

**MANAGING CONGESTION BY DISCOURAGING SHORT TRIPS ON FREEWAY  
SEGMENTS THROUGH RAMP METERING AND TRIP-LENGTH MANAGEMENT**

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## SUMMARY

Peak period congestion on urban freeways is a problem which transportation engineers are trying to solve. This problem has occurred because of the low cost associated with driving automobiles, as well as other factors. This low cost does not reflect the impacts of delays on other drivers or pollution of the environment. Society is at a point where the addition of more capacity coupled with stable costs associated with driving has forced transportation engineers to address reducing vehicular demand on the congested freeways.

Ramp metering is an effective technique for maximizing the efficiency of congested freeways. One objective of ramp metering is to divert some short-trip drivers, which reduces demand for the freeway. Metering also regulates the entrance ramp flowrates to minimize accidents and turbulence, thus allowing the freeway to operate at capacity.

Trip-length management is a concept which focuses on additional diversion of short-trip drivers from the freeway. In concept, drivers making short trips on urban freeways during the peak period would be assessed a fee greater than the fees for longer trips made on the same freeway section during the same peak period. The funds generated from these fees would be used for transportation improvements in the urban network. This technique can be implemented with current automatic vehicle identification (AVI) technology.

A ramp metering/trip-length management system might prove to be more effective than ramp metering alone. A secondary benefit is the generation of transportation improvement funding. When examining criticisms of past ramp metering and road pricing projects, several concerns were noted. These concerns are discussed to assist the reader in understanding several facets of a ramp metering/trip-length management system.

Recommendations for a ramp metering/trip-length management system are made on three issues. These issues are implementation sequence, adoption of AVI standards, and marketing techniques. Each of the three recommendations are critical to the success of the system.

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## INTRODUCTION

In the past, freeway congestion has been addressed by the construction of additional capacity. The 1990 Clean Air Act Amendments prevent this type of solution unless the addition of capacity does not cause current emission levels to increase. Therefore, basic and innovative freeway management techniques are receiving more attention to meet the need of congestion management.

Congestion can be caused by many things. One origin of congestion is when demand exceeds capacity during peak periods, causing the freeway section to "breakdown," thus reducing its capacity greatly. Long and short trips are made on freeways during peak periods; therefore, some demand is due in part to the short-trip drivers on urban freeways.

Theory and practice indicate that freeway congestion can be alleviated during this critical time by encouraging only a small percentage of drivers to divert from the freeway. Short-trip drivers constitute a component of the driver population during the peak period and appear to be prime candidates to divert from the freeway. Thus, it is desirable to keep short trips from increasing demand on the freeway or unnecessarily consuming capacity.

Although it would be difficult to prohibit short trips from the freeway, it may be feasible to make the freeway less attractive to short trip drivers. Currently, one objective of ramp metering is the diversion of short trips from the freeway. Ramp metering may in fact divert some short trips. New technology may provide the hardware necessary to make the freeway even less attractive through some form of vehicle management. One concept for vehicle management is trip-length management.

Trip-length management may discourage short-trip drivers by charging fares for the length of trips made on the freeway during peak periods. Trip-length management might be implemented with current Automatic Vehicle Identification (AVI) technology. If trip-length management were used in conjunction with ramp metering, this combination might make the freeway even less attractive to short trip drivers. Thus, some greater degree of congestion prevention may occur by reducing demand on the freeway.

## PEAK-PERIOD URBAN FREEWAY CONGESTION

A freeway's capacity is dynamic. The flow rates associated with Level-of-Service (LOS) F, or "break-down," are significantly less than the maximum freeway capacity. When vehicles enter a freeway operating at high volumes, some turbulence in the mainlanes occurs. This turbulence causes decreased speeds and induces delay on other users of the freeway. This turbulence can be increased with the entrance of subsequent vehicles, thus forcing the freeway to LOS F. Thus, "break-down" occurs and congestion sets in. Cameron has suggested that the level of congestion increases exponentially with each vehicle added beyond the carrying capacity (1). Therefore, the costs of increased delay and fuel consumption, as well as emissions, imposed by the other drivers increase exponentially also.

Although motorists pay a relatively high price for the right to drive (initial vehicle cost, maintenance cost, licensing fees, insurance, and fuel cost), they do not directly pay for the delay induced to other motorists in the transportation system or the impact on the environment. These costs (induced delay and environmental impacts) can be substantial when congestion occurs. Drivers entering the congested freeway needlessly increase the delay of other drivers, without paying any of the impact costs to other users of the system. Thus, there is some imbalance between the true cost of driving an automobile during the peak period and what drivers actually pay for currently. It is this imbalance in cost that has created a narrow view of what the motorist pays for.

### The Cost Imbalance

Supply and demand are the great economic regulators of society. Prices reflect the costs associated with supply or demand. If supply is greater, then prices are lower; when demand is greater, then prices are higher. The old, "add new capacity" attitude reinforced the abundance of supply in the transportation system, with low prices paid by freeway users to use the system. Today, many urban freeways cannot be expanded due to physical constraints and high construction costs, yet costs paid by the freeway users have not changed greatly. Cameron notes that the price paid for driving a vehicle is significantly lower than the cost of supporting the activity. (1) This cost imbalance has led to the uncontrolled growth of demand on the transportation system, growth which can not be accommodated with new capacity.

Figure 1 shows the cost and benefits of travel as the level of road usage increases. The two functions are the marginal social cost (MSC) and the marginal private cost (MPC).

The line D'-D' represents demand during the off-peak. Point E is the point at which the demand is equal to capacity. Vehicles are still able to maintain their speed at this point and do not experience delays.

The line D-D represents the demand on the roadway during the peak period. Since this demand is greater than that at Point E, vehicles are not able to maintain design speeds, and delay and operating costs increase. The current system allows the demand to settle at Point G. The costs drivers entering the freeway impose on other drivers are greater than

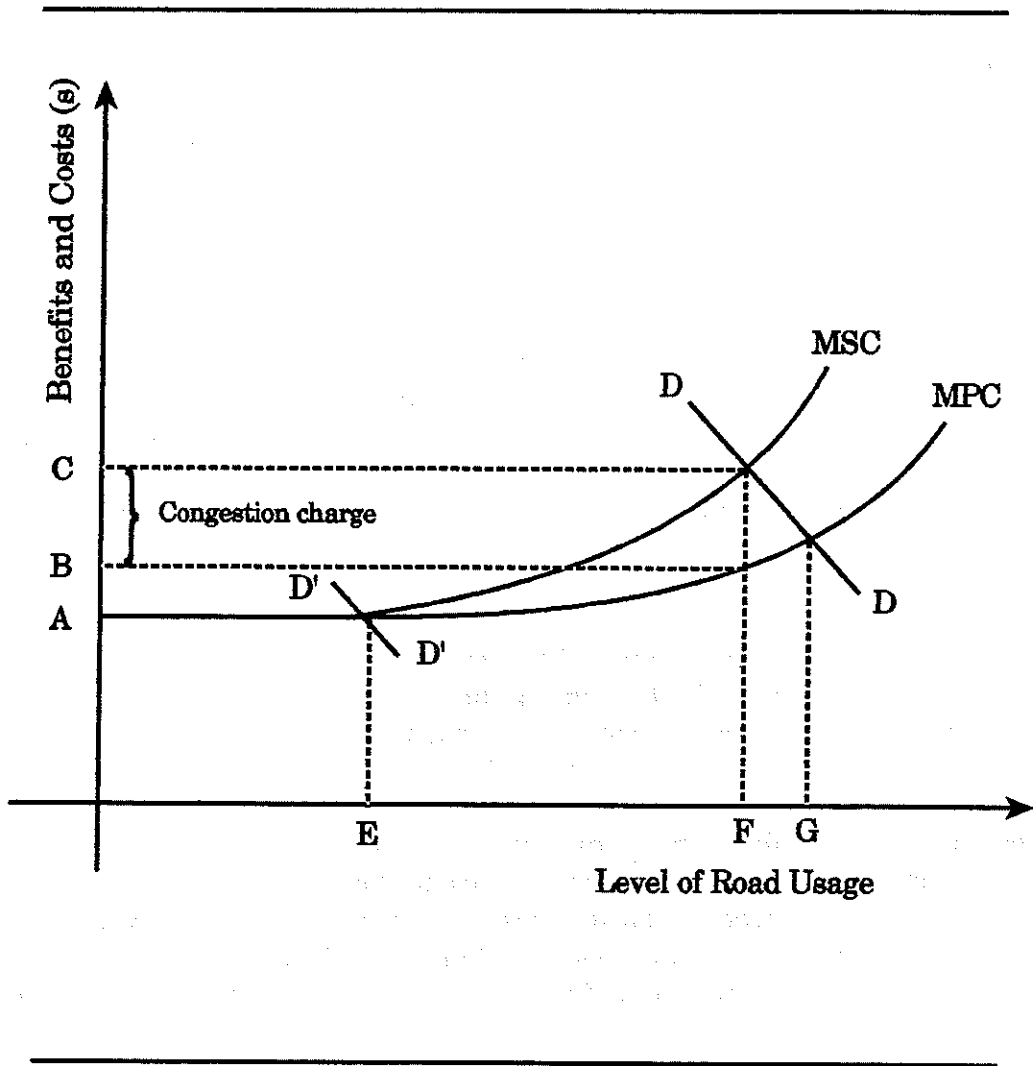


Figure 1. Costs and Benefits of Road Usage (2).

the entering driver's benefits. With some form of intervention to balance this cost, demand will settle at Point F. It should be noted that at this point, delays still occur. The system's users pay for the cost of those delays in the form of a congestion charge. This congestion charge, shown by the difference in Points B and C, is the difference between the MSC and the MPC during peak demand.

### Short Trips

Certainly, freeways should be used by both short- and long-trip drivers. Each views their trip as important as the other's. However, congestion might be relieved if only a small percentage of vehicles diverted from the freeway during the peak period. This scenario in fact did occur in Los Angeles, California during the XXIII Olympiad. The California Department of Transportation effectively reduced peak period demand on the urban freeways for the duration of the Olympiad by encouraging carpooling and flextime. During this two-week period, with an increased number of vehicles in the area for the Olympics, the freeways operated at capacity, and freeflow conditions existed (3).

An examination of freeway use during the peak period will reveal that long and short trips are being made. The question of which type of trip to prevent is then posed. Short-trip drivers might be able to use alternative routes to reach their destination, whereas long-trip drivers do not possess such readily available routes for their convenience. Therefore, short-trip drivers have an advantage in their choice of routes. This advantage makes them a possible group of freeway users who could be discouraged from using the freeway during the peak period.

Several transportation engineers feel that short-trip drivers do not have a great need for the freeway. Robinson and Doctor remark that, in concept, freeways are not intended to serve very short trips (4). Yagar concurs by noting that longer trips have a greater need for the freeway, and thus some capacity should be reserved for these trips.

These statements indicate that some congestion might be prevented during the peak period if short-trip drivers are discouraged from using the freeway. Short-trip drivers add unnecessary demand to the freeway during these peak periods. This excess demand might be reduced since alternative routes or modes (walking or public transit) are usually available to short-trip drivers. It is important to define what a short freeway-trip constitutes to better focus on the shorter trips being made with alternative routes available.

Leaders in the transportation field are divided on the definition of a short freeway-trip. Drawing from the responses to a small survey conducted for this paper, the average value of a short freeway-trip is suggested to be 2.7 miles or less (5, 6, 7, 8). This distance is dependent upon the specific geometry of the freeway and alternative routes. If there are physical obstructions such as rivers, railways, or discontinuous frontage roads, then these are special cases where short freeway-trips must be made. Otherwise, a typical short trip might be such that the driver enters the freeway to bypass an arterial traffic control device or a series of traffic control devices, and then exits the freeway at the next downstream interchange.



An examination of techniques used to control or manage congestion will assist the reader in understanding where the proposed techniques for managing congestion on freeways during the peak period originate.

## **Congestion Management Measures**

Congestion management has received greater attention since the early 1960s with the implementation of the Chicago and Detroit freeway management programs. Several measures or actions are conceived to reduce congestion by reducing the vehicle-miles of travel, while others attempt to control vehicle flowrates and driver route choices. These actions include the implementation of transportation system management and transportation demand management techniques, public education campaigns, and transportation pricing strategies.

### *Transportation System Management (TSM)*

One objective of transportation system management (TSM) is to regulate how vehicles operate in the transportation system. This strategy does not reduce the demand on the transportation system, but rather attempts to increase the efficiency of the system at current and projected volumes. Ramp metering, for instance, regulates the number of ingressing freeway vehicles per ramp, but does not reduce demand on the overall transportation system. High-occupancy vehicle (HOV) facilities attempt to move more people through congested areas through the use of special lanes. This is a unique strategy because it improves efficiency and attempts to reduce demand on the freeways.

### *Transportation Demand Management (TDM)*

Transportation demand management strategies are designed to reach the commuters before they make their trips and to encourage the use of more efficient commute systems (e.g., trip reduction ordinances, work schedule changes, carpools and vanpools, etc.). TDM actions are applied in the form of incentives and policies. These actions are enacted by employers and can be coordinated with local and regional government bodies.

### *Public Education Campaigns*

The objective of a public education campaign is to inform commuters of alternative modes of travel for the single-occupant vehicle. Educating the public about transportation problems, like congestion, and their solutions may be the best starting point for transportation engineers to reduce recurrent congestion. Past public education campaigns have focused on persuading commuters to change modes or times of travel when a long-term road construction project threatens to interfere with freeway flowrates on a recurring basis.

An example of this type of public education is a brochure named "Operation Kennedy Travelers Guide" which is published by the Illinois Department of Transportation. "Operation Kennedy Travelers Guide" presents several topics ranging from regional

alternative routes, construction phasing, local alternative routes, and alternative modes of travel (9).

Conversely, a brochure by the Illinois Department of Transportation, "Operation Green Light," discusses an eight point plan for combating congestion (10). These eight points range from improvements to the arterial network to reducing demand for highway use.

### *Transportation Pricing Strategies*

The objective of transportation pricing strategies is to serve as a regulator of demand. Assuming that prices are elastic, then as the cost for transportation increases, demand will decrease.

Several types of pricing strategies have been proposed and utilized. The most common of these strategies are toll roads, bridges and tunnels, and transit fares, which may utilize differential tolls (a form of peak-period pricing). These types of strategies have been in place in the United States since the Philadelphia and Lancaster Turnpike Road in 1795 and have been successful (11). Other strategies include areawide licensing schemes, as used in Singapore, and road pricing or congestion pricing, which was demonstrated in Hong Kong (12). Of interest to this paper is congestion pricing.

Congestion pricing is not a new concept. Transportation economists have discussed the theory and application of road pricing or congestion pricing schemes since Knight in 1924 (13). Edelstein and Srkal define congestion pricing as a "technique that attempts to spread peak period traffic demand to less congested segments of the network and to less congested periods of the day" (14). Suggested methods for the implementation of congestion pricing have been by cordon, link or junction, and route. Cordon pricing refers to fees assessed for travel between predetermined zones or cordons. Link or junction charges can be used at severely congested intersections or sections of roadway. Finally, route pricing charges drivers for the use of a route. This is very similar to current toll roads.

## RAMP METERING

Ramp metering is a technique used to balance freeway demand and capacity. This balance is a result of regulating the vehicular flow onto the freeway segment. Vehicle entry is regulated by a traffic signal which is activated by either a fixed-time, traffic responsive, or system control system. The main objective of this system is to supply traffic to the freeway in a measured or regulated amount, so that throughput is maximized, speeds remain more uniform, and congestion related accidents are reduced (15).

One method in which throughput is maximized is by discouraging long- and short-trip drivers from making a freeway trip during peak periods and diverting them to alternative routes. Ramp metering is able to achieve this diversion by essentially assessing drivers a fee in terms of their time spent in queue before entering the freeway. Yagar (16) stresses the importance of short-trip driver diversion through ramp metering:

Ramp controls generally result in shorter trips being replaced on the freeway [along its length] by longer ones, such that the freeway capacity is more fully utilized.

Thus the freeway capacity is 'reserved' for long-trip drivers. Excessive diversion to alternative routes is not desired. Although the ramp metering strategy is involved with diverting short-trip drivers to maximize freeway efficiency, the overall freeway corridor management strategy should balance demand on both the freeway and alternative routes.

### Suggested Warrants

Criteria for ramp meter installation has evolved through experience. Robinson and Doctor suggest that candidate freeways for ramp metering are usually plagued with poor peak period conditions such as speeds of 30 mph or less, and low throughput of only 1200 to 1500 vehicles per hour per lane (a 33% and 17% reduction in capacity per lane, respectively) (15). The Manual of Uniform Traffic Control Devices (MUTCD) states that an early indication of a developing congestion pattern is freeway operating speeds of less than 50 mph, occurring regularly for a period of half an hour (15).

### Issues

Several issues concerning ramp metering have been identified in the past. These issues include:

- Geometrics;
- Diversion;
- Public Acceptance; and
- Equity.

Each issue must be addressed so that the system operates efficiently and the public accepts it.

## *Geometrics*

The geometrics issue consists of three factors. First, there must be adequate storage for the queued vehicles entering the freeway. Second, an acceptable acceleration distance beyond the ramp meter is required to facilitate merging into the freeway lanes. Last, the merge area must be adequate for the entering vehicle to successfully merge. These factors will be further discussed later in the paper.

## *Diversion*

Two types of diversion occur when ramp metering is implemented. First, some short freeway-trips are diverted to alternative routes. Second, some trips are diverted to other times when delays are minimal. The first type of diversion was a concern to city officials in Portland, Oregon (15). The city and state agreed to adjust or discontinue the ramp meter system if traffic volumes on adjacent streets increased by 25% during the first year of operation. No significant increase in adjacent street traffic volumes occurred. The second type of diversion has been witnessed in Denver, Colorado. Drivers began entering the freeway before metering operation began in the morning, thus leveling out peaks or spikes in demand (15).

Several factors affect the amount of diversion from the freeway due to the ramp metering system. First, if the trip length is short, the driver will use an alternative route to reach the desired destination. Second, if there is a large queue at the ramp, drivers may divert to an alternative route or a successive ramp to bypass the ramp queue. Third, the entry delay is affected by the queue length, and results in the same effects. Fourth, diversion may increase with the availability of alternative routes. Fifth, if the alternative route is attractive (the driver feels safe), the diversion rate may increase. Finally, if the alternative route is less congested, diversion may also increase. Robinson and Doctor point out that diverting some trips may be desirable if there are alternative routes that are underutilized (15).

## *Public Acceptance*

Public acceptance of ramp meters, in some cases, is low when they are first installed. The public views the ramp meter system as a restraint on a roadway with a normally high degree of freedom (4). This issue diminishes greatly as time continues and the metering system is allowed to work. The public begins to experience the benefits of ramp metering and in some cases requests more meters on the freeway.

Still, public acceptance for ramp metering is low. This statement is true because there are fewer than 2,000 meters worldwide after 29 years of experience (17). This lack of implementation may be due in part to the political opposition of metering public freeways.

## *Equity*

Before implementation, residents near the system usually consider ramp metering to be inequitable. They believe that suburban commuters are receiving an advantage for living outside of the system, while they are subject to the delays on the ramps for all of their journeys.

This issue can be resolved by operating the meters in the outbound direction at first, which was done in Chicago in the early 1960s (17). This allows the public to experience the benefits of metering changing their negative opinion to a positive one. Another possible action is to operate the ramp meters only during the peak periods. This action affects the majority of commuters who make normal trips from home-to-work or work-to-home. This will appear to target the suburban commuters instead of nearby residents.

## **Case Studies**

Ramp metering systems have been used since 1963, in Maywood, Illinois (17). They have been implemented in several metropolitan areas around the United States. Notable systems include those in Chicago, Detroit, Minneapolis/St. Paul, Los Angeles, and Long Island.

### *Chicago, Illinois*

Chicago started ramp metering in 1963. Following tests of metering rates on New York tunnels and freeway ramp closure studies, Chicago ramps were metered with policemen. The policemen stopped traffic and released vehicles one-at-a-time, based on predetermined rates (18). For a 15.3 km section of roadway which was complemented with ramp meters, congestion was reduced from between 19% and 29% over three years (18). Congestion in this case was measured in terms of "min-miles"/day, where "min-miles" refers to the length of congestion both temporally and spatially.

### *Detroit, Michigan*

After installation of their ramp metering system, average freeway speeds increased by 29%; when delays are included, average speeds still increased 20%, and travel times decreased 16.5% (19). To combat the equity issue in the beginning of the project, meters were placed in only the outbound direction. After the public (mainly those who lived and worked within the limits of the system) realized that the metering system improved freeway peak period flowrates and decreased their overall travel times, meters were installed in the inbound direction.

### *Minneapolis/St. Paul, Minnesota*

This system was first installed in 1970 on a section of I-35E. Four years later, the system was expanded to another corridor, I-35W. An evaluation of the I-35E corridor 14 years after implementation revealed that average peak hour speeds increased 16% (from 37 to 43 mph) after metering began. Even with a 25% increase in peak period volumes over

the same period, speeds still increased (4). After 10 years of operation on the I-35W corridor, evaluation revealed that the average peak hour speeds increased 35% (from 34 to 46 mph) with an increase in peak period volume of 32% (4).

Before implementation, there was some difficulty in convincing local officials and the public that the meters would not cause diversion problems on the local streets. This problem has diminished with the expansion of the system as the public has seen that meters are beneficial and don't cause problems (5).

### *Los Angeles, California*

Ramp metering on the Los Angeles Harbor Freeway increased speeds greatly. Before metering average speeds in the peak period were between 15 and 20 mph. After metering, speeds increased to 40 mph (20). Los Angeles currently has the largest ramp metering system in the world, with over 2,000 meters (17).

### *INFORM Project, Long Island, New York*

This ramp metering system covers a 40 mile by 5 mile section of Long Island in the heart of New York City. An evaluation of the system revealed several important results:

1. Fuel consumption was decreased by 6.7%;
2. CO emissions were reduced by 17.4%;
3. HC emissions reductions totaled 13.1%;
4. Nitrous oxide emissions increased 2.4%;
5. 16% increase in average speed (from 29 to 35 mph); and
6. Overall travel time reductions of 13.1 % for motorists entering the freeway (4).

## TRIP-LENGTH MANAGEMENT

Trip-length management is a technique aimed at preventing congestion on urban freeways during the peak period by discouraging short-trip drivers from using the freeway. Freeway trip-lengths might be managed by allowing motorists to pay for the impacts which they impose onto other drivers during the peak period. Fees would be assessed by the distance of the freeway trip made during the peak period. A similar concept was proposed in early 1992 by Jones and Hervik for link pricing, although no detail was given (21).

### Pricing Structure

In concept, fees would be assessed for the length of trips made on the freeway segment during the peak period. A greater fee would be assessed for shorter trips than for those trips which are longer. This preference for long trips is consistent with previously cited literature, which suggests that longer trips have a greater need for the freeway. This concept of charging more for the shorter the trip is contradictory to conventional toll road policy. Conventional toll policy charges users a fee proportional to the trip length made on that facility. The difference between the two policies is that trip-length management tries to prevent short trips, whereas toll roads are indifferent to the length of trip made. Therefore, a base must be established for the cost of driving per mile before costs for trip distance can be instituted.

Several analyses have been made to determine the cost of driving per mile. Cameron has suggested that a maximum charge of \$0.60 and an average charge of \$0.15 be used in the peak period (1). Cameron makes no differentiation between urban and suburban roads, whereas a study by Keeler and Small has. Keeler and Small estimated that during the peak period, a charge of \$0.80-\$1.15 per mile for urban roads and \$0.21-\$0.28 per mile for suburban roads be used (in 1990 dollars) (22).

In comparison, tolls paid on "existing toll roads average approximately \$0.02 - \$0.04 per mile (23). This is an extremely low price to drive per mile and re-emphasizes the cost imbalance that is present today.

### Components

Several components are required for this system to operate. These components include the identification of vehicles, enforcement of system, billing for system use, and existence of an administrative staff. Figure 2 shows a sketch of the trip-length management system.

#### *Identification of Vehicles*

Trip-length management is dependent upon the accurate identification of vehicles or drivers. This accuracy can be accomplished by utilizing electronic means, such as automatic vehicle identification (AVI). AVI is discussed in detail in Appendix A.

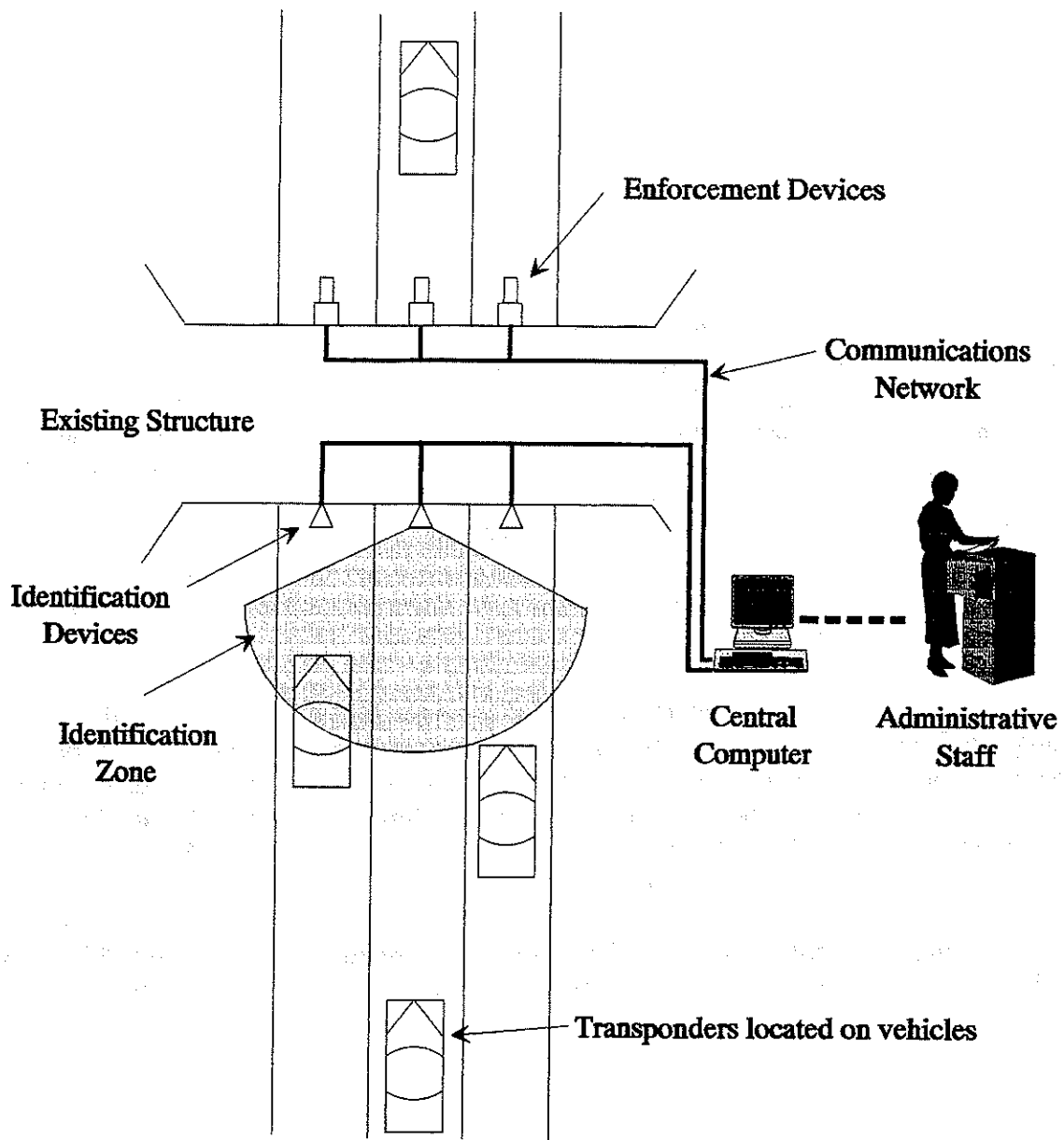


Figure 2. Trip-Length Management System.



Some type of electronic identifying device must be attached to each vehicle. This device can be either permanent or transferrable. Permanent devices can be installed in the vehicle while it is being manufactured. These devices are used primarily for identification of a vehicle only. Conversely, transferrable devices can be used to identify drivers; allowing them the freedom to switch between vehicles. A transferrable device (vehicle-to-vehicle) must have some type of security against modification of its identity. Examples of the type of information which can be programmed into the identifier is the vehicle's serial number or registration number, the driver's name, address, and driver's license.

A field-identifier is needed to communicate with the vehicle's identifying device to obtain information on either the driver or the vehicle. This device will read the information from the vehicle and transmit it to a central computer for processing. Upon exiting the freeway, the process will be repeated and the trip length will be calculated.

An extensive communications network is required for the field-identifiers to communicate with a central computer. Connections from the central computer to the enforcement equipment are also required so that photographs can be made of fraudulent users. This extensive network will require miles of either fiber optic or telephone grade cable.

A large-capacity, high speed central computer or system will be required to process all of the information as it is being "read" (24). This computer will require software which will enable the computer to process thousands of vehicles per hour (assuming that several ramps are monitored during the peak period). Processing will include trip length calculations as well as identification of system violators. Fees, based on trip length, will be assigned to each identifying device here.

### *Enforcement of System*

Field equipment capable of photographing vehicles is required to enforce the system. The use of closed-circuit television (CCTV) will be required to photograph the vehicles of fraudulent drivers in order to enforce pricing. Cameras will photograph the vehicle's registration number and transmit it to the central computer for further action (2). The images can be processed by either humans or computers with digital scanners. Violations will be defined as a failure to pay past billings or accounts which have been overdrawn.

### *Billing for System Use*

The method for billing in such a system can be either by end-of-the-month totals or by a predetermined, deposited amount into an account through which tolls can be deducted, much like a debit card. These bills can be identified directly with the user or indirectly by some personal identification number similar to those used on "pulse" cards.

Monthly billing can be made through a regional transportation authority or by contracting credit companies. This will allow for statements, similar to those which are sent

by telephone companies and credit corporations, to be sent directly to the user. Payment for system use can be through the use of cash, check, or money order.

Indirect billing will allow some degree of anonymity. No direct billing will be sent to the user's home, and no record of trips will be kept. Instead the user will deposit money into an account and a computer will track all debits made against the account. This method will require some visual device at exit or entrance ramps to inform the user if their account is low or overdrawn (21).

### *Administrative Staff*

An administrative staff will have several responsibilities. These responsibilities will include handling complaints and questions concerning the system, as well as verifying violators of the system from the photographs taken by the CCTV cameras. Finally, the staff will be responsible for managing the maintenance of the system.

### **Coordination**

Trip-length management will require coordination efforts from a wide array of agencies and manufacturers. Edelstein and Srkal have identified a potential list of those who might be involved: U.S. Department of Transportation (the Federal Highway Administration and the Federal Transit Administration, formally the Urban Mass Transportation Administration); state departments of transportation; turnpike and transit authorities; state and local governments; regional, county, and local transportation planning agencies; and major vehicle manufacturers (14).

This coordinated involvement is needed to set standards which are crucial for the system to operate among jurisdictions. If a national standard for transponders were adopted and mandated for installation in vehicles, trip-length management might receive greater attention. Several technologies are currently used for AVI. Appendix A discusses several technologies for transponders and data transmission. Also, several case studies are provided.

## RAMP METERING/TRIP-LENGTH MANAGEMENT SYSTEM

A freeway management system which combines both ramp metering and trip-length management might better prevent congestion on urban freeway sections during the peak period. This system might discourage short-trip drivers from using the freeway as a path if alternative routes are available. It will allow longer trips to be made on the freeway, while entering traffic flows are regulated by the ramp metering system. Thus, the system provides a reduction in unnecessary freeway trips and controls the entering vehicular flows.

### Implementation

Several considerations must be made before implementing a trip-length management/ramp metering system. These considerations include corridor selection, installation of the system and advance notification of modifications to the system.

First, a corridor should be selected on its level and duration of recurrent congestion and guidelines for the installation of ramp meters. Some type of regulation might be warranted if recurrent congestion is predominant on a section of urban freeway. Trip-length management might increase peak-period freeway capacity by discouraging short-trip drivers from choosing the freeway as a travel route, thus reserving that capacity for long-trip drivers who have a greater need for the freeway. Ramp metering will increase flowrates on the mainlanes by regulating ingressing flowrates to the freeway and diverting some short-trip drivers to alternative routes. Experience throughout several cities in the United States has reinforced the benefits of increased flowrates and speeds, and decreased overall travel times for urban freeway sections which utilize ramp metering systems.

Second, the system should be implemented in a modular manner. Ramp meters should be installed before trip-length management. This will allow for an "observation period," to determine if the ramp metering system is sufficient in preventing or managing the recurrent congestion on the freeway during peak periods. If recurrent congestion continues, trip length management should be installed at all exit and entrance ramps throughout the congested freeway section and possibly at ramps with high volumes.

Third, when it is decided that trip-length management is to be used, commuters should be given advance notification of the pricing structure (i.e., for at least one month) in order to allow them to plan their travel plans accordingly (14). Advance notification can be given in the form of changeable message signs (CMSs) on the freeway section to be regulated, notices in local newspapers, and announcements on local radio and television stations. Such a campaign must emphasize the benefits of the project as well as inform the public of the pricing structure. Drivers will then be educated about the objective of the system and be able to select alternative routes if they decide not to utilize the freeway section. Marketing concepts for advance notification are important. If the system is not marketed effectively, motorists will voice their concern to their elected official to condemn it and discontinue its use.

## Issues

Several issues concerning this system arise. These issues reflect past issues with ramp metering, as well as present issues with congestion pricing and AVI. The issues include: social concerns, economic concerns, political issues, geometric influences, system design and system operations.

### *Social Concerns*

The social issue is very important to engineers since their job is to help improve society. The two most prevalent social issues concerning this system are those of equity and privacy. Equity is a concern of both ramp metering and AVI-type systems. Privacy is an AVI-type system concern exclusively.

Equity of the system is an important concern. Many people feel that the residents in the suburbs are not subject to the prices one must pay to use the system as the residents of the inner city are and vice versa.

One view is that suburban commuters do not pay an equal price for time because the ramp meter system does not usually extend into the suburbs. Therefore, suburban commuters only experience ramp delays in the p.m. peak period as they journey from work to home. Urban commuters, on the other hand, are subject to ramp delays in the a.m. and p.m. peak periods as they make their work trip. This view is unfounded. Ramp meters are placed in both urban and suburban environments, without discrimination. Therefore, suburban commuters pay a price equal to that which is paid by urban residents. Chicago started their ramp metering system with ramps in both suburban and urban environments, thus making the system as equitable as possible.

AVI is viewed as a "have vs. have-not" system. Those who are willing and able to pay will be able to use the freeway, while those who cannot afford to pay will not be able to use the freeway. Certainly, this point of view is unfair to those who cannot afford to pay the price of short trips made on the freeway. If the funds generated from trip-length management are used to fund public transportation, more freeway management, traffic signal improvements, and low-cost capital improvement projects, those who cannot afford to pay to use the freeway during the peak period will benefit through these improvements (23).

Privacy is important to all people. Unfortunately, AVI could allow for misuse of the information which it so easily can provide. Citizens fear this misuse. A classic analogy of this misuse is "Big Brother," from George Orwell's novel, *1984*. Some politicians have even proposed enforcing speed limits through AVI use because of its ability to determine the average speed of a vehicle on a roadway (24). Others dislike AVI because it leaves a clear audit trail of where a vehicle has passed (24).

A case can be made against this concern by examining credit and phone trails. Credit and phone trails are similar to the audit trail produced by AVI systems (24). A person can be tracked through the use of his/her credit, debit, and "pulse" cards. Similarly,

the telephone companies track each call made by a customer as to the number called, duration, date, and time of the call. The public does not appear to fear their privacy in these areas. If the public does not feel threatened by their credit or phone trails, why should they feel threatened by an AVI trail if similar security and privacy actions are taken?

The system will also allow for the identification of stolen vehicles. This might ease owners minds if their vehicle were ever stolen.

### *Economic Concerns*

Economics is the foundation for the approval of any engineering project. An engineering project can be approved if its benefit-cost ratio is greater than one, if the funds are available, and if management wants it.

This proposed system requires a large capital investment. The cost for installing the field hardware and communication links, purchasing one or several computers, and development of software is expensive. Ramp metering has proven very effective, and metering systems are being expanded. The actual benefits of trip-length management cannot be determined at present, but only speculated. If congestion is reduced with this system and the revenues generated from trip-length management fund the transportation system, then trip-length management has a great benefit to society. It not only improves traffic flow but is another funding source for transportation improvements. In fact, support for road pricing in the United Kingdom increased from 30% to 57% when a similar scheme was proposed to allocate generated revenues to public transport, road safety, and the environment (21).

There is also a fear that these systems will cause employers in the CBD to move to other areas which are not subject to these management systems (23). An example of this fear is the attempt to demonstrate road pricing in the United States in the late 1970s. Few cities volunteered for these demonstration projects because they feared that road pricing would drive employers to the suburban areas. The mayor of Baltimore, Maryland (13) commented to the Urban Mass Transportation Administration that:

For a downtown area which is struggling to maintain its competitive position with suburban centers (served almost exclusively by auto, with vast amounts of free parking available), I am concerned over any proposal which would further weaken the position of Baltimore's downtown area.

A similar concern was expressed in Atlanta, Georgia. Trip-length management might be viewed in a similar manner. It should be noted that when road pricing was implemented in Singapore and Oslo, these same fears turned out to be unfounded (23). Singapore and Oslo are unique in that geography prevented employers from moving to areas outside of the pricing system.

The CBD might attract new employers if the revenue generated by this system was used to improve public transit and the surface transportation network. These improvements

might increase vehicular flow, as well as the number of people entering the CBD. Both of these improvements might appear attractive to prospective employers.

This system might appear to be another form of taxation for the transportation network. Currently, taxes on the right to drive a vehicle include vehicle registration fees, inspection fees, and fuel taxes. Fong notes that high vehicle registration fees combined with road pricing, a similar system, appears to be double taxing the user (12). In order to equalize these forms of taxation, one must consider lowering the vehicle registration fees or fuel taxes, otherwise the system will fail politically because of the large lobby of motorists.

### *Political Issues*

Every public engineering project is subject to approval by the citizens in some manner, either directly or indirectly. Citizens approve projects directly by passing bonds for the projects. Indirectly, citizens voice their concerns to their representative at the local, regional, state, and federal levels. The voice of a lobby of citizens speaks louder than the individual. This is by far the most difficult aspect of instituting such a proposed system.

Citizens, and thus politicians, were opposed to some proposed ramp metering projects. Some of these projects were accepted on a 'trial' basis and were found to be beneficial. More projects might have been implemented if the public and the politicians were better educated on the positive effects of ramp metering systems.

Likewise, road pricing attempts face the same problem. Liivamagi emphasizes this point by saying that it "would create a large and disaffected lobby of motorists" (25). When Hong Kong's road pricing demonstration was over, it was pronounced a technical success, but the system was not introduced on a permanent basis because of the large lobby of motorists who opposed it.

This system's biggest barrier will be the issue of its political correctness. Many economists and transportation professionals admit this fact. Serious thought and effort should be made to determine how to defeat this obstacle so that trip-length management might be implemented.

### *Geometric Influences*

The geometric characteristics of the corridor in which this system will be implemented is important. Factors such as interchange spacing, frontage roads, availability of acceptable alternative routes, and discontinuities of alternative routes are important to the proper installation of this system.

Interchange spacing is perhaps one of the most important factors to the proposed system. Most trips enter the freeway near an interchange, and likewise exit the freeway near interchanges. A close spacing of interchanges (less than 2 miles) might encourage more short-trip drivers using the freeway to bypass traffic signals on the frontage roads or alternative routes. Longer interchange spacings (more than 3 miles) might be able to

accommodate the temporary or short-trip driver so that there is a minimum turbulence on the freeway. This longer spacing of interchanges is suitable for the trip-length management portion of the system, but is contrary to one objective of ramp metering. The increased interchange spacing results in fewer entrance ramps. Since there are fewer ramps, higher ramp volumes result. These high ramp volumes are difficult to meter effectively (17). Therefore, a balance must be found where the objectives of both system components are addressed effectively.

A disadvantage of the proposed system where frontage roads exist, might be an increase of frontage road volumes due to increased diversion. Although one objective of the frontage road is to act as a form of extra-capacity during incidents, it also allows drivers to use a route parallel to the freeway. Diversion of short-trip drivers may occur on these roads because of its proximity to the freeway. In urban areas, delays on the frontage roads are caused by traffic control signals and failures to yield to exiting freeway traffic. This delay causes increased congestion and failure to access adjacent businesses due to the large frontage road volumes. However, the frontage road should carry a proportional amount of the diverted traffic with the alternative routes in the freeway corridor.

For the ramp metering/trip-length management system to be successful, there must be an availability of alternative routes. These alternative routes are critical for short-trip drivers to use. Availability of alternative routes is directly related to several factors: low levels of congestion, absence of discontinuities, and a favorable perception of personal safety. Low levels of congestion are desired to attract more short-trip drivers by providing a route with similar travel times to the congested freeway. The absence of discontinuities is important for diversion to be functional. Perhaps the most important factor is that of the driver's perception of personal safety on the alternative route. If the alternative route passes through high crime rate areas of the metropolitan area, drivers will choose the freeway because of the protection it provides to the motorist. In the local street network, the driver becomes vulnerable while stopped at traffic signals. Therefore, the alternative route must either appear safe to the motorist, or there must be an increase in law enforcement activity the corridor.

Discontinuities in the transportation system exist where physical elements restrict the design of roadways. In particular, roads may be discontinued when they approach rivers, large depressions in the ground, other roadways and railway corridors. These discontinuities sometimes force drivers travelling on the frontage road to use the freeway because their alternative route ceases to exist and is transformed into an entrance ramp. However, these ramp tend to be major contributors of congestion during the peak period because of high ramp volumes from diverted drivers and those drivers attempting to bypass freeway queues upstream of the ramp under consideration. Therefore, all vehicles entering at this ramp should be treated indifferently.

### *System Design*

System design has been important in ramp metering implementation and will be of equal importance to the application of trip-length management. Several variables must be considered. These include ramp storage, acceleration distance, and adequate merge area

for the ramp meters. Design issues for the AVI technology include receiver and CCTV placement.

There must be adequate storage on the ramp so that ramp queues do not interfere with adjacent or connecting arterials. If queues interfere with adjacent arterials, undue congestion on those arterials will result. Loop detectors near the intersection of the ramp with the adjacent street allow detection of long queues. Once detected, the meter goes to progressively higher metered rates to clear the queue.

An adequate acceleration distance is required to decrease the speed differential between the entering traffic and the mainlane traffic. If the speed differentials are too high, turbulence will occur in the mainlanes, reducing the freeway's capacity. This objective is achieved by making a long ramp and placing the meter some distance up the ramp to maximize the acceleration distance. McDermott suggested an acceleration distance of 91.4 meters from the freeway merge nose for metered ramps (18). The acceleration distance must be balanced between storage capacity behind the meters (18).

An appropriate merge area must be given for the entering traffic to successfully "blend" with the mainlane traffic. Poor merge areas can result in unnecessary ramp queues in the acceleration lane, as well as turbulence in the freeway mainlanes. Generally, it is desirable to not place entrance and exit ramps at the minimum distance because this causes short weaving sections, thus reducing the ability of entering traffic to successfully merge. By spacing ramps farther apart and allowing some recovery distance at the end of the acceleration lane, an adequate merge area is created reducing friction between the freeway mainlanes and entrance ramps.

Locations for the AVI equipment are crucial for correct identification of vehicles, as well as photographs of violators. AVI receivers can be mounted on existing structures, where possible, to read the vehicle transponders. Existing structures can include the ramp meters, luminaries, or overhead structures. Placement of the CCTV cameras should be downstream of the AVI receiver to photograph the vehicle license plate. If two ramp lanes are used, two CCTV cameras might be required to effectively photograph each lane. If the estimated violation rates on these multiple lane ramps are small or low ramp volumes are experienced during the peak period, then one camera might be sufficient.

### *System Operations*

System operations must consider a variety of concerns. These concerns range from high-occupancy vehicle (HOV) treatment to entrance ramp flow rates.

High-occupancy vehicles should be encouraged regardless of the vehicle management system used. A survey of transportation officials revealed that cost, as well as travel time savings, should be used to encourage HOV use. Currently, HOVs are allowed to bypass ramp queues in ramp metering systems. This provides the HOVs a distinct overall time savings. Although no charge for HOV use would be an excellent incentive, it will be too difficult to monitor (i.e., a system which monitors the number of people in a vehicle will be



required). If a charge is made to a HOV, the occupants are receiving a "discount" by sharing the cost of the trip. Therefore, this is also an incentive for HOV use.

Ramp flow rates are controlled by the "green time" on the meter and the cycle length. The minimum ramp flow rate should be 240 vehicles per hour (vph) (4). During the peak period, it is not uncommon for ramps to experience volumes over 900 vph for more than one lane (4). A monitoring program is required to assess the performance of the meters and to regulate the ramp flow effectively. One sign of poor operations is if the queue detectors are occupied on a regular basis. This can be corrected by relaxing the metering rate to clear the ramp queues.

Trip diversion is one objective of this system. An important assumption for the success of this system is that there is unused capacity on alternative routes which short-trip freeway drivers are not utilizing. Thus they impact the long-trip drivers which have a greater need for the freeway.

Trip diversion from freeway entrance ramps can vary up to 100% depending on the level of congestion of alternative routes (6, 7). Periodic studies of traffic volumes must be made on alternative routes to monitor the increase in traffic, which might be due in part to the diversion of short-trip drivers. If alternative routes are becoming increasingly congested, then either one of two scenarios is occurring: (1) excessive diversion from the freeway has left it with a large amount of unused capacity (this event is highly unlikely) ; or (2) the level of vehicle use has increased beyond the capacity levels of both the freeway and alternative routes. The system should then be assessed to see if its impacts on adjacent routes and neighborhoods is negative. Negative impacts might be grounds for the discontinuation of the project.

## CONCLUSIONS

Peak period freeway congestion is present in most major metropolitan areas in the United States. There are many causes of congestion. This paper examined two causes: (1) the cost imbalance associated with driving an automobile during the peak period; and (2) short-trips made during the peak period. The cost imbalance can be solved by the addition of some type of congestion charge where drivers pay for the delays induced on other drivers and the environmental impact. Short trips are present on the freeway during the peak period. Since alternative routes are usually available to these drivers, they are a good segment of the driver population to discourage from the freeway during the peak period. Several congestion management measures have been used in the past. Ramp metering and trip-length management are techniques which may have a good potential for reducing freeway corridor congestion during the peak period.

Ramp metering is an effective tool for reducing congestion related accidents, reducing delays, increasing overall travel times, and assisting in the maintenance of travel speeds. However, after 29 years of operation, ramp metering is not widely used as a congestion management measure.

Trip-length management is a new concept developed to manage peak period urban freeway congestion. Several aspects of this technique are loosely defined in this paper and require more thought and definition. However, trip-length management offers objectives similar to ramp metering with the addition of a form of fund generation for public transit operations or transportation network improvements.

A combined ramp metering/trip-length management system offers a freeway a way to reduce recurrent peak period congestion. It does this by regulating entering vehicle flowrates, as well as increasing short-trip driver diversion to alternative routes. Several issues were presented and discussed. The ramp metering/trip-length management system cannot be implemented at all if the social, economic and political issues are not addressed sufficiently. These three issues can be addressed in ways so that motorists and elected officials will view the system as equitable and secure from invasions of privacy. The issues of geometric influences, system design, and system operation gain importance after the system is implemented. Each of these issues plays an integral part in the overall efficiency of the system.

## RECOMMENDATIONS

Several recommendations can be made for the proposed trip-length management/ramp metering system. The recommendations cover a wide variety of topics from a need for research to marketing techniques that must be considered. These recommendations include:

- More Knowledge about Short Trips Made on Freeway Sections during Peak Periods. More research is required to better quantify trip lengths made on urban freeway sections during the peak period. This quantification will help determine the true impact of short-trip drivers on freeway sections during peak periods. Results will prove if there is a need for trip-length management, since this technique is aimed specifically at short-trip drivers during the peak period.
- Implementation Sequence. Ramp metering and trip-length management share a common objective which includes diverting short-trip drivers from the congested freeway during the peak period. Ramp metering has been used in the past effectively and therefore has proven itself. Thus, the system should be installed in a modular fashion with ramp metering preceding implementation of trip-length management. This modular installation will allow ramp metering to undergo an "observation period" to determine its effectiveness at managing peak period freeway congestion. If ramp metering fails to increase the freeway's efficiency, trip-length management should be implemented. This will divert more short-trip drivers to alternate routes and reduce demand on the already congested freeway. If the ramp metering proves to be effective, trip-length management should not be implemented. The money invested in the system will not be cost-effective. This would save greatly needed funds for other transportation improvements in the urban network.
- Adoption of AVI Standards. Trip-length management can be implemented today with current advanced vehicle identification technology if standards exist. The adoption of standards for AVI is an important step which needs to be taken. Currently, many different technologies are used for vehicle transponders and data transmission. The heterogenous mixture of technology is detrimental to any objective of trip-length management. These standards may not be proposed or adopted until a majority of toll authorities and public airports install AVI systems. A federal mandate for AVI technology installed in vehicles, when manufactured, will assist the expansion of AVI systems and technology.
- Implementation of Identification Devices on Existing Vehicles. The implementation of identification devices for vehicles or drivers is important to trip-length management because it depends upon AVI technology. These devices can be either subsidized, volunteered, or required by public policy. Public policy could require that these devices be installed at the time the vehicle receives its annual inspection or when the vehicle is registered annually. Regardless of the

implementation effort, all vehicles or drivers in the transportation network must have these identifiers for the system to operate effectively.

- Marketing. The system, especially the trip-length management portion, must be marketed to the public to accentuate the positive impacts (increased freeway efficiency, reduced delays, decreased overall travel times, funding source for transportation improvements, etc.) and not the costs the drivers will incur (time and money). This marketing is crucial because it will affect political decisions. If the motorist lobby believes it is a good idea, then it will surely be accepted by the politicians.

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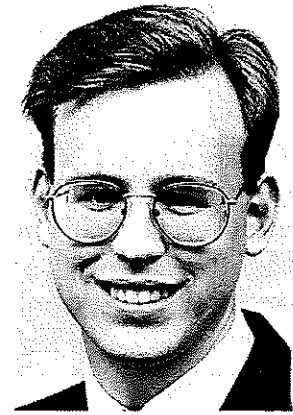
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## APPENDIX A. AUTOMATIC VEHICLE IDENTIFICATION (AVI)

Vehicle identification is a method which has assisted transportation researchers in conducting travel time and origin-destination studies in the past. It has been used since the early 1960s. This method included manually recording vehicle license plates and matching them to a registration database to determine the owner (in the case of O-D studies, questionnaires would be sent to the vehicle owners). Automatic vehicle identification is a technique which uses current technology to identify vehicles in the traffic stream at normal operating speeds. This technique is receiving more attention from toll facilities, airports, the Federal Highway Administration (FHWA), and state departments of transportation.

### Components

There are three components to a basic AVI system: (1) a transponder or tag; (2) a receiver; and (3) a computer. Although the communications component is not discussed here, it is an important part of the overall system.

Two types of transponders exist: (1) read-only; or (2) read/write. Currently, the read-only transponder is used exclusively in AVI systems.

The read-only or passive transponder is a proven technology and is readily available. The receiver sends a signal out and 'reads' the tag's information for processing. The read/write or active transponders may prove to be more efficient, but this technology is still in the development stages. These tags 'write' vehicle information to receivers for processing or the information can be 'read' by passive means. Active transponders will also require a power source to transmit data, which possibly can come from the battery.

The tags can be located in several places on the automobile: (1) underneath, attached to the chassis; (2) mounted on the license plate; (3) mounted on the windshield (inside or outside); and (4) placed on the instrument panel. The cost of the tag can range from \$20 to \$30 depending on subsidies to encourage its use (24).

Receivers are needed to interrogate the vehicle tags. Receivers can be located either above ground or below ground. Above ground receivers must be located within 15 feet of the vehicle to accurately read the transponder (27). It is desirable to mount these receivers to existing structures to minimize the cost of the receiver system. Above ground receivers have some difficulty identifying vehicles that possess a metal-film layer for defrosting and limiting solar gain because of the reflection of the RF/microwave (27). Below ground receivers are usually the inductive loops that are currently in the pavement for traffic monitoring. Since inductive loops, are subject to high maintenance they are less reliable due to the accuracy required for identification (27). Further development of this technology may prove that inductive loops are more desirable.

A central computer or network of computers is required to run this system. The computer is able to interpret the encoded vehicle identification and reference the vehicle



in the traffic stream at successive receivers. A successive identification leads to determination of trip length or travel time.

A computer network can be utilized in much the same manner as traffic control systems are structured. Perhaps one small computer can process local data, another computer might gather data from a series of receivers, and the central computer will calculate the necessary values.

### **Data Transmission Technology**

Several technologies have been developed and used by AVI for data transmission between the transponder and the receiver. These include: (1) infrared; (2) optical; (3) radio frequency (RF); (4) microwave; and (5) surface acoustical wave (SAW).

Infrared technology is similar to that which is used in grocery stores today. A laser beam is reflected off of a bar code and processed. Optical technology uses video cameras to digitize and process the vehicle's license plate. RF and microwave technologies offer high data transmission rates for both active and passive transponders. A transponder can be processed several times before it passes out of range, thus increasing reliability in the identification process. SAW technology utilizes a code which cannot be modified.

### **Case Studies**

Several AVI systems are in place and many more are being proposed. Brief examples of current and proposed AVI systems are presented below. Although a majority of the systems are located on toll facilities or restricted networks, one proposed system will operate on public facilities.

#### *Dallas North Tollway*

The Dallas North Tollway in Dallas, Texas uses RF technology with passive transponders. This system consists of 14 miles of roadway and 62 toll stations. Since its implementation in July 1989, over 40,000 tags have been issued and the system handles over 62,500 tag transactions per day (28). The manufacturers of the system state that it can read tags on vehicles travelling at 180 mph and has a calculated error rate of 1:800 million (24). Even though traffic has increased by 10% since its implementation, queuing has not worsened according to Jerry Shelton of the Texas Turnpike Authority.

#### *Oklahoma Turnpike Authority*

The Oklahoma Turnpike Authority implemented its AVI system on January 1, 1991. Currently, it is the world's largest AVI toll collection system. It includes 193 lanes on ten turnpikes. Since AVI has begun, more than 100,000 tags have been issued and the system has more than 60,000 tag transactions per day (28).

### *Harris County Tollroad Authority*

The Harris County Tollroad Authority in Texas will expand its AVI system to include all ramps and tollplazas in the Fall of 1992. The system currently has five tollplazas which use eight lanes. Two lanes will use AVI exclusively, while the other lanes will accept both AVI and coins. Over 40,000 tags are expected to be issued for this system. An interesting point in the collection of the AVI fees should be made. The tollroad authority has contracted with a credit institution who will bill customers on their credit cards (27).

### *Los Angeles International Airport*

Los Angeles International Airport in Los Angeles, California implemented an AVI system for commercial ground transportation in January 1990. The system includes 41 lanes of traffic and monitors over 5,000 commercial vehicles. Over 42,500 transactions are made each day. This system determines the "dwell time" for the commercial vehicles while in the airport. Since its implementation, congestion has been reduce 20% and revenue collection increased by more than 200% (28).

### *Houston, Texas*

The Texas Department of Transportation will implement an AVI monitoring program on two expressways and one toll facility in the Houston area. The system is designed to monitor travel times on these roadways to provide real-time travel information to the public. AVI stations are approximately three to four miles apart and are mounted on existing structures, wherever possible (27). This is one of the first AVI systems to monitor travel times.

### **Potential Applications of AVI**

Several potential applications exist for AVI systems. AVI can be used to: (1) implement congestion management actions such as cordon, link, or spot pricing; (2) collect real-time travel time information to assess current conditions on the freeway or arterial network; (3) collect origin and destination (O-D) information to better assist modeling and monitoring; and (4) implement trip-length management.