

Table 3-5 Recommended Pavement Markings

<u>Design</u>	<u>Operation</u>	<u>Access</u>	<u>Pavement Marking</u>	
			<u>Right side</u>	<u>Left side</u>
Concurrent-flow, concrete barrier	Full time	Restricted	Solid white 6"	Solid yellow 6"
Concurrent-flow, with channelizers	Full time	Restricted	Double solid white 6" defining buffer	Solid yellow 6"
Concurrent-flow, buffer separated	Full time	Restricted	Double solid white 6" defining buffer	Solid yellow 6"
Concurrent-flow, buffer separated	Full time	Continuous	Double solid white 6" defining buffer	Solid yellow 6"
Concurrent-flow, buffer separated	Part time	Continuous	Double skip stripe white 6" defining buffer	Solid yellow 6"
Concurrent-flow, Non-separated	Full time	Continuous	Solid white 8" or wider	Solid yellow 6"
Reversible flow	Directional	Restricted	Solid white 6"	Solid white 6"

* Based on HOV travel direction which is opposite of freeway direction.

The standard pavement marking used to delineate any form of preferential lane (HOV or managed lane) is a diamond placed on the pavement at regular intervals. The interval may relate to the application. Mainlanes typically require placement every 1000 to 2000 feet. Ramp spacing may be closer. All designated preferential lanes should include this diamond, in accordance with the MUTCD. Specifications are provided in Figure 3-48.

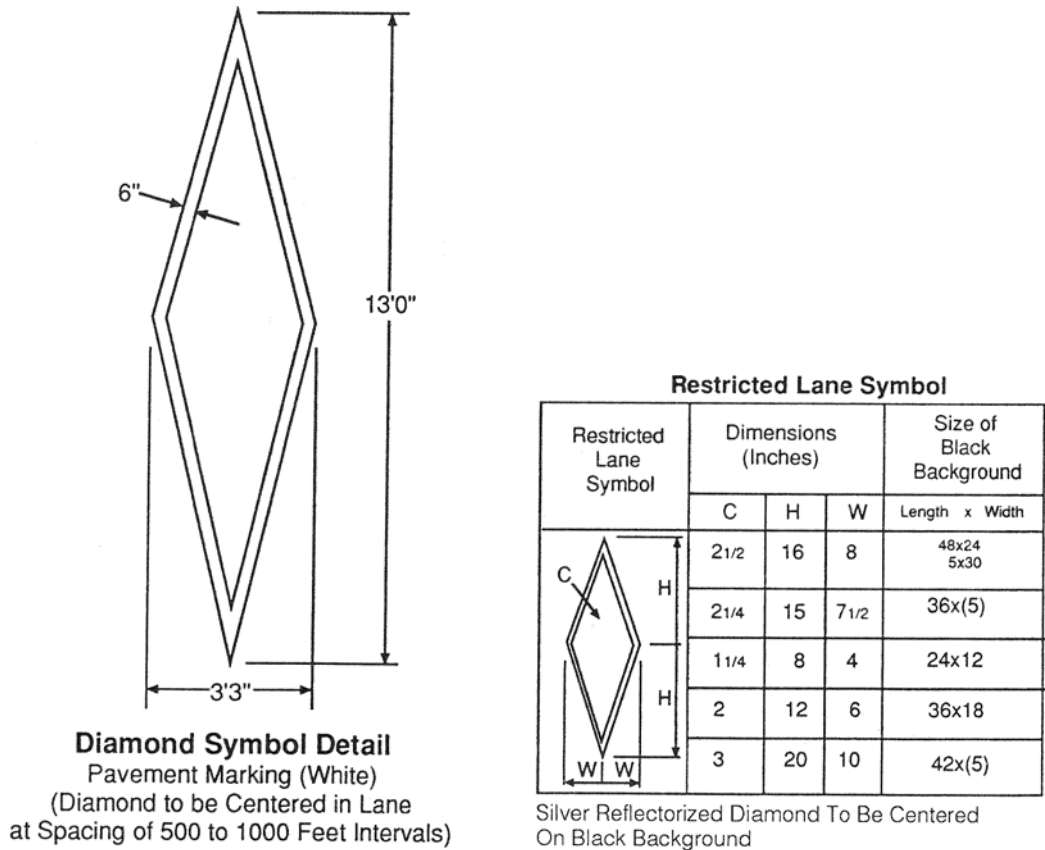
3.7 Pricing

Pricing is being applied to several freeway HOV facilities nationally and is planned for most managed lanes being planned and implemented. While current experience is limited, the following guidance is provided to accommodate electronic toll collection (ETC) to managed lanes. Specific design treatments for pricing management relate to the need to substantially segregate managed lanes from adjacent free lanes, provide communication to toll users, and enforce and administer the tolling process. While many options exist to address these needs, demonstrations implemented through the 1990s suggest that the most appropriate options involve the following design features:

- Separation of the HOV lane by concrete barriers, traffic pylons, or channelizers, with limited access. Open, unrestricted access has yet to be successfully demonstrated without a need for very frequent toll reading installations.
- Toll collection performed at one or a limited number locations along the managed lanes
- Enforcement considerations for occupancy, toll and ingress/egress violations
- Signing located upstream of the entrance ramps to communicate the toll and its related benefits
- An off-site facility or service that handles toll collection and administration

Each of these topics is discussed in this section.

Figure 3-48: Example HOV/Managed Lane Diamond Pavement Marking



Separation Treatments for Pricing

Pricing adds a new dimension to how HOV lanes are managed and enforced. The simplest approach to pricing is to operate a single tolling and enforcement site for the HOV facility. But this approach requires that the HOV lane be separated so that toll evaders cannot enter or exit the HOV lane at will. Separation is a key attribute that is effectively handled on priced HOV lanes that employ concrete barriers to separate opposing flow traffic. Continuous concrete barriers, such as permanently placed Jersey barriers or movable barrier systems, are permanent and durable and have been used for separation on a number of HOV facilities. They are also preferable from enforcement and traffic service perspectives as they prevent unauthorized vehicles from entering.

However, a majority of HOV lanes are likely to be concurrent flow designs. Separating these lanes may not be possible with concrete barriers. One design alternative applied in lieu of concrete barriers is plastic pylons or channelizers placed between concurrent managed lanes and general traffic in a designated and striped buffer area (Figure 3-49).

Figure 3-49: Plastic Channelizers on a Priced Managed Lanes



Tubular channelizers, pylons, or stanchions consist of a series of painted lightweight plastic tubes approximately three feet in height permanently affixed to the pavement at regular intervals. Because they rise vertically out of the pavement, they perform a greater psychological function than striping alone, but do not provide the physical protection of a continuous concrete barrier. One of their primary advantages is that they require a narrower buffer width than concrete barriers, which usually require separate breakdown shoulders along both roadways. Pylons on the State Route 91 project in California are positioned at 20-foot spacing and centered within a minimum 18-inch striped buffer. Maintenance issues are associated with all types of pylons. Experience shows that the displacement rate for traditional pylons is roughly 10 percent every 60 to 90 days, which means that all units would need to be replaced every year. Although generally durable, the adhesive-mounted plastic pylons can only be hit a certain number of times before they cease to bounce back up. They can also be hit with such force that they can dislodge from the pavement and become a hazard to traffic. Snow removal is also an issue as snow removal equipment can damage pylons, either by plowing snow onto the posts or by hitting them. Other types of vendor products are becoming available that may also be considered in providing a substantial separation between lanes.

Without physical separation, toll evasions cannot be effectively addressed. Some studies have suggested that lack of separation can be overcome by the frequent placement of tolling stations along the HOV lane (Figure 3-50).

Electronic Toll Collection

Electronic toll collection is the accepted means of applying pricing to HOV lanes and this practice will likely prevail on managed lanes. Each of the current demonstrations and many other tolled facilities across the country utilize electronic toll collection (ETC). ETC encompasses the use of various technologies for automated toll collection that eliminates the need for customers to stop and make cash transactions at a customary toll booth.

Figure 3-50: Toll Station on a Priced Managed Facility



ETC systems rely on three major in-lane/roadway components:

- Automatic Vehicle Identification (AVI)
- Automatic Vehicle Classification
- Video Enforcement Systems

This equipment can be mounted on overhead gantries (Figure 3-52), or in the pavement to allow drivers to be charged while traveling at normal highway speeds. One AVI technology features a radio frequency device called a transponder, located in the vehicle that transmits a unique identity to an antenna located on a gantry or in a toll lane. This information is received by a toll reader located in an adjacent roadside cabinet. Sensors also located at the tolling point verify the vehicle classification typically based on the vehicle's profile and number of axles, so that the proper toll can be charged. (The classification on the transponder is matched to the classification identity from the sensors. If there is a discrepancy between the two classifications the tolling administration agency sorts out payment or transactions for further investigations at a Violations Processing Center [VPC]). A video enforcement system can capture images of the license plates of toll evaders that use the facility. Those vehicle owners without a valid tag or with an observed discrepancy in classification can be identified as a violator. Legislation is typically enacted which allows the tolling administrator to pursue collection as a toll violation that includes the toll plus an administrative fee. All of these systems are linked by what is commonly referred to as a lane controller.

There is usually a single lane controller (micro processor) that coordinates the activities of all equipment monitoring the HOV lane, and it generates the transaction that is assigned to a particular customer. The lane controller also stores a list of valid tags so it can validate the information from the AVI. A larger computer collects transaction information from the lane controllers at each toll collection point and then communicates it to an administrative agency. The agency collects and consolidates information from one or more toll collection points in the system and transmits the list of valid tags to each lane controller for AVI validation, prepares audit report from each collection point, each lane and for each method of collection.

Some projects separate free HOV lane users from tolled users in the vicinity of the collection point (Figure 3-53). This design provides an opportunity for monitoring and inspection of free users from the toll traffic stream. Technology is also available which permits enforcement agents at any point along the lane, so segregation of HOV and toll traffic streams is not required. This design option is shown in Figure 3-51.

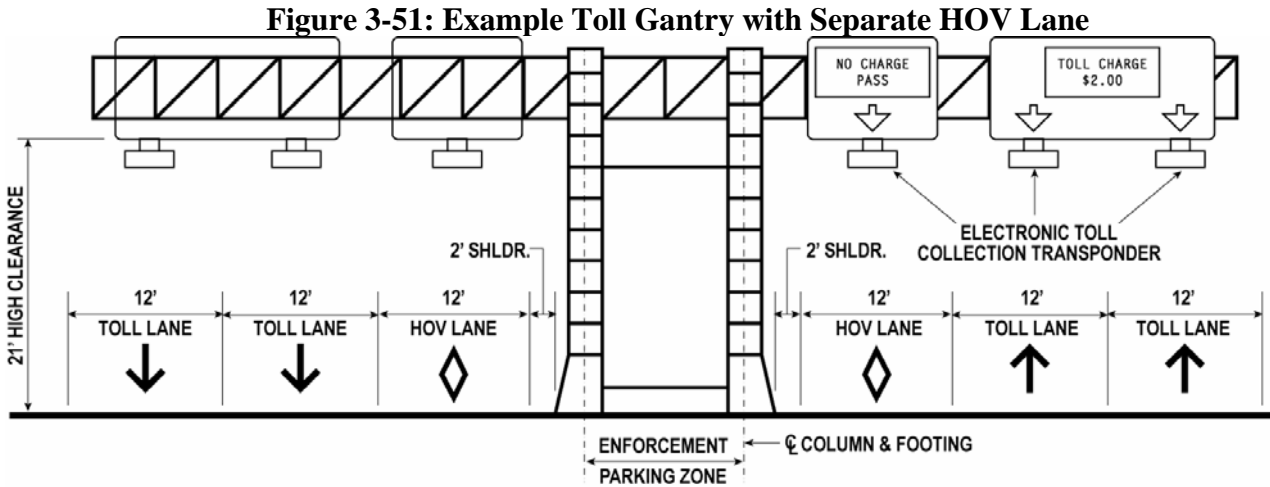
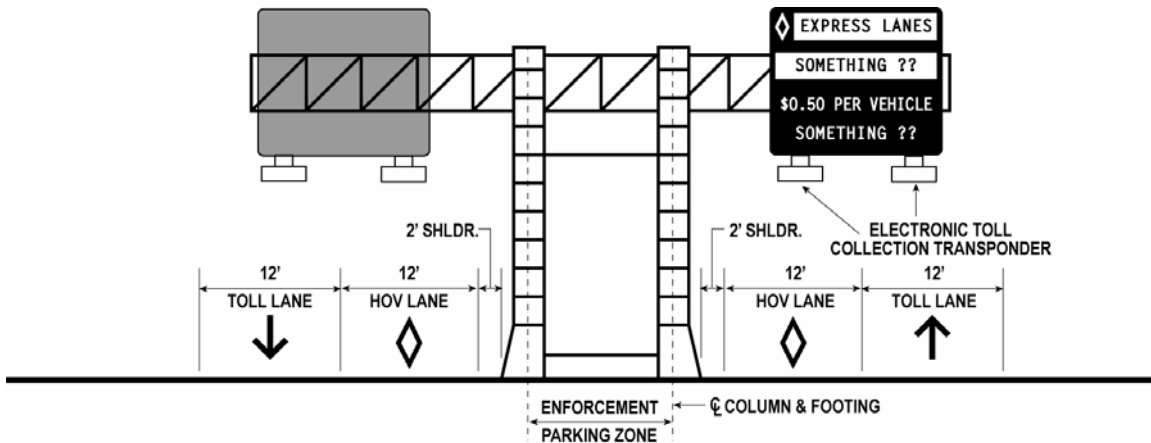


Figure 3-52: Example Toll Gantry Design without HOV Observation Lane



There are many observed variations on typical tolling systems described above. Putting this technology together can be a complicated process, and frequently administrative agencies hire a system integrator to add the technology to their existing toll environment or to develop a new toll system. Desirably, the selected transponder technology is compatible with other regional or statewide toll road operations so that user interoperability is possible with other facilities.

ETC implementation opportunities have largely been enabled by the changes in tolling technology. Automated or electronic means of collecting tolls through the use of various Automatic Vehicle Identification (AVI) systems has enabled tolling entities to collect toll fares without disruption to patrons or the roadway traffic flow. In addition to the

convenience of collecting the toll along the roadway, the overall cost of the collection activity is also significantly reduced.

While technology changes continue, the functional characteristics of the necessary tolling system remain the same. The tolling system involves an on-board device in the vehicle encoded with a unique ID used to identify the patron. The identification information is captured by roadside infrastructure (Figure 3-54), either at a tolling point or some other designated collection point, and passed through a communications network to a clearinghouse operation where the patron's account is managed.

Figure 3-54: Example of Overhead RF Antennae Used with AVI (right) and Cameras Mounted at a Tolling Installation (left)



Key considerations in determining the applicability of any given technology include: operating functions, capital and operating costs (both agency and patron), security, product maturity, compatibility and interoperability with existing or planned systems, standards compliance, maintainability, and ease of use.

In all cases the tolling system design for managed lanes involve developing a fully automated electronic toll collection (ETC) system. These real-time systems include roadside or overhead radio frequency (RF) transmit/read devices communicating with on-board automatic vehicle identification (AVI) units in passing vehicles. The identification (ID) of the passing vehicle is combined with other transaction information collected in real-time, e.g. the current toll rate, then packaged and sent to host or central computer to be processed against the registered toll account. If an ID is not obtained, the system captures the event as a violation. These sophisticated systems enable the possibility of implementing HOT lanes by efficiently permitting the collection of a toll.

Although sophisticated, tolling applications use relatively straightforward technology. ETC involves linking an identification device in a vehicle to an account maintained by a host computer system through communications infrastructure. The technology and systems used today for traditional tolling applications are proven and mature.

There are several issues that influence the design of a managed lane tolling system. These issues are presented in detail below. The design priorities of any potential project

are also dependent upon the characteristics of the facility and the desired management strategy.

Long term options (10-20 year timeframes) may include the use of GPS combined with GIS mapping systems to assess road user fees. These fees may be determined by time-of-day or prevailing traffic conditions, by individual roadway or designated regions or areas, the possibilities are virtually endless since vehicle travel is recorded by time and location. Privacy concerns, in addition to challenges to integrate the technology into a fee collection system, will be the biggest hurdles for this technology.

If the integration of a GPS/GIS based solution has not been proven, the automotive industry will likely have fully embraced in vehicle telematics and will be supplying vehicles equipped with on-board DSRC identification, GPS technology, and other in-vehicle sensor systems, such a seat occupancy systems, that will provide information to the on-board central unit that could be passed later to the roadside. Vehicle owners may be able to subscribe to any number of services, including a national toll account that can be used to travel on any tolled facility in the United States.

Technology

The benefits of capitalizing on an established ETC market of users, an established and stable revenue collection operation, and a program that is familiar to the public are enormous. Current RF based AVI systems are proven and mature and have been successfully integrated in ETC applications. Typically tolling systems involve proprietary software and complex hardware elements that require contracting directly with the manufacturer, supplier or system integrator. These services become more cost effective with scale, more naturally fitting the expansion of an existing system. The AVI function of ETC is defined within the industry as Dedicated Short Range Communications (DSRC). A DSRC standard is currently being developed that will standardize the technology applied for ETC and other Intelligent Transportation System (ITS) applications. Presently in the United States, all AVI equipment deployed in the field for ETC (transponders in vehicles and the roadside readers and antennas) operates in the frequency range of 902-928 MHz, a public frequency band. Several OEM's have provided equipment and systems in this band and there is little inter-supplier compatibility among them and no protection from interfering RF sources. The evolving standard will require that all equipment operate in a dedicated and protected frequency band centered on 5.9 GHz and that all suppliers' equipment be compatible. It is assumed that, at that time, the competition among the OEM's will result in a competitive environment for the agencies and authorities, as well as enhancing the mobility of the driving public. While it will take some time until OEM's qualify their products under the new standard, any new deployment planned should consider the ramifications of the implementation of the new standard. Its likely real changes won't reach widespread field deployment before 2010, but they could become standard vehicle products after this time. RF based AVI deployments of ETC have changed very little over the last 10 years. The most substantial decision has always centered on using passive or active technology for the tag or transponder, often a choice between low cost, non-battery units or high cost, battery powered units. Typically there were also trade-offs between function and data

storage. The majority of industry changes today involve designing lower cost, non-battery units which can also satisfy the more complex function and data storage requirements and never need replacing. These changes are also allowing the size of the units to decrease, which streamlines and improves distribution and supports point-of-sale purchasing from retailers of vending devices. Tag changes, designing multi-protocol readers and developing next generation DSRC products are the only technological changes being advanced for tolling.

All ETC tolling systems have the same general design parameters:

1. To identify the vehicle in the toll collection area by reading the identification number of the transponder (and other data that may be stored in the transponder) in the vehicle (the AVI function).
2. To determine the nature of the vehicle (known in the ETC field as classifying the vehicle) since most jurisdictions have different toll rates for different vehicle classes. This function is known as Automatic Vehicle Classification or AVC.
3. To photograph the license plate of the vehicle so that if any kind of violation occurs, the owner of the vehicle can be traced using the NDOT Department of Motor Vehicles files. Violations may include vehicles without a readable transponder, a vehicle class that does not correspond to class stored on the transponder, an invalid account held by the vehicle owner, among others.

To complete these functions, typically a well defined capture zone is established to detect and track the passing vehicle, communicate with the on board unit, interpret the on board data, and based on the interpretation determine the status of the event. A comprehensive planning and design phase should be completed and used to drive the technology solution.

Pricing Strategy

The selected pricing strategy affects the functional design of the ETC system for any managed lane facility. Managed lanes are designed to assess a road user fee that is inline with the value of reliable travel time to an SOV who is buying-in. In order to collect the road user fee some sort of tolling system is required. The design of the tolling system can be affected in two ways by the two major components of the pricing scheme to be implemented: 1) the price variability and 2) the price coverage area.

Price variability refers to the need to vary pricing according to a fixed, fixed variable, or dynamic variable toll rate schedule. Traditional toll facilities generally use fixed rate schedules according to vehicle classification. Some have introduced the concept of varying price by time of day, also known as fixed variable. For managed lane installations, pricing can also be set in real-time by the prevailing traffic conditions, an option known as dynamic variable pricing. Depending on the pricing concept to be used, the system design may involve additional subsystems, (e.g. traffic monitoring devices and advance signage, and / or more extensive modification to an existing toll collection operation, in order to accomplish the pricing mission).

Price coverage area relates to the roadway elements that are going to be priced. Is price being applied on a single facility, a corridor, or a region? The easiest to accommodate is a single or spot facility, which allows a toll to be collected at a particular trip point and is easily satisfied using traditional tolling techniques. Pricing will involve multiple tolling points to best regulate demand, and the rate structure may be defined by other parameters, e.g. miles traveled or specific route or roadway used. With traditional tolling techniques, multiple infrastructure locations are needed to determine what roadway or route is being used within the corridor and the various entry and exit locations. Regional pricing is similar to the corridor pricing model, multiple infrastructure locations are used to define the boundary of the priced region. Future tolling techniques might involve the use of Global Positioning Systems (GPS) that avoid the need for roadside infrastructure and potentially permit the application of dynamic, mileage-based fee across the entire roadway network.

Table 3-6 categorizes various tolling or pricing systems by the two major components of the pricing strategy. As suggested by the table, facility and corridor based toll systems employing variable pricing can be achieved with current ETC solutions. For applications looking to price regions or areas in any fashion, the table also clearly shows that solutions using existing ETC technology do not exist and alternative or future technologies may be better suited to address pricing needs.

Table 3-6: Tolling and HOT Applications by Price Coverage Area and Price Variability

Pricing Area / Variability	Fixed	Fixed Variable	Dynamic Variable
Spot / Facility (including closed corridor facilities)	Traditional Toll Plazas	Some Toll Plazas, SR-91 HOT (CA), US 290 HOT (Houston)	I-15 HOT lanes (San Diego)
Corridor (multiple entry/exit and/or priced parallel routes)	Traditional Toll Plazas	IH-10 (Katy) HOT lanes (Houston)	I-394 HOT lanes Minneapolis

All users would be equipped with a transponder for identification and electronic toll collection (ETC). The pricing approach likely to be adopted would be dynamic pricing that is responsive to the level of service being experienced in the HOT lane. VIDS monitors would detect traffic flow rates and adjust pricing according to a prescribed plan that assures flow rates are sustained.

Managed lanes would be ETC equipped and potentially have a variable toll rate for each segment. Multiple toll zones could be anticipated with intermediate ingress/egress. Tolls should be able to vary by segment, with segments experiencing highest demand charged more than others. Some flat-fee based tolling might occur outside peak periods when benefits do not justify variable pricing to manage lane demand.

The project could take advantage of CMS signing if already applied for mainlane incident communication. Highway advisory radio and other means of communication could also

be employed to communicate toll information to motorists. Communication for toll transactions would go back to a remote office for processing via fiber connection.

Toll Operations Management

The operator of the toll system could be the NDOT, RTC or a third party contract or vendor. They would be serving the owner/client under prescribed policies regarding the minimum and maximum tolling thresholds, regulations regarding how the toll rate is changed, who is eligible for free or discounted use, and how the excess revenue is vested. They might also be charged with maintenance and operational reliability of the ETC infrastructure.

Preliminary ETC Cost Considerations

Operating costs likely to be incurred for a priced managed lane are divided into three categories: operations, maintenance and violation processing. Each category includes functional areas for the provision of services associated with the tolling operation. Operation costs involve administration, finance and accounting, customer service, and support staff at the tolling center. Operating expenses can include facility costs, office equipment costs, supplies and other direct costs associated with account management and revenue handling. In an established operation, the operating costs / expenses can be estimated to increase somewhere between \$200,000 and \$500,000 (2005 dollars) for every additional one million transactions processed. Maintenance costs involve preventative and corrective maintenance activities of the roadside tolling equipment and collection locations and central computer systems and application software. Maintenance expenses include facility and vehicle costs, technical support type contracts, and consumables. Depending on the scale of the deployment, maintenance service costs will vary widely depending on such factors as the number of tolling installations, access locations, operation and enforcement plan and length of the project.

Violation processing costs involve violation image review, finance and accounting, customer service, and appeals and hearing support. Additionally the cost of on-site enforcement activities and judicial or other adjudication proceedings must be included. Violation processing expenses include facility costs, office equipment, lookup fees, supplies and other direct costs associated with revenue handling. Excluding fixed costs for facilities and computer assets, the operating expenses in 2005 could be estimated to be between \$100,000 and \$500,000 annually per 100,000 violations processed, based on experiences from San Diego's I-15 HOT lanes.

Operating costs can be significantly reduced if the operations activities are supported by web-based applications. On-line account management and payment, including for violation fines and fees, on-line account statements and other e-services dramatically reduce the cost of service center operations.

Table 3-7 provides some preliminary cost estimates for tolling infrastructure deployment that may be anticipated for a prototypical 6 to 8-mile simple managed lane operation with up to five tolling stations.