

CONGESTION PRICING FOR HOV FACILITIES

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SUMMARY

Examination of existing high occupancy vehicle (HOV) facilities indicates that many facilities operate with excess capacity. One way to utilize this excess capacity is to implement a policy that allows single occupancy vehicles (SOVs) to use the HOV facility if they are willing to pay a toll. Recent federal legislation facilitates a user fee system by allowing up to 35% of capital or maintenance funds used to come from federal sources. Legislation initiative at the state level has been demonstrated by California, where the Route 91 express lane project is scheduled to be fully implemented in 1994.

A SOV congestion pricing policy can be implemented on any facility that can adequately separate authorized and unauthorized vehicles. Barrier separated facilities are often conducive to adequate separation, as are facilities with limited access and egress opportunities. HOV facilities that provide little separation between authorized vehicles and the mixed-flow lanes of traffic can be evaluated for modification that would allow adequate separation. Such modification techniques may include changing a traversable buffer to a nontraversable buffer, retrofitting pylons or a barrier in a buffer separated facility, or adding automatic vehicle identification (AVI) equipment at periodic intervals on the HOV facility to provide continuous identification and enforcement capabilities.

The efficient operation of the facility is critical to the success of the project. The most important operational aspect is the maintenance of freeflow travel on the facility. Freeflow travel ensures a reduced and predictable travel time, the main incentive for use of the HOV facility. Freeflow travel is maintained by limiting the volume on the facility. The demand of SOVs on the facility can be controlled through the toll rate charged. Another operational aspect to be considered is the method of toll collection. AVI provides one attractive alternative, because it is convenient for SOV drivers and does not interfere with the operation of HOVs.

The proposed project, congestion pricing for the use of SOVs on HOV facilities, offers one mechanism for the efficient operation and full utilization of HOV facilities. While the project is not appropriate for all HOV facilities, it does appear to be a viable alternative in some situations. The implementation of SOV congestion pricing is an operating alternative that should be carefully considered for implementation on all HOV facilities that are currently underutilized.

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INTRODUCTION

Congestion in urban areas is a pervasive and ever growing problem in many American cities. Congested transportation facilities waste time and fuel and contribute to driver frustration and accidents. To provide an alternative to commuters driving private automobiles, some cities have created special facilities to be used by high occupancy vehicles (HOVs). These facilities offer an attractive alternative to the personal auto, while reducing congestion by moving more people using fewer vehicles. These facilities serve to encourage the use of ridesharing, as well as transit services. However, in some circumstances the capacity of HOV facilities exceeds the demand for such facilities. In such cases, it is appropriate to examine the alternative uses for the available capacity on HOV facilities. One such alternative is to allow single occupancy vehicles (SOVs) to use the available capacity on HOV facilities, if SOV drivers are willing to pay a toll.

The objective of this paper is to explore the feasibility and issues related to the practice of allowing SOVs to use available capacity on HOV facilities if they are willing to pay a toll. This paper will be an issue paper that identifies and addresses the various aspects to be considered for the implementation of the use of SOVs on a HOV facility. Areas to be addressed include the justification for such a project, the problems that might be encountered during implementation and operation, the applicability of the project to various HOV facilities, and the operational aspects of the system. Because there is currently no system of this type in operation, research will focus on related operations in existence, as well as the insight of professionals in the field.

JUSTIFICATION FOR PROJECT

The rationale for the SOV to utilize available capacity on HOV facilities includes basic operating advantages, as well as advantages relating to the use of congestion pricing.

Operational Advantages

The operational advantages are fourfold. First of all, it makes sense to fully utilize the capacity of all transportation facilities, this includes HOV facilities. If HOV facilities are functioning at less than capacity, there is an obvious justification for the exploration of alternative operations to fully utilize the facility. The second justification of the project is the benefit available to SOVs that are willing to pay a toll to use the HOV facility. The third justification for this project is the public perception of adequate use of HOV facilities. By increasing the number of vehicles on the HOV facility, users of the adjacent mixed-flow lane will recognize the greater utilization. The final operational justification of the project is that the total person movement of the HOV facility will increase, even though the occupancy rate will decrease.

The project would utilize unused capacity on HOV lanes.

HOV facilities provide an efficient mechanism for the movement of commuters. The free flow travel characteristic of a well managed HOV facility results in reduced delay which translates into a reduced and more predictable travel time. Because HOV facilities are able to move more people using fewer vehicles, there is often unused capacity. This capacity can be utilized by a limited number of SOVs. As long as travel is free flow, and thus consumption is nonrival, HOV users are not negatively impacted by sharing the HOV facility with SOV users.

As can be seen on Table 1, various facilities throughout the nation are operating with excess capacity. Table 1 displays morning peak direction bus, vanpool and carpool ridership data from 1988 (1). A capacity of 1200 vph per lane is assumed for all facilities. This capacity of 1200 vph is the lower extreme of the range identified as a desirable maximum volume for exclusive facilities and concurrent flow facilities utilizing regular traffic lanes (1). Using a bus equivalent of 2.5 cars (2), the car equivalent is calculated for each facility. The volume available for use by SOV is found by subtracting both the bus equivalent and the van/carpool volume from the capacity of the facility. The last column indicates the number of SOVs that the facility could accommodate per hour, without compromising operating speeds. There is significant capacity available on some of these facilities. For example, I-84 in Hartford could accommodate 1031 SOVs per hour, and I-15 could accommodate 1106 SOVs per hour, according to 1988 data.

Table 1. Morning Peak Direction Vehicle Volume on HOV Facility.

| City | Number of HOV lanes | Peak Hour Volume | | | | Capacity | Volume Available |
|-----------------------------|------------------------|------------------|----------------|-------------|-----------|----------|---------------------|
| | | Bus | Car Equivalent | Van/Carpool | Total HOV | | |
| Hartford, CT I-84 | 1 | 20 | 50 | 119 | 169 | 1200 | 1031 |
| Houston, TX I-45S (Gulf) | 1 | 30 | 75 | 848 | 923 | 1200 | 277 |
| I-10 (Katy) | 1 | 37 | 92.5 | 913 | 1005.5 | 1200 | 195 |
| US 290 (NW) | 1 | 17 | 42.5 | 824 | 866.5 | 1200 | 334 |
| Minneapolis, MN I-394 | 1 | 13 | 32.5 | 430 | 462.5 | 1200 | 738 |
| Pittsburgh, PA I-279 | 1 | 13 | 32.5 | 147 | 179.5 | 1200 | 1021 |
| San Diego, CA I-15 | 2 | 14 | 35 | 1259 | 1294 | 2400 | 1106 |
| Washington, D.C. I-66 | 2 | 13 | 32.5 | 618 | 650.5 | 2400 | 1750 |

The project would benefit the SOV users who are willing to pay a toll for the use of the HOV facilities.

The average peak hour traveling speed on Los Angeles freeways is 35 mph (3); thus there is an obvious benefit to SOV drivers who are willing to pay a toll to travel 55 mph on an HOV facility. SOV users of the HOV facility will experience the same benefits gained by HOV users: a decrease in delay and a reduced and more predictable travel time. Furthermore, the SOV users of the facility clearly believe that the benefits of travel on the HOV facility are worth the price of the toll, any driver who disagrees would use the mixed-flow lanes.

The project would increase the public perception of adequate utilization of the HOV facility.

The operation of an HOV facility must balance the need for future growth and public perception of adequate minimum use. While most HOV lanes currently in operation carry at least 50% more peak-hour person trips than an equivalent mixed-flow lane at capacity (2), the perception of non-HOV drivers is that the facility is not adequately used when they do not see many vehicles on it. Actually, they are merely recognizing that there is unused capacity on the facility. This is termed "empty lane syndrome". The best counter to this is, simply enough, to make better use of the existing capacity. The perception of underutilization may create pressure to roll back occupancy restrictions, curtail off-peak operation, or terminate the project altogether (2). By increasing the number of vehicles on the facility, the SOV congestion pricing project will increase the public perception of utilization, and help alleviate the "empty lane syndrome".

The project would increase total person movement of the HOV facility.

One of the measures of effectiveness for the operation of an HOV facility is the person movement of the facility. When the HOV facility is meeting the demand for HOV operation and still has additional capacity, the total person movement of the capacity can be increased by allowing SOVs to use the facility. As long as the operating volume is kept below capacity and operating speeds are maintained, the additional person movement is increased by the number of SOVs on the facility. As seen in Table 1, a facility such as Rt. 101 in San Jose could accommodate 788 SOVs per peak hour, increasing the person movement of the facility by 1576 for the two hour morning peak period. While the occupancy level of the HOV lane would decrease, the total person movement would increase. Furthermore, the SOVs operating on the HOV facility are removed from the mixed-flow lanes, marginally increasing the operation of the mixed-flow lanes.

Advantages of Congestion Pricing

The proposed project is an example of congestion pricing, which is currently a topic of national interest. Additionally, congestion pricing is inherently an appropriate mechanism to allocate a limited resource, which in this case is the capacity of a freeway. Finally, congestion pricing can be used as a mechanism to manipulate demand, and therefore can facilitate operational flexibility.

Demonstrations of congestion pricing operations are of national interest.

Recent policy statements in the United States have encouraged the exploration of congestion pricing and other alternative funding mechanisms. The National Transportation Policy released in 1990 emphasizes an "increased reliance of user fees...(4)"; one method for responding to this policy is congestion pricing. In February 1991, the Bush Administration unveiled its proposed Surface Transportation Assistance Act of 1991. This highway bill will increase developer interest in road pricing by easing restrictions on federal funding of toll roads and by giving states greater latitude to mix public and private funds. The proposed 1991 legislation calls for removing the restriction on the use of federal funds for the construction and improvement of toll roads on non-interstate routes. It allows the federal share on toll projects to run as high as 35%. This makes a toll-financed highway a more achievable alternative (5). This new tolerance, even encouragement, of alternative financing was foreshadowed by the Federal Highway Act of 1987 which allowed eight demonstration projects across the country to mix toll revenues with state and federal funds on new projects (6). The provision for these funding alternatives defies earlier precedent: from 1916 until 1987, federal law prohibited states from building toll roads with federal funds (5).

Congestion pricing is an appropriate allocation mechanism to maximize utilization of a limited resource.

Any commuter sitting in peak hour traffic will concur that the urban infrastructure is in limited supply and is functioning inefficiently. Transportation economists would agree, citing that a major reason for much peak-hour traffic congestion is that vehicle users pay for road use indirectly through license fees and the gasoline tax. Such indirect pricing fails to take into account the location and time of use (7). Motorists consider only their own time costs and not the time effects on other users (8,9). A commuter entering a roadway affects the speed of all travelers on the roadway but ignores these external costs in his commuting decisions. Congestion pricing has the potential to improve the efficiency of our existing transportation systems at a relatively low cost as compared with more capital-intensive projects (10).

Not only do economists recognize the benefits of congestion pricing, but commuters also recognize the benefits to be gained by an efficient pricing system. A nationwide survey on the public's attitude toward toll roads as a funding source. More than 66% expressed a negative or neutral opinion when offered a choice. However, when asked if they would support a toll road if a system of automatic tolls were implemented, the acceptance rate was 85% (11). The public is apparently aware of the advantages of a congestion pricing policy and is not opposed to such a policy if it is convenient and efficient.

Congestion pricing is a common and widely accepted practice in other public industries; the most widely implemented policy is in the long distance phone industry. The success of congestion pricing in the phone industry may, in part, be due to the marketing of the service. Rather than pay an additional premium for daytime calls, consumers are accustomed to the reduced rate for evening and weekend calls. It has been suggested that the initiation of SOV congestion pricing be similarly marketed. However, the benefits of any marketing strategy should not be overestimated. Because there is currently no charge

to use a public road, any "reduced rate" for non-peak travel is not a reduction compared to what is currently paid: nothing. Effort should be spent in a thorough and extensive educational campaign that clearly explains the reasoning behind a congestion pricing policy, as well as the potential benefits that can be gained by the operating efficiency of such a program. Eventually drivers are likely to accept roadway congestion pricing just as they accept utility congestion pricing, and they will then think of non-peak travel rates as "reduced", regardless of what the rates are called.

Congestion pricing facilitates operational flexibility by manipulating demand through variable rates and occupancy requirements.

The management of an HOV facility requires a careful balance between utilizing the capacity of the facility and retaining freeflow travel. A lack of vehicles on the HOV facility can lead to the "empty lane syndrome", which erodes public support for existing and proposed HOV facilities. Excess demand for the HOV facility results in congestion on the facility; this congestion translates into increased delay and reduced travel times, essentially eliminating the benefits and incentives for ride sharing. With conventional HOV facilities the demand is primarily managed through occupancy requirements. In some circumstances, the use of occupancy requirements is an adequate mechanism for managing demand, because occupancy requirements can be varied by time of day and for each corridor or facility. However, the use of occupancy requirements to manage demand has its limitations. Table 2 provides the estimated impact of alternative demand strategies (12). The first strategy suggested, requesting a voluntary shift of commute time, results in an almost insignificant effect. However the next suggested alternative, raising the occupancy requirement by one, will decrease the carpool volume by 75%. Under most situations, this would leave the facility vastly underutilized. The last two solutions, vehicle authorization and limiting access, provide significant, but not drastic, reductions that may be appropriate. However, the problem with these solutions is that each is either implemented or not, reductions are either 75% or none, 20-40% or none, or 25+ % or none. These alternatives do not facilitate incremental changes in demand.

Fear of not having enough users at a successive higher occupancy level, a valid concern supported by Table 2, has also prevented some project operators from pursuing a course of raising occupancy requirements. When this happens, effectively the person-moving capacity of the facility is capped. In some circumstances a facility will be congested if a 2+ occupancy requirement is mandated, but will not be adequately utilized if a 3+ occupancy requirement is issued. While the number of 3+ vehicles may increase to meet the recommended minimum recommended usage of 400-800 vph (2), in the interim the facility is underutilized, which will be recognized by the public. Similarly, the growth that contributed to the utilization of the facility is equally likely to continue until the facility is congested. Eventually this will require a change in policy to decrease the vehicular demand, possibly creating underutilization once again. In summary, the difficulty with limiting the demand merely through occupancy requirements and time of day specifications is the inability to affect small variations in the volume.

Table 2. Estimated Impact of Alternate Demand Management Strategies.

| <u>Peak Hour Management Action</u> | <u>Est. Reduction</u> |
|--|-----------------------|
| 1. Voluntary spreading of the peak hour | 0 - 3 % |
| 2. Impose minimum 3+ occupancy during peak hour (rather than 2+) | 75 % |
| 3. Require vehicle registration during peak hour | 20 - 40 % |
| 4. Close and/or meter entrance ramps | 25 + % |

The use of variable toll rates would allow incremental variations in demand. The demand, the number of vehicles that choose to divert and pay a toll rather than use the mixed-flow facilities, is a function of the toll rate being charged and the speed of the mixed flow lanes (13). The volume of SOVs on the facility can therefore be controlled by variance of the toll rate. For example, assuming the speed of the mixed-flow lanes remains constant, if a toll of \$4.00 results in unused capacity on the facility, then the toll rate could be lowered to \$3.50, or until the desired volume of SOVs choose to pay the toll and use the facility. Once the elasticity of demand is determined, the facility can be managed by observing the speed of the mixed-flow lanes, monitoring the available capacity, and adjusting the toll rate accordingly. The resultant demand will result in full utilization of the facility without congestion.

The toll rate is specified as an interactive function of the real time conditions on the entire facility: as the number of vehicles on the HOV lane increases, the toll rate increases, decreasing SOV demand and avoiding congestion on the HOV facility; however, this will cause a higher volume on the mixed-flow lanes, lowering the speed and making the HOV facility a relatively more attractive option. The facility chosen by the SOVs may or may not have a measurable effect on the speed of the mixed-flow lanes. The sensitivity of operating conditions on the mixed-flow lanes will depend on the relative capacity of the HOV and mixed flow lanes. For example, when there is one HOV lane, and five mixed-flow lanes in each direction, the impact on the speed of the mixed-flow lanes will be minimal. However, the analysis of the demand for a proposed facility in California (State Route 91) that will have two express (HOV) lanes and four mixed-flow lanes contends that the SOV's facility choice will have a measurable affect. Obviously, management of the system requires current and accurate information. Real time changes in the toll rate can be easily enacted through the use of automatic vehicle identification for the collection of tolls. The toll rate can be communicated to the SOV driver through the use of changeable message signs at the entrance to the facility (allowing the driver to enter the mixed lanes if he chooses not to pay the current toll rate). The toll rate could also be communicated through various other driver information systems, such as radio traffic reports, and eventually, through IVHS in-vehicle technology.

POTENTIAL PROBLEMS

Conceptual problems with the suggested project include three areas. The first problem associated with congestion pricing for SOVs is that the perception of benefit to the common commuter is likely to be small. A second problem, related to the first, that may arise is that implementation of the project may not receive public and political support due to the fact that vehicles are excluded or included based on their ability to pay. A third potential problem of the system is that it removes an incentive for the use of high occupancy transportation. Further problems associated with such a project are the limited number of facilities that are conducive to such a project, and problems associated with the operation of the project, such as maintaining freeflow travel, and the collection of tolls. These problems are addressed later sections of this paper.

Benefit to the Common Commuter

Necessarily the toll charged must be high enough to exclude the common commuter, and the number of SOVs removed from the mixed-flow lanes may be too small to significantly affect travel times in the mixed-flow lanes, thus the benefit to the majority of commuters is small. Any travel time savings for the mixed flow lanes will likely be "lost" in a short period of time, because demands in most urban areas are continually increasing. While the project would decrease demand for mixed-flow lanes by the number of SOV users who are willing to pay a toll for use of the HOV facility, the effect would be negligible due to latent demand.

The scenario is analogous to the removal of HOVs from the mixed flow lanes when the HOV facility was opened. Travel time surveys indicate that very few HOV facilities have had a significant long-term effect on adjacent mixed-flow lane traffic volumes, although freeway conditions are no worse than before the projects were implemented. The freeway mixed-flow lanes approach congestion again due to the latent demand in the already congested corridor. This demand comes from commuters who switch from surface streets to take advantage of improved freeway operation and from trips not previously made that now materialize. Others who traveled during the fringe of the morning and evening peak, thus spreading the peak periods, readjust their travel schedules to take advantage of improved operation during the mid-peak period. The result is that the spaces made available become filled and very little time is saved for mixed-flow freeway users (14).

Benefit to the Wealthy

The importance of public support should not be underestimated. HOV concepts are often not understood by the public, politicians or media. An important lesson that has been learned from project failures to date is that the public must be involved and must be able to understand and appreciate the role that HOV systems can serve (2). Similarly, the public must understand and appreciate the role of SOV congestion pricing on an HOV facility. While the entire public pays for the construction of a typical HOV facility through gasoline and license taxes, only a select number are able to use the facility with their personal auto. This may cause the project to lack public and political support. The best mechanism to

foster public support is an educational campaign that explains why the number of SOVs using the HOV facility must be limited. Additionally, it is important to emphasize that any commuter can still gain the benefits of travel time savings by participating in a carpool, riding the bus, or otherwise utilizing an HOV.

Removal of Incentives for the Use of HOVs

It could be argued that allowing SOVs to use HOV facilities would send mixed messages to the public and therefore be undesirable. It is true that this system could create an attractive alternative to the HOV by allowing a SOV to gain the travel time savings without meeting the occupancy standards. However, while the travel time reduction is an incentive, the toll charge is a disincentive. Furthermore, the focus of the facility will remain on HOVs. When the facility volumes near capacity it will be the SOVs that will be restricted. It could be argued that charging SOVs a toll charge until the facility reaches capacity is actually a marketing tool for HOV use: it gives SOV drivers an opportunity to experience the benefit of a reduced and predictable travel time and might prompt them to use an HOV to continue to gain the travel time savings when SOV toll charges increase or when SOVs are otherwise restricted.

APPLICABILITY OF PROJECT

Congestion pricing for SOVs to utilize excess capacity on HOV facilities is not applicable to all HOV facilities. There are three areas to be addressed with respect to the applicability of the proposed system to various facilities. The first is the legality of such a system. The second issue to be addressed is the type of HOV facility that would be conducive to use by a limited number of paying SOVs. The final issue to be addressed is the modification of existing HOV facilities to allow the implementation of SOV congestion pricing.

The Legality of SOV Congestion Pricing

Recent federal legislation facilitates pricing policies on roads, by allowing some federal funds to be spent on such projects; this aspect was addressed in Section I. California has demonstrated how states can take the initiative, and how privatization can help bridge the widening gap between transportation infrastructure investment and funding. California was chosen as a demonstration site in the use of federal funds and state funds on toll facilities, as specified by legislation in 1987. In July 1989 the California legislature passed Assembly Bill 680 (AB 680) which permits developers to build private toll roads and collect tolls for 35 years. Toll rates and fees are limited only by market conditions. Provisions of the project include (6): lease terms and profit levels will be negotiated with Caltrans; facilities developed privately will be owned by the state (this reduces liability of the private developer); projects must supplement the existing "free" system and offer a reasonable choice to potential users and the public.

The initiative for action lies with the state, and California has set a precedent with the appropriate enabling legislation. State Route 91 in Orange County will most likely be the first facility to demonstrate the operation of "express lanes", which will charge a toll for the SOVs, but provide free service to HOVs for at least the first two years. A typical section of this project is shown in Figure 1 (13). The facility is scheduled to be open and fully operational in 1994.

Design of HOV Facilities

No two HOV projects are exactly the same because each is tailored to the specific objectives that address operational problems the corridor exhibits. Because of this diversity of existing and proposed HOV systems, it is difficult to state definitively where a SOV congestion pricing project would work, and where it would not.

The critical element is that the HOV facility must be conducive to the separation of SOVs that pay a toll and are thus authorized to use the HOV facility and SOVs that do not pay a toll and are therefore not authorized to use the facility. Two areas that contribute to the feasibility of exclusion are the type of facility and the method of ingress and egress.

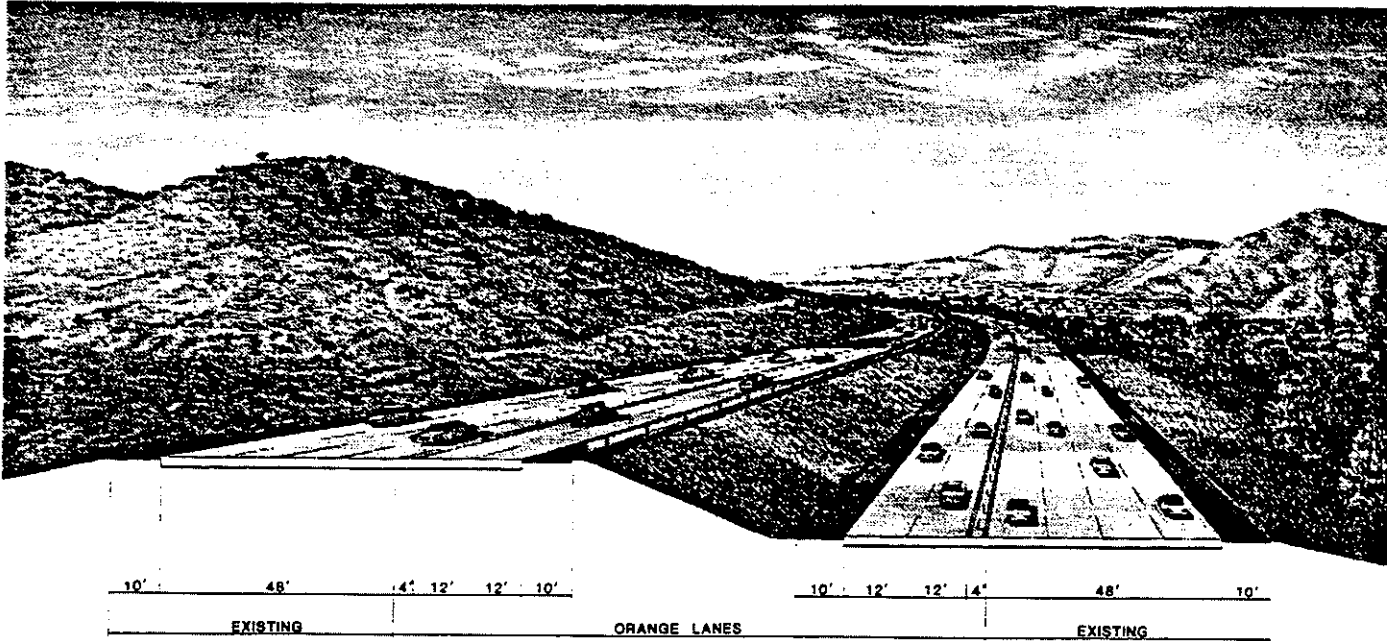


Figure 1. Proposed State Route 91 Facility in California.

There are four basic types of HOV operation (2):

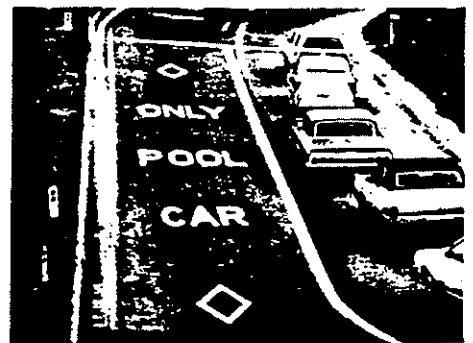
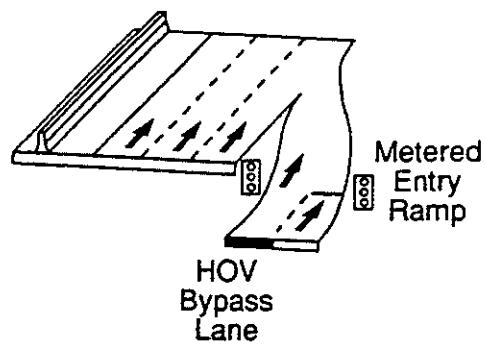
1. Queue bypass,
2. Contraflow,
3. Two-way (also called concurrent flow), and
4. Reversible-flow.

A queue bypass HOV facility is a short distance HOV facility operating alongside mixed-flow lanes or on an adjacent roadway. The queue bypass HOV facility is used to avoid isolated congestion or delay due to ramp metering, toll plazas, and isolated bottlenecks. The use of SOV congestion pricing should be carefully considered before being applied on a queue bypass HOV facility. The intention of SOV congestion pricing is to utilize excess HOV facility capacity, without a negative impact on the adjacent mixed flow lanes. Fulfillment of this objective should be considered when evaluating applications of SOV congestion pricing projects to queue bypass facilities.

One example of a queue bypass facility is ramp metering, as shown in Figure 2 (2). A ramp metering project is one where HOVs share the mixed-lane facilities with SOVs. Ramp metering for SOVs is initiated due to the capacity constraints of the freeway, in this case it would be inappropriate for certain SOVs to avoid the ramp metering and by-pass other SOVs waiting at the meter. For this reason, SOV congestion pricing is not recommended for queue bypass facilities.

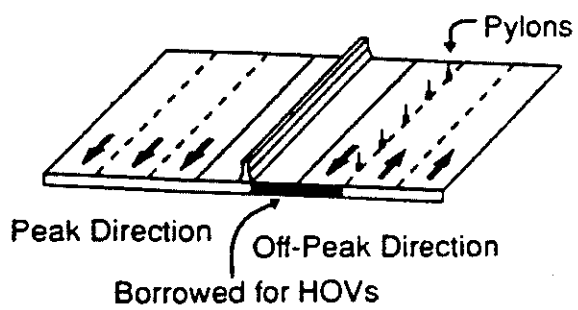
Another example of a queue bypass facility is at a toll plaza. It is possible for SOVs and HOVs to share a toll processing lane, each equipped with the appropriate automatic vehicle identification (AVI) transponder. The HOV would be identified as an HOV and would not be billed, and the SOV would be identified and billed, as appropriate. This does not compromise the service to the mixed flow lanes or HOVs and therefore it would be reasonable to allow SOVs to utilize the lane. However, since mixed-flow lanes also pay a toll, SOVs using the AVI lane may not be considered congestion pricing but merely an alternate, and more efficient, mode of operation.

Contraflow HOV facilities "borrow" a lane from the off-peak direction. This can be done only where there is unequal directional commuting on a facility, and taking a lane away from the off-peak direction does not cause excessive congestion. Often the HOV lane opposing traffic is separated from the mixed-flow lanes merely by cones or temporary pylons. An example of a contraflow HOV facility can be seen in Figure 3 (2). Because the HOV lane is directly adjacent to the opposing mixed-flow lanes, without a substantial barrier, safety and liability considerations mandate that only authorized drivers are allowed on the contraflow facility. Authorized drivers include bus drivers and, in some cases, taxi drivers and vanpool drivers that have had specialized training. Due to limitations placed on drivers, generally carpools are not authorized to use the lane. Similarly, it would be inappropriate for SOV drivers to use the facility; therefore, a contraflow facility would not be appropriate for SOV congestion pricing.



Ramp meter bypass, California

Figure 2. Queue Bypass HOV Facility.



Route 495, New Jersey

Figure 3. Contraflow HOV Facility.

Two-way (also called concurrent flow) HOV facilities, usually the inside median lanes, operate in both directions of travel during at least portions of the day. An example of concurrent flow is shown in Figure 4 (2). The physical design can be either barrier-separated, buffer-separated or nonseparated. A barrier-separated facility is physically separated by a guardrail or concrete median barrier from the mixed-flow freeway lanes. The opposing directions within the barrier-separated facility may be separated by a barrier or buffer. Due to the separation from the mixed-flow lanes, a barrier-separated HOV facility could be appropriate for SOV congestion pricing. A buffer-separated HOV facility is separated from adjacent mixed-flow freeway lanes with a designated buffer of 1 foot or more. Narrow buffers (1 to 4 feet) are either traversable or nontraversable. A traversable buffer can be legally crossed at any point. A nontraversable buffer cannot be legally crossed except at designated access points. Due to the unlimited access provided by a nontraversable buffer, such a facility could not effectively separate authorized and unauthorized SOV users and would not be an appropriate facility for SOV congestion pricing. A buffer-separated facility may have plastic pylons or simply painted pavement. While plastic pylons may provide adequate deterrent to keep non-paying SOVs off the facility, some locations have found that plastic inserts separating the reserved lane did not prevent illegal weaving (15). A painted buffer-separated facility, or a nonseparated HOV lane is not separated from adjacent mixed-flow freeway lanes, and would be inappropriate for SOV congestion pricing due to the difficulty in keeping non-paying SOVs off the facility.

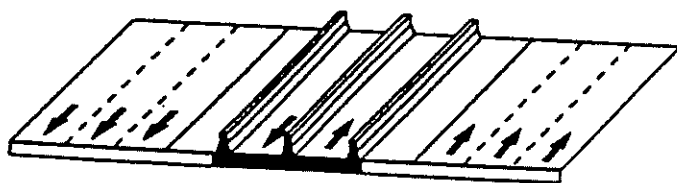
Reversible-flow HOV facilities are barrier-separated lanes operating in one direction in the morning and the opposite direction in the evening. The direction of traffic flow can be changed at different times of the day to match the peak direction of travel during periods of peak demand. An example of a reversible-flow HOV facility is shown in Figure 5 (2). The complete separation between the mixed-flow lanes and the HOV facility would effectively keep the unauthorized SOV users off the facility, thus reversible-flow facilities could be appropriate for the application of SOV congestion pricing.

There are two physical types of ingress and egress:

1. At-grade access and
2. Direct connections.

At-grade access utilizes the adjacent mixed-flow lanes to enter and exit the HOV facility. An example of at-grade access is shown in Figure 6 (2). While at-grade access facilities may be used for SOV congestion pricing, special provision must be made for storage of any SOV queue of cars waiting for entrance onto the HOV facility, so that HOVs are not blocked from the facility and the mixed-flow lanes are unaffected.

Direct connections utilize local streets, freeways, support facilities, or other HOV facilities to enter and exit the HOV facility. Generally direct connections imply grade separation between the mixed-flow lanes and the HOV entrance and exit facilities. An example of a direct connection is shown in Figure 7 (2).

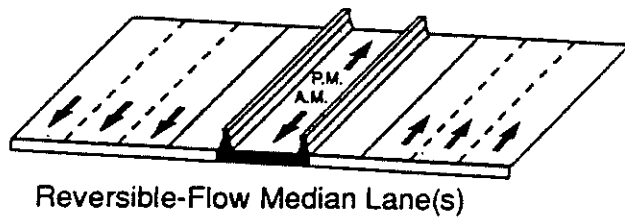


Two-Way Barrier-Separated Lanes
(Also Buffer-Separated or Nonseparated Lanes)



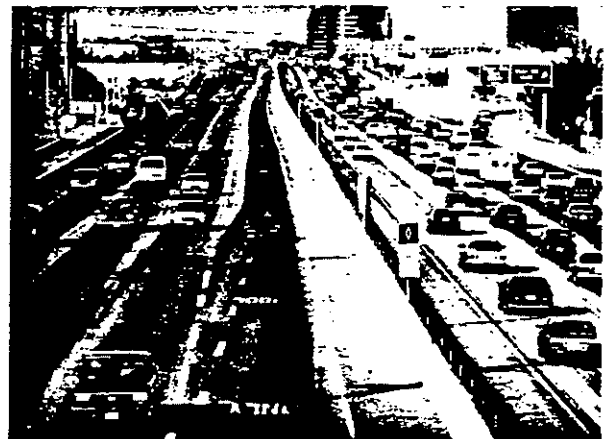
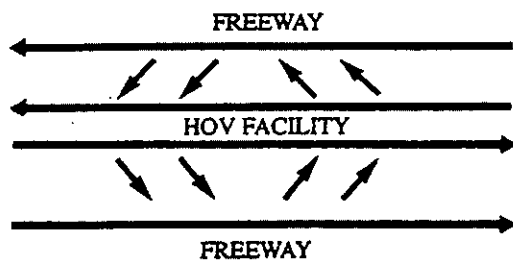
El Monte Busway, Los Angeles, California

Figure 4. Two-Way HOV Facility.



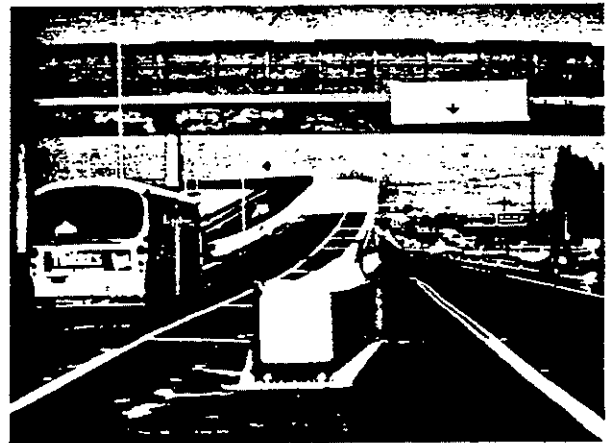
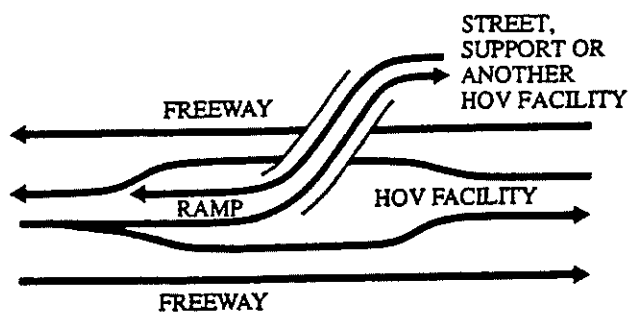
Katy Transitway, Houston, Texas

Figure 5. Reversible HOV Facility.



Route 55 at-grade access, Orange County, California

Figure 6. At-grade Access to/from HOV Facility.



I-10 Del Mar ramps, Los Angeles, California

Figure 7. Direct Access to/from HOV Facility.

Either at-grade access or direct connections could be used with a SOV congestion pricing project. For enforcement purposes it would be desirable to have a limited number of access points and exit opportunities. A limited number of entrances is desirable if toll collection facilities are to be located at every access point. A limited number of exits encourages compliance by limiting the opportunity to evade enforcement by exiting the facility.

The ingress must provide adequate space for any toll collecting equipment, if AVI is used then the necessary space is minimal. Furthermore, if the toll collection requires vehicles to stop, then adequate space adjacent to the entrance must be allocated so that the HOVs are not blocked from entrance to the facility. Similarly, if any metering of the SOVs is done, then sufficient queue storage must be available. Ingress should be properly signed to inform all potential users of the system. Signing should be early enough to allow traffic to divert if toll is too high.

Before increasing the volume of traffic by allowing SOVs to use the HOV facility, a careful examination of facilities should be made to assure that they are adequate in every respect. Possible limitations of the facility are exemplified in the following HOV design guidelines (2): "Typical volumes using HOV access ramps are less than for commensurate freeway ramps. This may permit shorter weave and merge sections. HOV volumes accessing a local street seldom overwhelm a signalized intersection. Average peak-hour ramp demand at an intersecting street will probably not exceed 300 to 500 vph." Weaving and merging areas should be considered, as should high volume exits and the end of the HOV facility. Often the HOV facility terminates by merging with the mixed flow lanes. The additional merging volume added with the inclusion of SOVs may create a problem not only for the mixed flow lanes but also may back up onto the HOV facility and compromise service.

Modification of Facilities

The many facilities currently in use that do not allow separation of authorized and unauthorized vehicles could be modified to allow separation. The extent of modification required, and the investment required for modification, varies from project to project. Areas that may require modification are the areas discussed previously: method of separation between the HOV facility and the mixed-flow lanes and ingress and egress from the facility.

A buffer separated facility can be retrofitted with pylons or a barrier to separate the mixed-flow lanes from the HOV facility, converting a traversable buffer to a nontraversable buffer with limited access and exit opportunities. While a barrier provides more complete separation than pylons, pylons can be retrofitted with a lower investment and require minimal buffer space. In some urban areas, pylons and a vigilant enforcement policy may be sufficient to minimize violation rates. Closely spaced pylons that do not allow a vehicle to slip back and forth between the mixed-flow lanes and the HOV facility might adequately deter violation. Other areas have found that pylons do not adequately deter violators; in these areas it may be appropriate to locate AVI equipment at periodic intervals along the facility, this would provide continuous identification and could alert authorities to violators.

It is possible that motorists would recognize AVI equipment locations and cause a safety hazard by merging back onto the mixed-flow lanes at unauthorized locations.

Similarly, it may be possible to modify contraflow facilities so that SOV congestion pricing could be implemented. The major concern with contraflow facilities is safety. One option would be to certify SOV driver through rigorous training and testing. A second option would be to modify the facility to increase the safety. For example, if the facility has an inside shoulder, it would be possible to construct a moveable barrier that would separate the inside contraflow lane from the mixed-flow lane during the morning peak, and be moved back to the far side of the inside shoulder during the evening peak, to give the inside lane back to the mixed-flow lanes during the evening peak. A moveable barrier would provide maximum safety, however it would decrease the size of the inside shoulder and would require significant investment for implementation.

Travel Time Savings

The travel time savings gained by using an HOV facility depend on the travel time of the adjacent mixed-flow lanes and the travel time of the HOV facility. Because SOV users must pay to use the facility, the time saved must be considered significant. The amount of time required to pay a toll or wait for metering must be considered when calculating the reduction in delay gained by using the HOV facility. For this reason, the use of AVI would be beneficial, because it does not require the user to slow down, in addition to being convenient. Longer (line haul) HOV facilities would be expected to offer more travel time savings and may be more conducive to SOV congestion pricing.

OPERATIONAL ASPECTS

The efficient operation of the facility is critical. The first operational aspect to be addressed in this section is the collection of the SOV tolls. The second aspect to be addressed in this section, necessary for the effectiveness of all HOV facilities, is the importance of maintaining freeflow travel on the facility.

Toll Collection

The efficiency of toll collection is critical to the success of the project. Any time a vehicle spends paying a toll must be subtracted from the travel time savings gained. For this reason, an automatic vehicle identification (AVI) system would likely be the preferred option for toll collection. Other systems briefly addressed include conventional toll booths and a monthly (or periodic) pass or sticker.

Automatic Vehicle Identification (AVI)

The characteristics of an automatic vehicle identification (AVI) toll collection system make it an ideal technology for application to the SOV congestion pricing project. Major types of AVI technology include radio frequency (RF) and microwave antennas, and optical and infrared scanners. Optical and infrared systems operate similar to retail store scanners that read bar codes; these devices can be read at vehicle speeds up to 45 mph. RF and microwave systems can identify vehicles traveling at speeds up to 100 mph (16); use of either of these systems would allow toll collection without affecting the operating speeds of the facility. Keeping the SOVs at operating speeds is desirable not only to save time, but also because it minimizes potential conflict with the HOVs. SOVs waiting to pay a toll, decelerating to do so, or accelerating to enter the HOV facility would all create potential operating conflicts and a safety hazard.

The use of AVI requires that each vehicle have a passive transponder (sometimes referred to as a "toll tag"). The passive transponder emits a coded radio signal when bombarded with radio energy, this signal identifies the vehicle. The vehicle is identified with a unique identification number, and would be classified as either an HOV or SOV and charged appropriately. RF systems can utilize either overhead antennas or inductive loops in the pavement. If antennae are used, the system antenna can be mounted overhead, one antenna per lane, on any available overhead structure (17). RF systems in the pavement utilize low voltage, twisted pairs of cable. When triggered by the inductive loop, small transponders mounted underneath or on the front bumper of the vehicle emits signals containing the unique user account numbers (16). This transponder can be attached to the vehicle in about 5 minutes, requires no electrical connection and once fitted requires no manual intervention or maintenance (18).

The system used in a road pricing project in Hong Kong is shown in Figure 8 (18). As shown in the diagram, the electronic loops in the road are activated by the vehicle. The vehicle is then identified by the numeric code transmitted to the roadside equipment (the roadside equipment looks similar to a standard traffic signal controller box). The roadside equipment (also called an outstation) uses telephone lines to link to a central computer

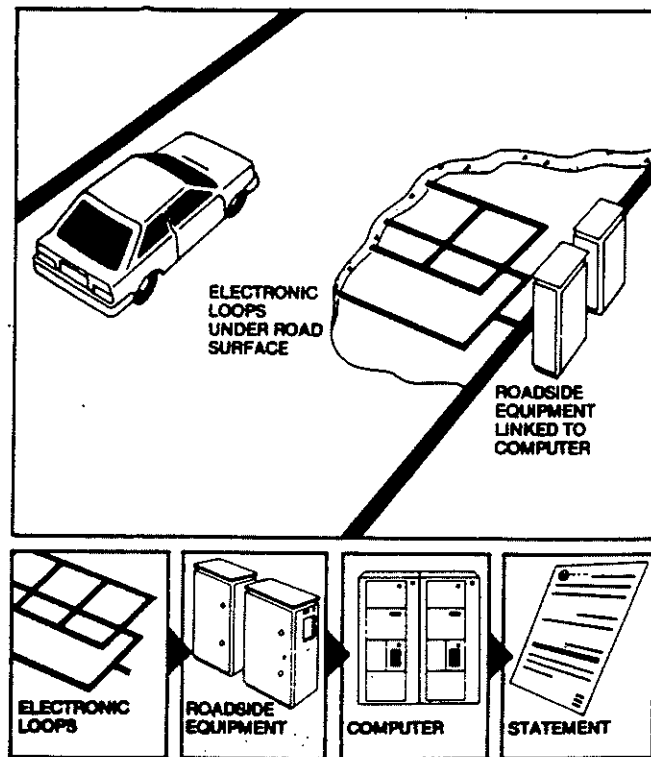


Figure 8. Hong Kong Electronic Road Pricing System

where all account records are kept, and transactions are tabulated. The transmission to the central computer may occur immediately, or at the end of the day, depending on the particular system. Validated transactions are accumulated during the month and the vehicle owner is sent a statement of road use charges at the end of the month. A typical account statement is shown in Figure 9 (18).


Rather than operate on a credit system, where the user is billed at the end of the month, it would also be possible to utilize a debit system where the a transponder is purchased with a value programmed into it. The value of the transponder would decrease with use. Such a system would not keep track of the vehicle's travel pattern, which may alleviate concerns regarding user privacy. The lack of specific user charges would, however, create problems with questions regarding user account balances (if a user felt an inappropriate charge had been debited). A debit system would require that the transponder have both read and write capabilities. Such a system may offer the potential for sophisticated customers to tamper with their account balance (17).

Privacy concerns should be addressed with the adoption of any system. All records of vehicle travel should be used for billing purposes only. There should be strict controls for access to the vehicle travel data, and records identifying a vehicle's travel transactions should only be kept until the appropriate charges are paid. The user should be informed about the policy of transaction records upon receipt of a transponder. The consumer could be informed that use of the facility implies understanding and acceptance of the operating policy.

The AVI system can be expanded to provide enhancement to auxiliary functions, such as enforcement. The computer can relay information to police when a vehicle without a transponder or with an invalid transponder uses the system. Closed caption television can be used to photograph any vehicle that does not have an appropriate transponder; the computer can pass information to the camera equipment for automatic imprinting of the registration number on the photo (18). This could be used for enforcement by having vehicles registered as high occupancy photographed, and photos observed to assure that the occupancy requirement is met. While this is ideal from an enforcement standpoint, from a privacy standpoint it might raise concern. Each roadside outstation is also capable of driving a toll display unit. This display would show the toll rates as specified by the operating agency.

The AVI system provides a sophisticated tool for data collection. Because the system can keep track of the number of vehicles entering the facility, and displays and charges the toll, eventually it might be possible to have the system automatically set the toll based on the number of vehicles that have entered the system. In essence, such a facility could manage itself by gauging the current use and setting the real time toll to control demand.

A final benefit of an AVI system is that all HOV facilities within a region could share billing and administration facilities. Under this kind of network, additional HOV facilities could be added to the system without incurring all of the central processing costs. This would also be convenient for the user, because it would allow access to multiple facilities with a single transponder.



Road Use Statement

PPN = 6752

ACCOUNT NO. **E533294**

STATEMENT DATE **11/11/90**

PERIOD **09/10/90** TO **08/11/90**

DATE **11/11/90**

PAGE NO. **0001**

DETAILS **MP**

ACCOUNT **MP**

BALANCE B/F \$104.50

19/10/90 PAYMENT \$104.50CR

SUB TOTAL

VEHICLE

BV 860

TOLLS

32

CHARGES

\$0.00

| | | |
|----------|---|------------------------|
| 11/10/90 | 4 | \$11.00 |
| 12/10/90 | 3 | \$9.00 |
| 13/10/90 | 1 | \$3.00 |
| 18/10/90 | 6 | \$12.00 |
| 21/10/90 | 2 | \$5.00 |
| 25/10/90 | 2 | \$7.00 |
| 26/10/90 | 4 | \$11.00 |
| 28/10/90 | 3 | \$10.00 |
| 05/11/90 | 4 | \$5.00 |
| 08/11/90 | 3 | \$4.00 |
| | | BALANCE |
| | | NOW DUE \$77.00 |

REF NO

ACCOUNT NO **E533294**

BALANCE

STATEMENT DATE **11/11/90**

NAME & ADDRESS

CHAN CHUN LEE

RM 2 4/FL

FUNG YIP BLDG

931 POK FU LAM RD

HONG KONG

T A G

JC

Figure 9. Typical Statement of Charges

Other toll collection options

While AVI offers many advantages, it is not the only option. Conventional toll facilities would be possible in some situations. Conventional toll facilities that require an attendant would allow visual observation to ensure compliance with HOV occupancy requirements for non-paying vehicles. This would encourage enforcement. An attendant would also be capable of enforcing a variable toll for different occupancy levels: a reduced toll for occupancy 2 on a 3+ facility. Additionally, unlike AVI or a monthly pass, conventional toll collection would be convenient for the one-time user. However, conventional toll facilities would require adequate space not only for the toll booth but also for storage of SOVs waiting to pay the toll, adequate deceleration and acceleration to and from the toll booth and a non-stop lane for the HOVs. If conventional toll facilities are used, the travel time savings of the HOV facility must be great enough to offset the additional time required to pay a toll.

A final option to be considered would be the use of passes or stickers for SOVs. This might be appropriate for a trial program to avoid the capital investment of toll equipment. Under this policy, a SOV windshield sticker could be purchased, valid for one month (or any designated term). The SOV could then use the facility as a HOV would, and enforcement would continue as usual, each vehicle on the facility must either have a sticker or the required occupancy. When pricing the monthly sticker, the price should be set high and lowered as necessary, so that operating conditions are not degraded for the entire term of the project if demand is higher than anticipated. It would be appropriate to limit the number of stickers sold for each operating period to the excess capacity during the worst of the peak period. While this system does not allow much operational flexibility through the variance of toll price, it is an inexpensive way of testing a pilot project. Furthermore, since demand is fairly constant for a one month period, it would not be difficult to reasonably estimate the number of stickers that should be sold each period.

The toll rate

In order to limit the demand for SOV use of the HOV facility, the toll must be sufficiently high to exclude the common commuter. If the toll is too low, the demand for SOV use of the facility will exceed the excess HOV capacity, and the number of SOVs would have to be restricted via metering or other demand control mechanism. This is undesirable because it requires storage for the waiting SOVs and also because it causes additional delay which will erode travel time savings. The toll rate should initially be set high, and decreased as necessary so that the system is not overloaded until the demand response is well understood.

Furthermore, the toll charged could be either for entrance to the facility or per distance traveled on the facility. Charging merely for entrance to the facility would be easier because it would only require identification of vehicles at entrances to the facility. It would also facilitate accounting processes, as the single transaction would occur upon entrance to the facility. Charging a toll for distance traveled on the facility would require AVI at the entrances, and either at periodic locations along the facility or at each possible exit from the facility. It would also be possible to charge by zone rather than by mile.

Under this operating scheme, each facility would have any number of zones, with an additional charge for entrance to the more congested zones. Charging a toll based on the distance traveled or zone entered would require more specific data regarding the vehicle travel characteristics and would likely be viewed as more invasive of the user's privacy. Additionally, a specified rate for entrance to the facility would be more easily understood by the user. A complex toll charge based on distance traveled and zone entered would be more difficult for the user to understand, and it would be more difficult to provide real-time information about the current rate being charged, making the decision whether or not to enter or stay on the facility more difficult.

The use of funds collected

The use of the revenue from toll collection is an issue that needs to be addressed before the project is implemented. It would be reasonable to use the funds to offset the cost of the HOV facility, and the adaptations necessary for the inclusion of SOV users. The funds could be used to cover administrative and operating costs for toll equipment and personnel, as well as capital and maintenance costs for the necessary equipment. Equipment costs would include all toll collection equipment, as well as changeable message signs that inform the potential user of the facility and its use. The funds could also be applied to expand the SOV congestion pricing project to other HOV facilities with excess capacity.

Hours of operation

The specific hours of operation could be either for peak hours only, or for a portion of the day. Obviously, the largest market would be for the peak hours. Generally, HOV facilities are characterized by one of 3 operating scenarios (5):

1. 24-hour operation,
2. morning and afternoon/evening operation, or
3. peak-period only operation.

The hours of operation for SOV congestion pricing would likely reflect the hours of operation for the HOV facility. If AVI is used, operation would logically be 24-hour, with significantly reduced rates during the non-peak periods. If traditional toll collection methods are used, then revenues probably would justify peak-period only operation. Obviously the demand will be greatest when there is the least capacity available, the peak period.

Communication with the driver

Communication with the driver is critical. The driver must be made aware of the current toll rate early enough to decide a course of action and follow through. The driver should have time to either enter the HOV facility or the mixed-flow facility. It might be appropriate to tell the driver not only the current toll rate, but also the conditions of the mixed-flow lanes, this would allow the driver to make an informed decision. Information

could be conveyed through changeable message signs, as shown in Figure 10 (13). Because standard information should be conveyed to the driver (toll price and condition of mixed-flow lanes), it would be possible to use a static sign with dynamic elements. It would not be necessary to inform the driver of the operating conditions of the HOV facility, as that facility should be maintained at freeflow speed. If it is not, due to an operating error or incident, perhaps policy should dictate that no SOVs be admitted to the facility.

Freeflow Travel

Possibly the most important aspect of operation is the maintenance of an appropriate travel speed. If the speed on the HOV facility is not maintained at an acceptable level, then the incentives of reduced delay and a reliable and reduced travel time do not exist. For this reason, it has been suggested that the HOV operation capacity is equivalent to LOS C (2). According to the 1985 Highway Capacity Manual (19), LOS C

"provides for stable operations, but flows approach the range in which small increases in flow will cause substantial deterioration in service. Average travel speeds are still over 54 mph. Freedom to maneuver within the traffic stream is noticeably restricted at LOS C, and lane changes require additional care and vigilance by the driver. Average spacings are in the range of 175 feet, or 9 car-lengths, with a maximum density of 30 pc/mi/ln. Minor incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage. The driver now experiences a noticeable increase in tension due to the additional vigilance required for safe operation."

While the capacity is specific to each project setting and facility type, it is usually in excess of 1200 vehicles per hour. Once volumes exceed 1500 vph, operating speeds can drop below 55 mph for isolated periods, and the LOS deteriorates. An adequate LOS has been obtainable on some projects for carpool volumes of up to about 1700 to 1800 vph.

The estimated speed and volume relationship for a typical transitway is shown in Figure 11 (12). Examination of this graphical representation reiterates the importance of limiting the number of vehicles in order to provide an adequate level of service.

Another critical element in the maintenance of an appropriate operation speed is the specification of a minimum speed. A single lane traffic stream is constrained by the slowest-moving vehicles.

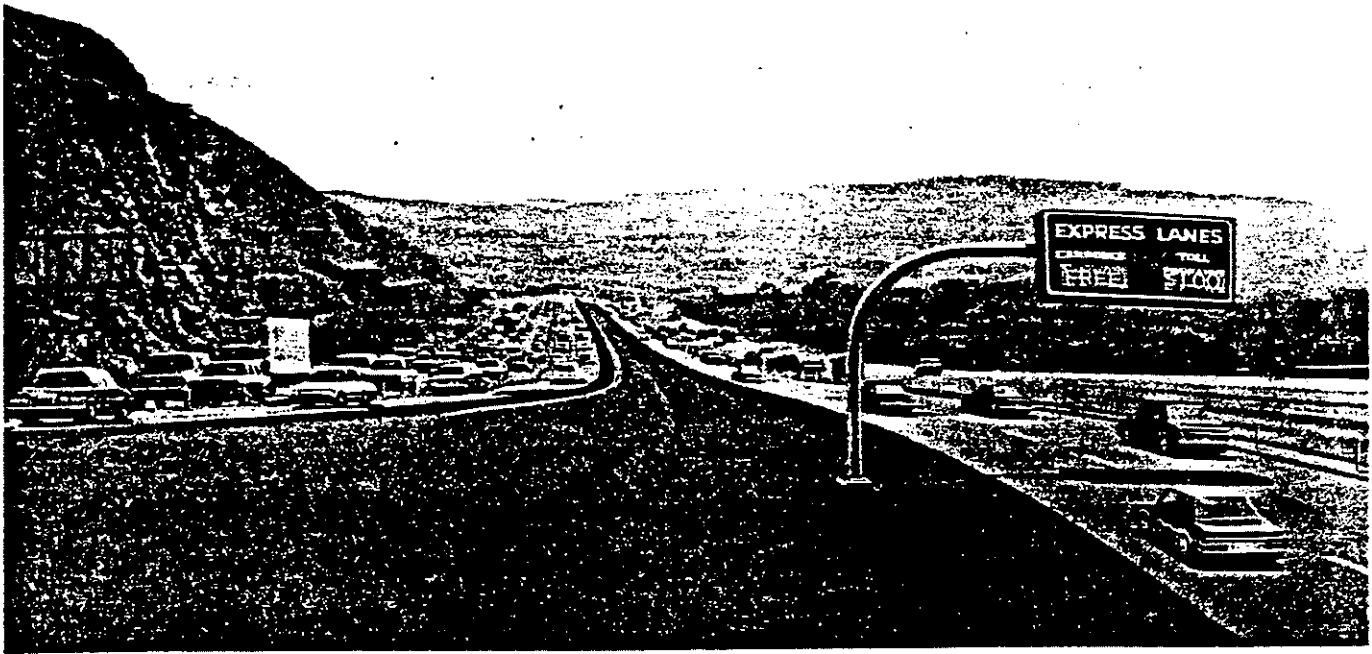


Figure 10. Toll Rate Communicated on Changeable Message Sign.

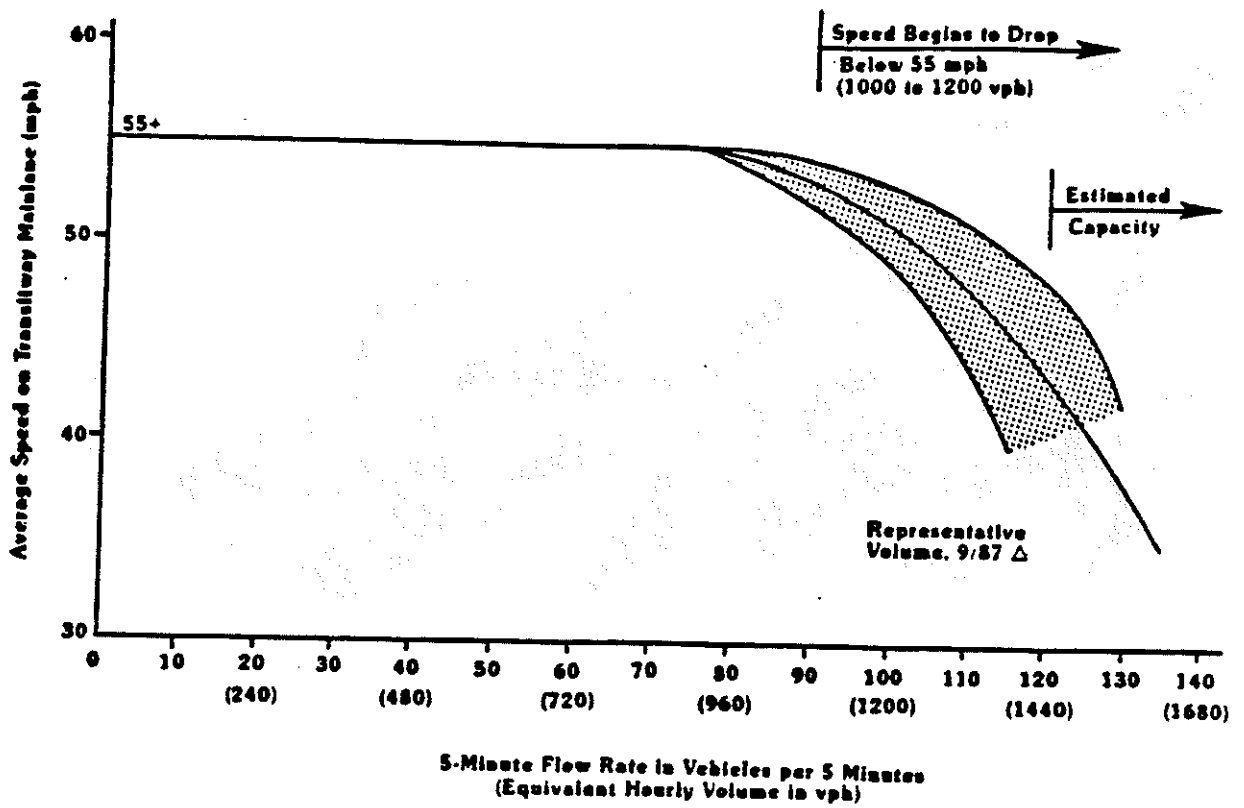


Figure 11. Estimated Speed-Volume Relationship for Typical HOV Facility.

SUMMARY OF FINDINGS

Examination of existing HOV facilities in various locations across the country indicates that many HOV facilities operate with excess capacity. This excess capacity on the HOV facility could be utilized by SOVs who are willing to pay a toll. This policy of SOV congestion pricing offers four operating advantages, as discussed in the paper: an SOV congestion pricing policy would fully utilize all of the capacity on an HOV facility, increase the person movement of the facility, benefit the SOVs that are willing to pay a toll to use the facility, and increase the public perception of adequate use of the facility. Furthermore, the proposed project is an example of congestion pricing, which is currently a topic of national interest. And finally, congestion pricing can be used as a mechanism to manipulate vehicular demand and therefore can facilitate the operational flexibility of the facility. These advantages of the proposed SOV congestion pricing project make it an attractive option that should be considered for implementation on any facility where there exists unused capacity.

There are problems that might be encountered during the implementation of an SOV congestion pricing project, most of these problems relate to the public reaction to the project. A campaign to educate the public about the project should be implemented to counter any negative public reaction. The educational campaign should explain why it is desirable to fully utilize the HOV facility and why the number of vehicles on the facility must be limited. This campaign should also emphasize that any commuter can gain the benefits offered by the HOV facility, merely by using a carpool, vanpool, or public bus. A extensive and well planned educational campaign should effectively counter some of the public resistance that otherwise might occur.

Another limitation of SOV congestion pricing, also discussed in the paper, is that it can only be implemented where the vehicles authorized to use the facility are effectively separated from vehicles not authorized to use the facility. All barrier separated facilities would thus be appropriate for SOV congestion pricing, as would facilities where pylons are sufficient to deter violations. It is possible that a facility could be modified to allow a congestion pricing project, possible modifications include the addition of a barrier, moveable barrier, or frequently spaced pylons. AVI could be located periodically along the facility to detect vehicles that entered the facility at unauthorized locations.

The use of AVI is both convenient and efficient and is the method suggested for toll collection in most situations. AVI requires little space, and because the AVI roadside equipment can be located either in the pavement or overhead, it could be implemented on most facilities. Furthermore, an AVI system can be coordinated so that a single transponder will be identified by various toll facilities in the region; this provides an added degree of convenience for the driver. The AVI system also allows toll collection to occur without affecting the speed of the facility--this saves time, is convenient for the user, avoids vehicle queues, and provides for operational safety by maintaining the speed of all vehicles on the facility.

The maintenance of an appropriate operating speed on the facility is a critical operational aspect that cannot be overemphasized. If freeflow speed is not maintained on the facility, then the incentives of a reduced and predictable travel time do not exist. Freeflow travel is maintained by limiting the volume on the facility; the volume of SOVs on the facility can be controlled through the toll rate charged.

Congestion pricing for the use of SOVs on HOV facilities provides an operating policy to efficiently utilize the excess capacity on HOV facilities. While neither this, nor any, project is appropriate for implementation on all HOV facilities, the implementation of SOV congestion pricing is an operating alternative that should be carefully examined.

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