances. Basically, parking controls fall into two categories which are both aimed at reducing the overall demand for parking services. The first category of parking restraint deals with parking charges while the second is related to the control of the number of spaces. In addition to these categories, some reduction in travel may be achieved through the location of parking facilities; however, this is more directly related to the flow on the traffic network than to parking restraints.

Total accessibility is one of the major factors involved in determining travel to an urban region. Accessibility is directly attributable to the roadway network and the parking facilities of the area when considering automobile travel. Therefore, it is evident that a reduction in the supply or an increase in the price structure of parking facilities could result in a reduction of auto travel to that area. This situation, if improperly handled, could result in a basic consequence of congestion and potential economic deterioration of the city. This fact is emphasized by May (31) in studies of parking in London. In his work, May set objectives and methods

of achieving restraint through the use of parking controls for the City of London. These objectives were flexibility, selectivity, equity and simplicity. He concluded that a preferable method of restraint can be achieved through parking price control rather than supply depletion. This view was reiterated by Silence et al (51) and Roth (44) who expressed the desire to implement parking innovations in the form of increased rates and zonal changes to restructure the parking system. This induced traffic would be in the form of carpools and through mass transit vehicles.

In the study of May (31), it was found that an increase in parking charges at four parking lots in London resulted in considerable change in lot usage. Table 1 indicates the changes in use of the four lots.

In a study undertaken in Glasgow (21), it was concluded that control of parking was the only feasible means of effectively achieving restraint of traffic for that city. Such a measure required an authority to fix location, supply and costs of the parking. In essence, this implies that such a measure could only be implemented if the majority of the central business district (CBD) parking was within government control. Without this centralized control there would be no effective means of regulating supply and rates, thereby, rendering an inefficient restraint technique. A similar view was expressed in an article by Heggie (20) in which he stated that the most effective means of achieving restraint is through a pricing scheme. After examining both road pricing and parking charges it was concluded that a structural parking charge would offer the best results in restraining travel. In the work by Heggie, quantitative effects of parking charges were presented through a travel survey conducted at Oxford University. The general implication of these results are that, if parking charges could

TABLE 1

EFFECT OF CHANGES IN CHARGES AT

FOUR PARKING LOTS (31)

Parking Pattern	Before	After	Change (percent)
Arrivals, 8:00 to 9:00 a.m.			
Affected parking lots	628	121	-81
Unchanged parking lots	300	309	+3
All parking lots	928	430	-60
Arrivals, 8:00 to 10 a.m.			
Affected parking lots	897	314	-65
Unchanged parking lots	702	685	-2
All parking lots	1,599	999	-37
Arrivals, 10:00 a.m. to 6 p.m.			
Affected parking lots	266	516	+94
Unchanged parking lots	478	596	+25
All parking lots	744	1,112	+49
Durations (660-space lot)			
Less than 3 hours	73	217	+200
More than 7 hours	496	116	-77
Median duration (hours)	8.9	3.2	-72
Purpose (660-space lot)			
Work	528	178	-66
Employer's business	39	94	+140
Other	64	154	+140

be extended to all on-and-off street commuter parking spaces in a medium sized city, a fairly modest charge (50¢) could reduce commuter car travel to the CBD by up to half. These commuters would be diverted either directly to mass transit or would park along the fringes of the CBD and use a combination of foot and bus.

Southampton, England has also utilized this method as a component of the overall plan which is in implementation. (6) The increased parking rates were combined with priority bus lanes to discourage long term parkers from parking in the CBD and to induce them to park in the fringe areas where rates are lower and direct accessibility to the CBD was provided through the priority lanes.

The previous discussions indicate the widespread application of parking as a restraint technique in Europe and particularly in Great Britain. There is also some evidence of the consideration of such application in the United States in recent years. It must be recognized that in the United States, planning decisions related to parking were made on a fragmented basis. Generally, the comprehensive transportation planning studies which we accomplished during the 1960 period projected parking demands which were necessary to accommodate traffic movements. In fact, it has been only in recent years that parking came to be considered in the context as an active component of the highway system.

A study (63) in 1970 reviewed terminal facilities as a component of transport systems. The concept of terminals such as parking posing a constraint was explored with conclusions that the lack of parking could affect the demand for transportation and the structure of the urban area.

About the same period, Shulman (49) developed planning programs which integrated the supply of parking into the trip distribution and modal split process.

A more recent article based on studies conducted in Boston imply that CBD traffic can most definitely be controlled by a careful combination of price restructuring and supply depletion of parking. (48) The study, which was conducted for environmental purposes, concludes that by control of parking, trips would be diverted to another mode of travel, this being some form of mass transit. This would result in reducing congestion thereby improving the air quality of the Boston area.

Burns (4) also presented an article which dealt with the National Air Quality Standards which were set by Congress. He suggested the usage of parking surcharges to assist in restraining peak-hour CBD traffic. From the reaction to such a method voiced by various groups, it is imperative that a careful, time staged program of selective parking surcharges, law enforcement and mass transit planning be employed to implement a feasible method of imposing peak-hour charges.

Parking controls have become an integral part of the transportation control strategies which are being developed for the purpose of improving air quality in the urban areas. For example in Hartford, five alternate parking management regulation plans were considered. (42)

Parking space, once needed for automobiles in the CBD, is now in demand at the less densely populated suburban terminal facilities. An article by Ellis (9) dealt primarily with developing planning implications for location, design and service of transit provided at fringe parking facilities. Ellis presented these planning implications in an attempt to maximize the potential use of these facilities, thereby relieving congestion within the CBD. Within these implications are stressed such considerations

as the necessity to locate these facilities so that they intercept the home-to-work trip at a point where there is sufficient density transit demand to ensure that high quality service may be offered. Also, consideration must be given to the impacts on the land use and activities in the immediately adjacent area, which usually is the neighborhood. To the maximum possible extent, these potential impacts should be minimized so as not to interfere with the established patterns of the community. Where possible, joint use activities should be considered during design

to ensure effective integration of transportation and other functions. Furthermore, the pricing of the fringe parking transit service should be carefully considered to ensure its competitiveness.

Finally, it is significant to note that in 1973 the Highway Research Board (now the Transportation Research Board) devoted an entire publication to the topic of parking as an alterant to traffic pattern. (38) While several of the papers in that publication have been previously cited, a paper by Jackson (26) should be also noted because it contains a discussion of the application of parking policies as they are related to the long range growth in Denver. Thus, there is definitely increasing evidence of the use of parking controls as tools for controlling growth and the demand for transportation. It must be recognized, however, that the use of parking as a restraint mechanism does present some inherent problems. This is evidenced by the following conclusion which was based on a study of parking taxes:

"Parking taxes have been overrated by many as solutions to some problems of the automobile age. They may well have a role to play, along with other traffic restraint policies, in the reduction of congestion, but they promise very little help in

alleviating the other unpleasant consequences of widespread automobile use." (27)

NETWORK ALTERATIONS

Two approaches to restraining traffic might be included under network alterations. The first is the creation of pedestrian malls or auto free zones (AFZ). This might be considered one of the older and probably the most widely utilized form of restraint. This is evidenced by the study conducted by the Institute of Traffic Engineers which addressed the development of these facilities beginning in the late 1950's. (58) At that time, it was felt that the pedestrian mall represented an attempt by downtown interests to incorporate one of the principal basic features of successful suburban centers. This feature was the separation of pedestrians from more serious traffic conflicts within the retail environment, thereby the shopping atmosphere was improved. However, to accomplish this end product, a complete revitalization program was necessary with the final step consisting of the actual mall implementation. The preliminary actions required in the program included among other things:

- a) the development of adequate perimeter streets to accommodate displaced traffic;
- b) provision of adequate off-street parking facilities;
- c) improvement of loading facilities for the actual establishments involved; and
- d) improvement of public transportation. Only when this total program was considered would the pedestrian mall scheme prove to be of any value.

The second method is quite different from the total banning of autos as represented by the pedestrian mall scheme. However, it does possess the

necessary requirements to be considered a cause of network alteration. This method consists of reserving highway lanes for the exclusive use by high occupancy vehicles such as buses and carpools. At the current time, there are a number of projects being conducted in connection with the development of priority lanes.

Pedestrian Malls and Auto Free Zones

Due to a relatively low initial cost and relative ease of implementation the auto free zones represent the most common form of restraint as evidenced by their popularity in European countries. (37) The pedestrian mall or auto free zone prohibits the travel of vehicles within certain sectors of the central business district either continuously during the day or on a specified time basis. This method of restraint presents many advantages concerning the overall environmental management of the area. Orski (36) presented a review of projects that are operational and that are to be implemented utilizing this concept of restraint. He stated that within the last several years the number of cities that have utilized this procedure has grown impressively. In Germany alone 28 cities have created auto-free zones since 1967. Large numbers of pedestrian zones have emerged in Dutch, British and other European towns. The evidence that is available from these projects indicates that auto free zones are indeed an effective means of lowering the levels of air pollution at the street level. The experimental closure of Madison Avenue in New York City to traffic resulted in a reduction of CO concentration levels from 22 ppm to 8 ppm. The recently introduced auto-free zones in the inner city of Vienna has lowered CO levels by 54 percent and lead levels by 67 percent. Similar advantageous results were reported for projects in Tokyo and Marseilles. It should be noted, however, that traffic bans of relatively

small areas will contribute little to improving the overall urban air quality. Air quality in the urban area is influenced by two separate factors, the highly concentrated street level pollution and the less concentrated but more widespread pollution from fixed sources and vehicle exhausts. Because these airborne pollutants tend to rapidly disperse and mix into the atmosphere, it is the concentrated street level pollutants that become critical. Therefore, the main objective is to reduce these local street levels and strategies concerning auto-free zones and other measures tending to reduce vehicular activity deserve careful consideration.

In addition to the improvement of air quality, this method of restraint is also responsible for a reduction in noise. A basic parameter of noise is volume. Therefore, as volume is reduced so is the amount of noise that is produced from a facility. For example, in New York City, noise levels during a temporary ban on Fifth Avenue dropped from 78 decibels to 58 decibels.

A further advantage of the auto-free zone is the improvement of aesthetics which Fruin (14) discussed in connection with an AFZ which was located in Minneapolis. This zone, known as the Nicollet Mall, is comprised of eight blocks in previously deteriorating downtown Minneapolis. Special features that enhance the aesthetics of the area include a winding street, two-thirds of which is designed for pedestrians and one third for public transit. Numerous plantings and furniture line the mall and lighting is provided both to enhance the aesthetics and to improve the environment of the pedestrian. These special design features enable and encourage interaction between people and the surrounding environment.

Environmental improvement is but one of the advantages of this restraint technique. This method is also responsible for improvements to safety. Also the need to separate vehicular and pedestrian of traffic within the CBD increases with increasing congestion. Pendukar (40) brought this view forth

in an article dealing with three means of traffic separation:

- a) vertical separation with pedestrian movements above ground;
- b) vertical separation with pedestrian movements below ground; and
- c) horizontal separation.

With respect to traffic restraint, only one of the techniques offered by Pendukar is applicable, that of horizontal separation. Cooper (6) also presented an article dealing with this problem in Southampton. In this particular case, two main shopping streets have been closed to traffic

with the exception of specified bus crossings. The results have shown significant improvements in both pedestrian and bus operating conditions.

When first examining auto-free zones and pedestrian malls, a slight problem may arise concerning retail establishments. Merchants held a view that was anything but encouraging. They felt that prohibiting traffic from these areas would definitely have an adverse effect on business. However, after some trial implementations, it was found that retail commerce was positively effected due to the improvements of safety and aesthetics. Several articles can be found which focus on this question. For example, in "Foot-Streets - Managing the Environment", Wood (62) presented such evidence. This article dealt with the experimental conversion of London St., in Norwich, England. Reactions to the experimental scheme were obtained from the London Street merchants. Of the 32 merchants located on the street, 30 replied. Of these, twenty-eight claimed to have done more business during the experimental period. The increase in business directly attributable to the traffic ban was estimated at about 5 percent. Orski (36,56) also presented some available evidence to substantiate the belief that auto free zones do enhance the retail commerce of the affected area. In Vienna, reported increases in business ranged from 25 to 50 percent within the first two weeks

of the ban. In Essen, the increase in trade was reported to be between 15 percent and 35 percent. The results in Rouen showed similar increases between 10 percent and 15 percent. In Tokyo, where a relatively large auto free zone is in effect, 74 percent of the merchants were definitely in favor of the scheme. Fruin (14) cited two additional zones that have displayed an increase in business, the Nicollet Mall in Minneapolis and the AFZ in Stroget, which have shown retail commerce increases as high as 30 percent. Orski (36) presented a widely held view as to the rationale be-

hind these improvements which have revitalized historic CBD's. It is felt that a traffic free environment makes walking more pleasant. Therefore, an area from which the auto has been excluded is:

- a) likely to attract more shoppers and strollers,
- b) be able to resist more effectively the competition of outlying shopping centers, and
- c) contribute toward a healthier and more viable city core.

This effect of revitalization is also brought forth in an article concerning the pedestrian mall of Munich (57). This article manifests the need for a well rounded, comprehensive plan. The mall would be ineffective without adequate accessibility. However, this pedestrian zone is highly accessible with the accessibility being characterized by a vertical and horizontal separation of the means of transportation. Mass transit includes busses, streetcars and underground railways. The underground railway enables a large region surrounding Munich direct accessibility to the heart of the city.

There is a very unique traffic zone system in the city core of Gothenberg, Sweden. (10,29) It is based on the auto-free zone concept but differs in the respect that it is a system of compartmentation. The CBD has been divided into five separate sectors with a ring road circumferentiating the

area. Traffic is permitted freely in and about each sector; however, travel is prohibited between adjacent sectors and traffic movements of this nature must utilize the ring road for such maneuvers. This traffic movement prohibition is accomplished through the use of barriers. Public transit, however, is allowed to cross sector boundaries thereby inducing the utilization of this means of transport. The results of this system are extremely favorable. The environmental improvements were most beneficial resulting in a reduction of both air and noise pollution along with a reduction in overall traffic through the Gothenberg CBD. Accessibility to commercial districts was relatively unchanged by this scheme.

When undertaking such a measure for whatever purpose, environmental, safety or economical, certain aspects become imperative to consider. For example, a report by OECD (56) states ..." when planning traffic free zones, special provisions should be made for traffic and parking facilities around the areas affected, and for public transport to the controlled areas. There is a need for an overall transportation plan insuring high accessibility to these zones." One of the major drawbacks associated with this system of restraint is the increase in traffic levels and pollution levels occurring on surrounding streets. These effects are detrimental and could far outweigh the advantages if not handled properly.

Reserved Highway Lanes

There has been a considerable amount of literature published on the concept of reserved highway lanes for high occupancy vehicles. This measure is gaining in popularity basically for the same reason that makes the auto free zone popular, that is its relative low cost and ease of implementation. (22,55) This method of restraint is based on the utilization of existing space within the highway right of way for high occupancy vehicles. (56) These

vehicles would receive preferential treatment in so much as they would be allowed to travel in priority lanes. Studies have been conducted to evaluate such a method used for restraint. An article by Sparks and May (53) discusses the development of a model to evaluate travel time on freeways with priority lanes and compares these values to those obtained from existing conditions. It was found through the application of this model, that situations exist such that total passenger travel time on a facility for a particular period of time may be reduced through the utilization of priority lanes. If a decrease in total passenger travel time is obtained by adoption of this strategy, the associated savings is a product of providing preferential service to those utilizing the high occupancy vehicles. This savings would be expected to produce a shift in the vehicle occupancy distribution and result in an increased average vehicle occupancy for the facility. By increasing the average vehicle occupancy it is then possible in certain situations not only to reduce the total passenger travel time and to increase the passenger capacity but also to decrease the individual travel times for all persons using the facility. The necessary data required for this evaluation includes:

- a) a speed flow relationship for the facility under consideration,
- b) either the total vehicle demand or total passenger demand as a function of time,
- c) the length of the freeway section under study,
- d) the number of directional lanes,
- e) either the modal split factor or the bus demand and the average bus occupancy,
- f) the capacity of the facility in equivalent vehicles per hour, and
- g) the distribution of automobile occupancies.

Application of this model enables an investigation of all priority lane strategies and selection of those that show promise for more detailed investigation. It also enables a sensitivity analysis of the effects of the particular parameters involved in the decision process.

Chapell (5), utilizing the previously discussed model, attempted to accomplish two major objectives in a study of bus lanes. The first was the determination of the feasibility of moving more people with fewer vehicles and of improving traffic operations on highways by utilization of reserved lanes by high occupancy vehicles. The second objective was the development of a plan for demonstration and evaluation of operational effectiveness of the reserved-lane concept. These objectives were accomplished through certain project tasks such as analysis of freeway types, analysis of traffic operations, analysis of modal choice to estimate potential shift and analysis of user costs to compare reserved lane operation to normal operation. Reserved-lane operation configurations were considered for 3, 4 and 5 lane freeway facilities (one direction of flow only). Varying parameters were employed with these configurations. The general conclusions of the feasibility of such a strategy are as follows:

- a) The concept of reserving an urban freeway lane for the exclusive use of buses and car pool vehicles during commuting hours is basically sound.
- b) Reserved-lane operation will result in a reduction in the total number of vehicles required to serve a given level of travel demand when sufficient numbers of commuters shift from low to high occupancy vehicles and from low-occupancy cars into buses.
- c) The feasibility of the reserved-lane concept depends largely on the characteristic of each specific freeway. Freeways with 4 or 5 lanes

in each direction provide the greatest amount of flexibility.

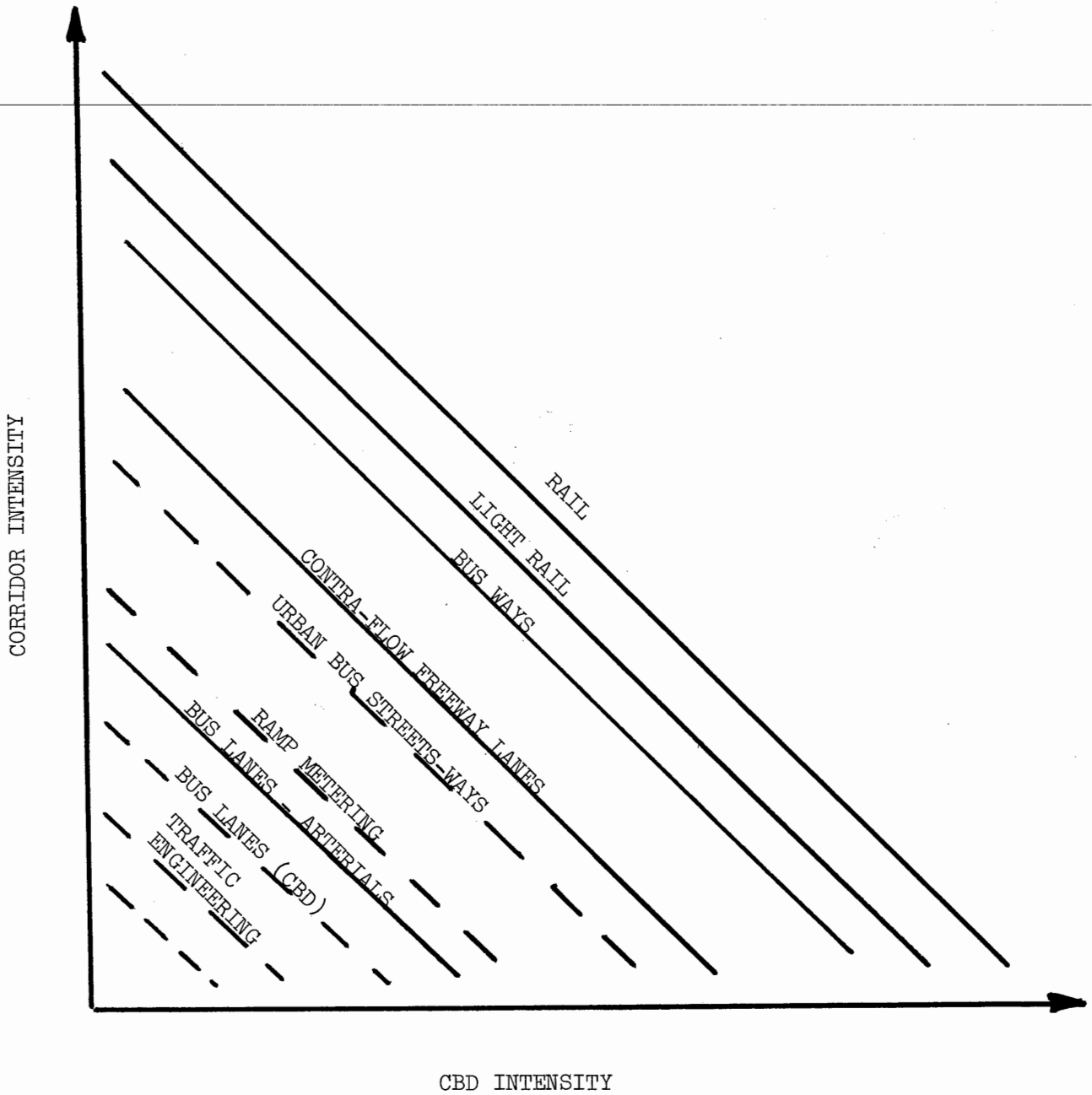
d) No dramatic changes in highway safety can be expected.

Papers have been written attempting to establish a hierarchy of these priority systems. Levinson and Hoey (28) presented the different techniques of the reserved lane concept and their preferential order of implementation. It was made clear that utilization of existing highways should take priority whenever feasible. Other methods in the order of their preference included: metered freeway ramps, contraflow bus lanes, lanes to be used to bypass congested areas, and finally the construction of separate facilities for high occupancy vehicles. Constructed facilities are the least preferential from the standpoint of cost. The specific technique of express bus service is dependent upon the intensity of the corridor which it serves and the intensity of the CBD. The existing and potential proportions of CBD travel by bus in these specific corridors will influence the extent to which buses should be given priority over automobiles. The relationships of these intensities to express bus service are shown in Fig. 2.

Warrants for the implementation of this concept are offered by Levinson and Hoey. (28) They stated that the underlying principle in formulation warrants for bus priority treatments is whether an exclusive bus lane will carry more people than if that same lane is used by automobiles during the peak period of operation. Tentative warrants for bus priority treatments are basically expressed in terms of peak-hour buses and passengers. It should be noted that for contra-flow bus lanes to be applicable two specific conditions of the facility must be present. The first is that the facility have more than four lanes and the second is that the peak period flows be highly unbalanced. As volumes become more balanced, a greater number of

FIGURE 2

BUS PRIORITY TOPOLOGY⁽²⁸⁾



buses are required to offset the time losses to opposing traffic resulting from lane reductions.

Goodman (16) presented a discussion of techniques for implementation on existing facilities. The techniques include the reservation of the peak flow median lane, the off peak flow median lane, utilization of reversible center roadway, metering of the freeway and exclusive use of a facility by buses. These techniques are dependent on the type of facility and the method of access and egress used for the facility.

There are certain factors which must be considered when implementing this concept. A determination of the implications which the concept presents is needed. It is also necessary to evaluate the user costs of the priority lane system with respect to the costs of maintaining normal operation. Consideration of legislation and enforcement also becomes necessary in that these priority lanes must be kept free of low-occupancy vehicles for this technique to have any chance of being effective. (5,15) Enforcement of such a system is difficult through conventional means of apprehension and citation; therefore, greater reliance must be placed on voluntary compliance through an effective public information program and deference through a program of increased concentration of police patrols. Another possible alternative for enforcement lies with the prospect of metering the facility; however, this system may prove to be economically infeasible under certain conditions of extensive lengths of priority lane utilization.

These factors have been considered and presented in various papers published concerning reversed lane systems in operation. The Shirley highway project of Washington, D.C. is one such operational facility. (12,15,60) This system consists of a two lane reversible busway constructed within the median area of the Shirley Highway. Quantifiable benefits, as presented by

Gersten and Kahan (15), included the economic value of passenger travel time savings, auto operating cost reductions and elimination of parking fees.

Additional benefits included:

- a) reduced traffic congestion and user frustration;
- b) reduced downtown parking demand;
- c) reduction in air pollution;
- d) reduction in the need for a second car by suburban families;
- e) provision of a continuous non-stop bus roadway, uniquely attractive to commuters now driving to work over the Shirley Highway; and
- f) the implementation of a demonstration project which can be used as a national proving ground for bus rapid transit. Early studies of the operation of this project by Fisher (12) have indicated a substantial change in mode choice for commuters in the corridor.

A similar exclusive busway was planned in the Pittsburgh area as a part of the overall transit system. (50) The busway consisted of a two-lane, two-way highway and was intended to serve commuter corridors with existing passenger volumes lower than those requiring a transit expressway but higher than can be adequately served by conventional bus service. The buses were to extend the service directly into the neighborhoods. This ability to operate independently off the busway is an advantage over fixed rail systems while offering the further advantage of exclusive right-of-way on the congested highways.

An urban corridor project has also been undertaken in the Minneapolis-St. Paul Metropolitan Area. (23) Two concepts were to be combined in this project, one being express bus operation and the other, surveillance and control of freeways. Buses were given preferential access to the freeway through special bus ramps and an override of the ramp meter. Automobiles

were metered onto the freeway only when their presence will not reduce the desired level of service. As part of the project, facilities were to be provided alongside the freeway for utilization by park and ride commuters.

A study of the bus priority measures that have taken effect in London are presented in a paper by Huddart and Allen (25) along with a projection of future implementation. These projections assume that some measure of disturbance to other road users will be found acceptable. In addition to the exclusive bus lanes, London has implemented bus precincts. These precincts, modified AFZ's, are areas where autos are banned but mass transit vehicles are allowed.

This concept of reserved highway lanes, as is the case with all methods of restraint, is no panacea; therefore it is not applicable to all situations. Some implementation problems and possible disadvantages are discussed by Stimpson (55) and Barnett (2). Stimpson feels that the exclusive bus freeway is superior to the reserved lane concept of an existing facility in regard to potential implementation difficulties. In order for the reserved lane concept to be effectively implemented, it must be fully understood and accepted by the public. If this is not achieved, then problems arise with enforcement. During periods of initial implementation, it will become quite inviting for low occupancy vehicles to leave their congested lanes of travel and utilize the lane reserved for high occupancy vehicles. If this occurs, the reserved lane concept will have proven to be ineffective. On the spot apprehension, as also pointed out by Chappelle (5), is difficult and would only tend to retard flow and further add to the congestion which this concept is designed to relieve.

Barnett (2) summarizes the following possible problems that can occur with the implementation of the reserved lane concept:

- a) The assignment of one lane out of three or four to buses could reduce capacity sufficiently to seriously upset the operation of the whole freeway system or at least cause congestion and even back up.
- b) The assignment of the outer lane to buses makes it necessary for general traffic to cross the bus lane to enter or leave ramps, most or all of which connect on the right. This could be hazardous and disruptive of bus and access operation.

- c) The assignment of the inner high speed lane to buses may be more desirable than assigning the outer lane but this may cause operational hazard in bus speed change when moving between the freeway fast lane and a bus stop.
- d) The assignment of a lane to buses aggravates the psychological effect on drivers of other vehicles, delayed in their lanes when the bus lane is relatively free of traffic. It may be virtually impossible to control all drivers and a certain number will venture into the bus lane regardless of signs and ordinances. This will have the effect of reducing speeds of buses.

Barnett indicates that some of these problems can be alleviated by physically separating these streams of traffic. If not accomplished by separate facilities then by placement of flexible dividers between the bus lane and the other lanes.

One study raised questions regarding the feasibility of exclusive bus lanes. (30) This study of the San Francisco-Oakland Bay Bridge concluded that an exclusive bus lane for the bridge is impracticable even though it would result in savings to the bus patrons. This savings is far outweighed by the loss incurred by the private passenger vehicle. It was determined

that the overall capacity of the facility would decrease due to the excessive headways of the high occupancy vehicles and at the present demand there is no modal split that would render this measure feasible.

The advantages of a reserved lane system are similar to those of most traffic restraint systems. It reduces congestion by offering priorities to high occupancy vehicles thereby, inducing bus patronage. By relieving congestion, this measure also reduces the frustration to drivers which generally accompanies congestion. (15) Also, high occupancy vehicles aid in reducing the level of pollutants emitted into the atmosphere and reduces the demand for parking space within the CBD. (41) Reduction of this space for parking vehicles liberates this land for utilization by other land use forms.

ROAD PRICING

Pricing policies can be utilized within the transportation network to control travel demand. Work by Roth (43,44,45) qualitatively show the road pricing of congested facilities can be considered a means of reducing vehicular travel demand. The basic principle underlying this concept is the charge levied on the road user for the use of the facility. This charge is dependent upon the level of congestion within the facility, as greater charges are levied during periods of greater congestion. Roth points out this is to imply that roadway facilities follow the supply-demand doctrine. He supports this supply-demand doctrine for roadways with analogies to hotels and utilities. These charge-varying rates depend upon the season and time of day. However with these facilities the consumer is led to believe he is charged less for patronage in off-peak times when in reality he is being charged greater amounts for use during peak, congested periods.

A basic view held on this concept of congestion pricing concerns the addition of a vehicle into the traffic stream and the results of this action. When this occurs there is a resulting increase in travel time, thereby increasing costs not only to the entering vehicle but also to every vehicle within the traffic stream. (32) Zettel and Carll (64) contend that the determination of the driver to resort to an alternative roadway is a function of economics, time and convenience. In essence, the levying of charges for congestion imposes an additional cost to a situation which already is economically unappealing. The levying of this excess charge will a) induce motorists to travel another facility which is less congested and more economically attractive, or b) alter their plan of travel. This will produce reduced travel time thereby creating greater economical benefits. (17)

Studies have been undertaken to incorporate this concept to actual situations. One consideration that must not be overlooked when dealing with this concept concerns the increase in traffic on alternate routes. This increase results from the motorists from the toll facilities who are not willing to pay the added charge. St. Clair (54) concluded that pricing is not a preferential method of controlling congestion if it only results in the diversion of traffic to alternate routes. One such study that gives consideration to this problem was conducted by Bellomo. (3) A model was developed which projected traffic within a specific section of highway for various user charges. Obviously, it would be expected that traffic volumes would decrease with increases in user charges.

Hedges (19) offered documentation of economic analysis which can assist in planning and administration of transportation networks. From this work, a framework is suggested for evaluating such alternatives as road pricing. Mohring (32) also presented a method which concerns the development of

rough estimates of the optimum congestion toll structure for a large urban area. He presented his basic argument for setting congestion tolls through utilization of models. This argument was that in the absence of these tolls individual drivers consider only the cost incurred to them by the congested facility. By ignoring the cost that their additional vehicle imposes on the other vehicles of the traffic stream which they are entering, they tend to make trips of less value than the total cost. If each driver were required to pay a toll equal to the cost imposed upon other vehicles of the stream, then that driver would theoretically limit trips to those with values in excess of their costs.

Holland presented a paper which dealt with approaches for evaluating alternative methods of restraint. (24) The various methods included:

- a) an electronic point-pricing system;
- b) peak and off-peak charges for crossing or operating within boundaries of a few large zones; and
- c) parking charges which could be varied by location and time of day.

The basic approach for evaluation of these methods was conducted with the use of a model, one which is similar to those in use for traffic and public transport studies. The model was used in an attempt to devise design patterns for a city and to analyze the costs, problems and performance of these methods within the area rather than choose among different pricing methods in terms of their abstract characteristics. Parsonson (39) specifically dealt with the development and evaluation of a practical, economical and rational system for monitoring urban traffic congestion and the road user costs which accompany this condition. By utilizing tables of vehicle operating costs which were developed by Winfrey, speed-time graphs were converted to dollar costs due to congestion. Computer calculations of time cost plus

operating cost were plotted against observed travel speeds. These plots yielded the congestion components of road user costs. In order to implement the concept of road pricing, it is necessary to develop a scheme for collection of these charges. The current method, that of toll booths, used by most rural toll highways is not feasible in a congested urban area. These booth facilities would only cause greater congestion due to the time delay incurred during payment. Various methods have been offered to achieve a smooth, organized means of collection. The user charge collection systems that have been offered generally can be classified in one of two categories, a) those that operate on a pre-payment basis, and b) those that operate on a post-payment basis. The publication sponsored by OECD (56) offers discussion concerning development of both plans.

Footnote (13) presented a paper concerning three different types of post-payment devices which record the user charges based on the roadway used. The user must then pay for the charges that have been recorded. These are classified as automatic vehicle identification devices. The three types of devices utilize optical, radio frequency, and microwave detectors. A majority of this article is devoted to the radio frequency system due mainly to its high degree of accuracy. Four systems were performance-tested on a bus terminal ramp for 3 months and were checked against each other. The GE system had the most transactions and out of a total of 13,814 bus passengers, all but 181 were measured correctly. Therefore the accuracy of the GE system was 98.69 percent. The WABCO system was on line for the longest time for this test, with its one loop sensing a total of 9,199 transactions, all but 48 of them correctly, for an accuracy rate of 99.48 percent. The highest accuracy was attained by North American Phillips system. Once initial tuning was completed, which delayed the placement of the system on line, the Phillips interrogator sensed 5,226 vehicles, all but 8 of them correctly, for a performance rate of 99.85

The authority to levy these taxes lies with the state legislatures. For a city to tax streets, they must be granted the power from this governing body. Certain groups of vehicles might be exempted from the tax, but there must be a valid purpose for the exemption otherwise the ordinance would be in danger of violating the equal protection act of the U.S. Constitution. An example of one such group which might be excluded is public transit vehicles. This being done in an effort to encourage transit ridership, thereby reducing congestion further.

Coit also discussed problems in the use of increased bridge tolling and its effects on congestion. Bridges are subject to various federal statutes according to their date of construction, funding and other factors. Many however are subject only to state and local law. She cited a report by the Secretary of Transportation which recommended changes in bridge regulation to allow for congestion pricing, but many bridges are subject to individual charters which stress responsibility to shareholders. Therefore, if pricing experiments are likely to lower total revenue, they will not be accepted in many instances. If revenues can be kept constant or increased, however, there is little that would hinder bridge pricing experiments.

Another legal problem mentioned both by Zettel and Carll (64) and by Creighton (8) is the fact that these tolls could be ruled discriminatory measures against those who are not financially capable of affording the additional cost. This would cause ramifications, especially among the underprivileged.

A final problem may arise with a system that can record the position of each motorist and all stops made by a motorist. Acceptance of such a system within a democratic society could be a slow and painful process. (20)

With respect to road pricing, it is significant to note that much of the work in this area is associated with European countries. To date, there has been little support for this concept in this country. It should be recognized, however, that this concept is not totally new in that user tolls have been imposed for the use of specific bridges or highways. Historically, the application has been intended for the generation of revenue while road pricing is directed towards control of use.

ENERGY PROPOSALS

The consideration of traffic restraint as it is related to energy availability and cost is a relatively unexplored area. Only within recent years when this country experienced fuel shortages have studies been undertaken concerning this topic. Effectively used, the control of energy represents a possible means of controlling or restraining traffic. In some cases, the restraint results in reductions in automobiles through more efficient use. Sagner (46) presented an article dealing with the impacts suffered by cities in a fuel shortage. He offered possible alternatives of which two are increased car pooling and greater utilization of mass transit. The alternatives are a function of the density of the city employment. Statistics were provided on the impacts resulting from the limited supply of fuel.

Orski (35) also expressed his views in a paper dealing with the limitation of fuel and its influence in the use of mass transit facilities. Musial and Stearns (33) reiterate these views in dealing with rationing. They bring forth the view that rationing would increase the utilization of car pools and mass transit.

Two other studies, however, failed to substantiate these views. The first, a report by Sacco and Hajj (18) studied the impact of the energy shortage on travel patterns and attitudes. The study was conducted in an auto-

oriented suburban area of Columbia, South Carolina. In general, the findings showed that the energy shortage did not appreciably reduce the amount of automobile travel nor did it substantially increase the patronage of mass transit. However, this can be attributable to two factors. The first being the belief that the shortage was temporary, and secondly it can be attributed to the less than adequate mass transit facilities serving this area.

One definite result of the study showed that in general the price of gasoline did not have much immediate impact on driving patterns. It was felt that the increase in price alone is not an adequate enough measure to reduce traffic volumes. However, when the shortages were at their peak there were decreases in traffic volume and increases in transit patronage. Therefore, it was felt that the factor of supply was the critical factor for utilizing energy with respect to traffic restraint.

The second study was undertaken by the Federal Highway Administration (52) and focused on the effect of gasoline shortages on travel patterns. For this study, participants were volunteers from the field staff of the Federal Highway Administration. This study concluded that:

- a) The demand for gasoline was not price responsive for the study population which was high income and small city oriented.
- b) The shortages of the winter of 1974 were of insufficient duration to cause changes in the travel patterns of the study population. Such changes were hypothesized to have been smaller car purchases with small engines, lessened miles traveled, greater frequency of gasoline purchase, and changes in home or work location. These changes did not occur.
- c) The only means available to reduce the amount of gasoline purchased

for the study population was constrained availability - either by gas rationing or by reduced allocations to stations.

There are conflicts in the literature that has been published to date with respect to the effect of energy on traffic demand. While energy cost and availability should cause theoretical changes in traffic demand and shifts to public transport, the studies have not fully substantiated this theory. It must be recognized, however, that this may be a function of the rather short period of critical shortages, the relatively small and incremental price changes, and public attitudes and beliefs.

SUMMARY & CONCLUSIONS

Planning studies conducted by various agencies and groups show that it is becoming more difficult and will continue to become nearly impossible to meet the full demand for automobile travelers in urban centers. Attempting to accommodate fully this mode of transport potentially could prove to be economically infeasible and environmentally hazardous. The aim of the traffic restraint concepts is to introduce measures which reduce or control the demand for vehicular traffic while minimizing social and economic impacts. In actuality, it has been revealed that many of these techniques may enhance the social, economic and environmental conditions of these centers. It must be emphasized, however, that these techniques should form only part of a comprehensive transportation plan ensuring high accessibility for all citizens to all areas. The objective of restraint, therefore, must be to improve the accessibility and environment of a center, while limiting the choice of mode for the benefit of the populace.

At the current time, the literature makes reference to a variety of methods or techniques which may be applied in cases where traffic restraint is desirable. These methods include parking controls, network alterations, road pricing, and energy proposals.

Parking controls represent a viable means of attaining the end product of restraint. By supply depletion and/or surplus charge, the number of automobile trips to the urban center can be limited. This is due to either the difficulty in locating and/or the added expense of parking. However, this technique poses little effect on trips not terminating in the urban center. Again it must be noted that this technique of and by itself will not be effective and could create deteriorating effects if accessibility to the

center is not maintained through alternate modes. It is considered to be one of the more feasible approaches to controlling demand even though considerable public reaction to such proposals can be anticipated.

Network alterations can conveniently be categorized into pedestrian malls or auto free zones, and the reservation of highway lanes. Pedestrian malls have proven to be extremely successful in European centers due basically to their enhancement of economic, social and environmental conditions. Traffic cells or compartmentation which can be considered a form of this technique is extremely desirable where conditions warrant. Before any form of this technique is implemented, a broad multidisciplinary study should be conducted. The traffic characteristics in and around the affected area should be given careful consideration. This is to ensure that the effects of such a measure will be advantageous and not create adverse conditions in the adjacent area accommodating the diverted traffic. Other factors which should be given consideration are the land use function of the affected area and the parking supply adjacent to the zone. Along with the parking supply study, consideration must be given to the availability of alternate transport modes to the pedestrian mall.

The reserved lane concept provides for the utilization of specified highway lanes exclusively by high occupancy vehicles. The basis behind this priority lane concept is to transport greater numbers of passengers in reduced time. By accomplishing this, it is felt that a significant shift in mode would occur. This resulting modal shift would potentially relieve congestion and the many by-products associated with it. Obviously, this type of restraint technique is applicable only in dense, heavily travelled corridors of commuter traffic. Because this particular method presents problems concerning enforcement, it is highly dependent upon the acceptance

of the general public. An adequately publicized campaign must precede implementation for this measure to be successful. If this does not occur, then acceptance during the critical beginning stages is unlikely; and the program subsequently will be met with harsh opposition.

Road pricing involves charging for the use of roads or streets in which reductions of traffic are desired. When a journey is made by a particular mode, the cost and difficulty of that trip are weighed against the advantages of that mode. If it is too expensive or too time consuming, the decision may be made to make the journey by a different mode, at a different time, to a different destination, or not at all. Thus, a trip which is only marginally valuable to the person making it potentially causes delay to those whose time is important to them. By adding a surplus charge for the utilization of the roadway, the facility will be utilized by those who determine it to be economically feasible. This method, in which vehicles pay for the use of road space by electronic or other means is theoretically attractive because of the benefits. Problems do arise, however, with respect to the legal aspects. There is the problem of revenue, how it is to be handled, and surveillance in a free society.

Restraint through the aid of energy proposals is a relatively unexplored area at this time. The control of traffic demand may be potentially controlled through the availability of fuel or its price. The main problem that is associated with this method is that the restraint is of a general nature and cannot easily be directed to small or distinct segments in the urban area. The studies of the effects of energy have resulted in mixed results. While energy theoretically represents a viable means of controlling traffic demand, it has not caused significant shifts in the urban area transport needs.

Each of these methods or techniques must be carefully considered in terms of the problem or situation that exists and the results that are desired. The application of restraint represents a segment of technology which involves the complex dynamics of an urban area. It must be recognized that the state-of-the-art with respect to traffic restraint is currently undergoing a relatively rapid change. Nevertheless, the response of the public and the urban area to the application of restraint has not yet been adequately explored. While there are currently urban areas which could benefit from the reduction in automobile traffic, the application of any restraint method must be carefully considered and well planned before implementation.

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