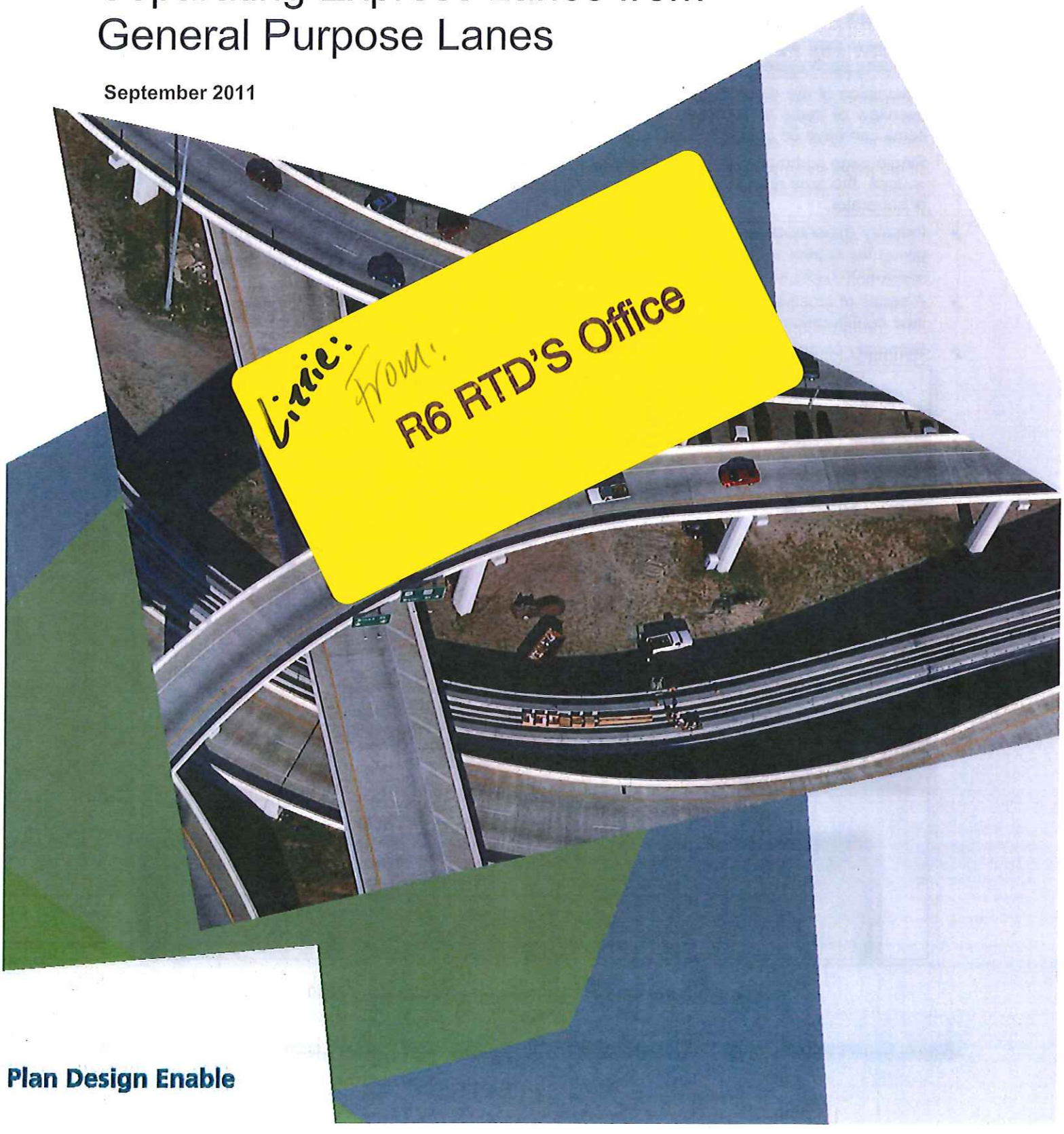
ATKINS

White Paper: Current Industry Trends for Separating Express Lanes from General Purpose Lanes

September 2011



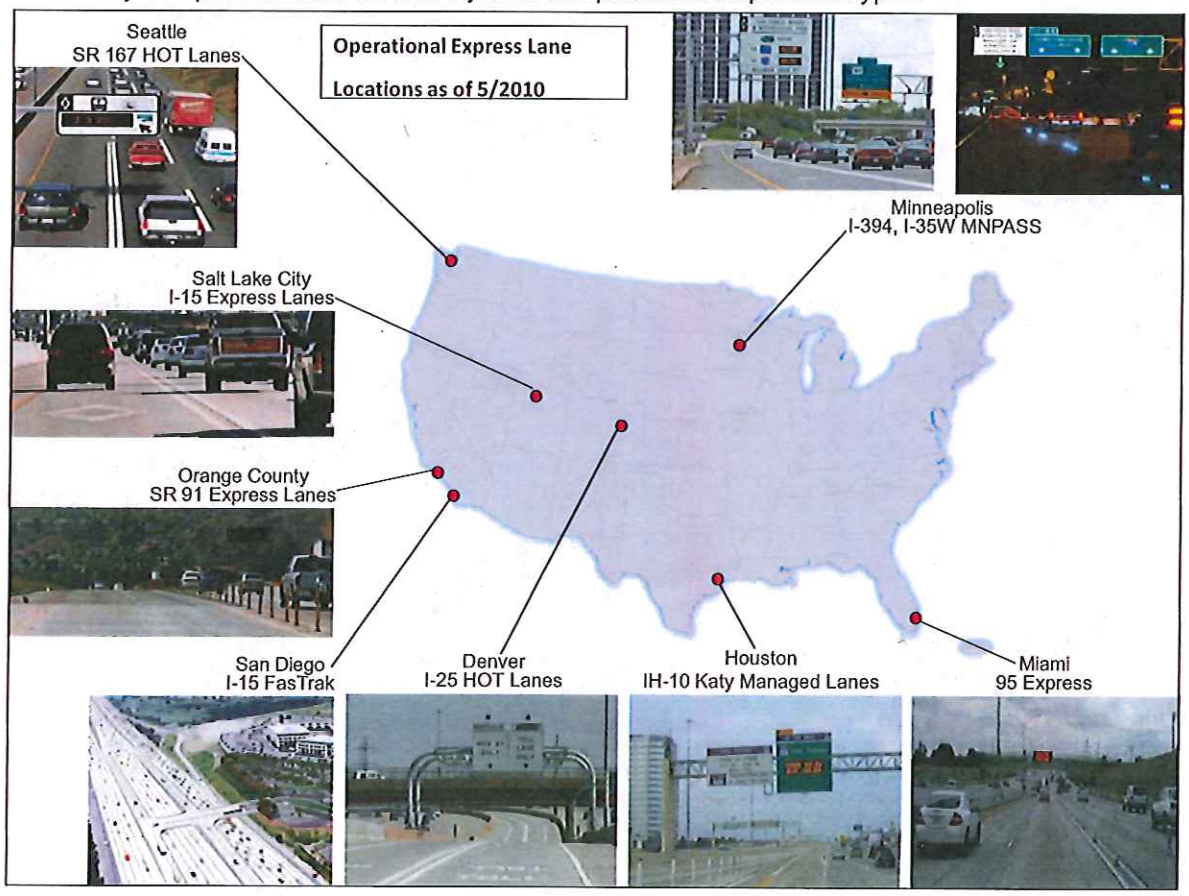
Plan Design Enable

Introduction

With the increased deployment of Express Lanes (EL), also known as Managed Lanes or High Occupancy Toll (HOT) Lanes, the transportation industry has been able to better understand the advantages, disadvantages, and impacts of lane separation techniques. The purpose of this white paper is to discuss the separation types currently in use in the industry today, the factors that often drive the choice of separation type, and also pros, cons, and considerations for each type.

The document is structured as follows:

- Overview map showing the location of the operational EL systems along with a thumbnail photo depicting each system.
- Discussion of the different factors that affect the selection of a separation type giving the reader an overview of items to consider when selecting a separation type along with the impacts that these items can have on operations and cost.
- Single page summaries for each separation type. Each summary shows the locations where the type is used, the pros and cons associated with the type, and points to consider when selecting that type of separator.
- Industry experience and lessons learned and study results from some of the systems in operation, giving the reader a better understanding of what to expect from an EL operation with respect to the separation types identified in this document.
- A series of cross-section diagrams of various systems that allows the reader to better understand the lane configurations and shoulder areas for the systems.
- Summary comparison table for side-by-side comparison of separation types.



Operational Express Lane Systems as of May, 2010

Factors Impacting Separation Selection

With each project and/or location where EL are installed, there are many factors that affect the type of separation to be used between the EL and the General Purpose Lanes (GPL). Below are some of the major factors that should be considered:

- **Safety** – Based upon traffic flow and interaction expected between the EL and the GPL, highway safety becomes a factor that could impact the separation type used. There have been studies conducted that show the barrier separated systems are the safest, however, there are concerns with these systems when it comes to incident response, due to limited access points. In addition, barriers offer the vehicle the least amount of forgiveness when there is contact, thus not giving the driver a chance to correct a mistake when it happens. For these reasons, safety items to consider are:
    - Incident Avoidance
    - Incident Management
    - Lane Clearance

- **Right-of-Way** – Some separation types require more right-of-way due to the need for additional shoulder room in addition to the space needed for the device placement. The space requirements needs are typically the biggest in the areas where access points to/from the EL are established. This is because of the need to give the driver a proper merge configuration and to separate the EL and GPL vehicles accordingly. In addition, there may be the need to use a certain type of separation within a fixed Right of Way, and therefore design modifications will have to occur.

- **Cost** – Some separation types cost more for initial installation. From a pure per-mile basis, barriers are the most expensive type, with flexible/tubular delineators being next, followed by pavement markings only. Cost can also be associated with the need to maintain/replace devices and should be included in the analysis. The flexible/tubular delineators tend to be the most maintenance needy type since they tend to get dislodged by errant vehicles.

- **EL Roadway Characteristics** – The way the EL is designed to operate impacts the separation type used. EL operation could be identified as one of the following:
    - Reversible – Lanes operate directionally based upon the peak direction of traffic. In this operation, the same lanes are used for both directions of traffic at different times of the day. This operation always requires the use of barriers to separate the EL from the GPL due to safety impacts of oncoming traffic.
    - Concurrent flow – Lanes operate in the same direction as the GPL for both directions of traffic. This is one of the most common types of operation since it is how most HOV lanes are operated today. This is also the operation that most agencies convert an existing system of GPL to because there is usually no need for additional right of way when delineators or pavement markings are used as the separation type.

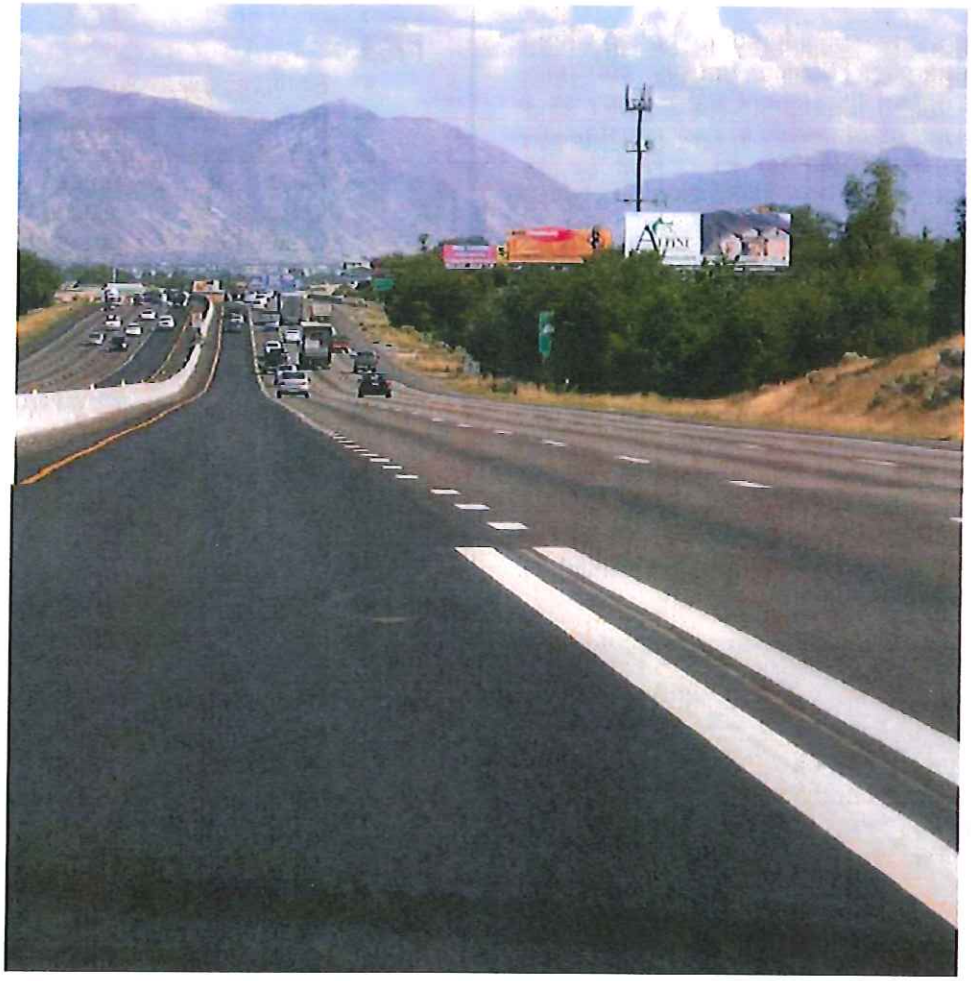
- Elevated – Lanes operate at a different level than the GPL. This is not a very common operation type due to the high cost; however, it is considered the most effective operation type since the EL and GPL vehicles are not only physically separated, but visually separated, which eliminates conflicts and confusion during congested periods of the day.
- Mixed mode – Lanes operate differently depending on the time of day and traffic needs. For instance, during peak times the lanes would operate as EL with HOV restrictions and tolled vehicles, but off peak the lanes would not have any HOV requirements. This is also not a very common operation type because of the confusion it could cause with different modes of operation at different times. It also is not an easy operation to explain to the drivers via signing.

- **EL Operational Characteristics** – The restrictions or requirements to vehicles that use the EL and how the lanes will be tolled can impact the separation type used. Controlling factors are:
  - Vehicle Occupancy – Are HOV requirements part of the EL operation. This would impact the need for additional enforcement needs to verify vehicle occupancy. This is typically done by law enforcement visually and requires an enforcement area be established so the officer can be stationed in a vehicle at access points to verify the occupancy. This requires larger shoulder areas and may impact the type of separation used.

  - Vehicle Type – With large trucks, lane widths allowed will be impacted. This in turn can affect the EL footprint and the ability to use certain types of separation in existing cross sections.
  - Dynamic Price Tolling – With Dynamic Pricing, the toll amounts are constantly being revised based upon the number of vehicles using the EL and the needs associated with the congestion of the GPL. For this reason, constant monitoring of traffic is necessary and multiple tolling points are required. If this type of pricing is used, access to/from the EL is crucial since this will determine how pricing is established and how the lane use is regulated. It is also a pricing type that is easily violated if the proper separation type is not in place or if additional detection devices are not installed. With barriers, this type of system is controlled by the physical separation. With delineators or pavement markings, the control is in additional detection devices and enforcement.
  - Time-of-Day Tolling – With this type of pricing, the tolls are set based upon when the user is accessing the lanes. Control of the lanes via pricing is not constantly changing and therefore, the separation type is not as critical as with the dynamic pricing scheme.

- **Access Points** – The type of access and the number of access points can impact the separation type used. Whether there are multiple access points to/from the GPL, minimal access points to/from the GPL, or direct access to/from crossroads. This has an effect on the interaction between EL and GPL vehicles and how the merging between them will occur. It also affects the length of opening needed

in the separation types used since barriers require crash attenuators on their blunt ends, while delineators and pavement markings are more forgiving.

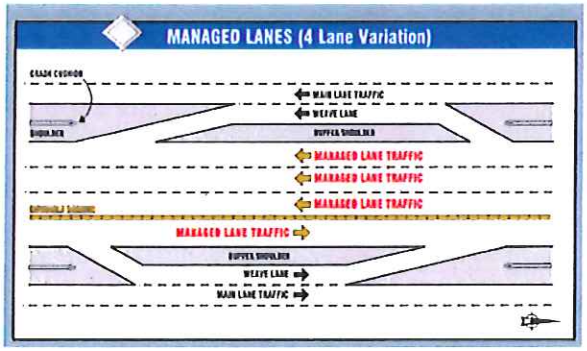


Rigid Barriers

Rigid barriers are considered to be any hard physical separation device (mostly concrete) and can be found throughout the country as a separation type used mostly in new construction or major reconstruction for EL. Due to the potential for head-on interaction between vehicles, rigid barriers are always used in reversible lane operations. This separation type is the least forgiving to the vehicle and therefore, can cause the most damage if impacted. It does, however, eliminate the chances of sideswipes between the GPL and EL vehicles and also reduces the discomfort of the EL drivers when GPL traffic is slowed or stopped. Because of the need for physical transitions when access points are required, this separation type usually requires additional right of way or sub standard design criteria if used within an existing highway footprint.

Existing Locations

- I-15 (San Diego) (also includes a movable barrier between EL)
- I-394 (Minneapolis) (Reversible Lanes)
- I-25 (Denver) (Mixture of both Reversible & Concurrent Flow Lanes)



Pros

- Reduces toll avoidance
- Reduces GPL and EL side swipes
- Low maintenance
- Allows for overhead sign structure uprights to be placed within barrier, which reduces sign structure spans
- Access points are controlled by physical separation making them easier to enforce and limits violators
- Physically controlled access points
- EL traffic is separated from incidents in GPL
- Allows for higher operating speeds in Concurrent Flow operations

Cons

- Access to lanes is restricted, therefore Incident Management response may take longer
- With an incident in the EL, the impact to EL traffic is high because of lane blockage
- Higher cost for installation than other methods
- Right of way typically needed for access points installation
- When installed within existing roadway cross sections, design constraints may be involved
- Possible flyovers or extra ramps required for GPL left exits
- More difficult to vacate lanes in an emergency
- Mixed mode operations in non-peak times are not applicable
- Special openings or devices may be needed for emergency vehicles during incident responses

Considerations

- Good for new construction
- Good for EL with limited access points
- Good in areas with aggressive drivers
- Evaluate the possibility of Design Exceptions when converting an existing system
- Location of Emergency access points along the barrier via removable barriers

Flexible/Tubular Delineators

Flexible/Tubular Delineators are considered a soft physical separation device and are found throughout the country in many different applications. These devices are traversable; however, with close spacing between devices, and proper upkeep, these devices can serve as a lower cost way of restricting access to/from EL. These devices are typically subsidized with traffic stripes to create a buffer area between the EL and GPL. While this separation type does not physically separate the EL and GPL traffic, it does give EL drivers more comfort when the GPL traffic is slowed or stopped. Replacement of these devices is frequent and maintenance costs need to be included when factoring this type of separation. If spacing allows, the use of shoulders next to the delineators, can reduce the number of impacts and prolong the life of the delineators.

Existing Locations

- SR 91 (Orange County, CA)
- Katy Managed Lanes (Houston)
- 95 Express (South Florida)

Pros

- Easy installation
- Low installation cost
- Access points are controlled by visual/soft separation limiting violators
- Easier access for emergency vehicles since delineators can be driven over
- Easy adjustment of access points after initial installation
- No right of way typically needed for installation
- Provides some physical separation which can help reduce toll avoidance
- Reduces illegal lane changes
- Controlled access points

Cons

- Easily traversed
- High maintenance costs due to frequent replacement of delineators that are hit by vehicles
- Frequent maintenance on delineator replacements
- Impacts to delineators can create roadway debris
- Vehicles in the GPL are not physically separated from EL if an incident does occur
- No location for overhead sign structure uprights within area separating GPL & EL, which results in longer sign structure spans
- Hard to operate in mixed mode during non-peak times
- GPL traffic may have to merge with EL traffic for left exits
- Operating speeds may be lower than posted because of limited physical separation
- Hard to establish enforcement areas

Considerations

- Good for EL with multiple access points
- Evaluate delineator products for most durable
- Good for systems converting existing lanes to EL

Pavement Markings

Pavement Markings are considered a non-physical or buffer separation type that has typically been used to separate HOV lanes from GPL. Pavement Markings are traversable and when used for EL operations, typically require the need for wider buffer areas and wider stripes to help delineate the lane differences. When used, these markings are typically subsidized with reflective markers or in-pavement LEDs to help delineate the lanes at night. This separation type offers no physical means of separation between the GPL and EL; therefore, violation opportunities exist more than other separation types. Also, since there is no physical separation, these lanes can be confusing to unfamiliar drivers unless good signing and pavement marking messages are present. With slow or stopped GPL traffic, this separation type typically has slower EL traffic because of the driver's uncertainty of last second maneuvers from the GPL into the EL.

Existing Locations

- I-15 (Salt Lake City)
- I-394 (Minneapolis)
- I-35W (Minnesota)
- SR 167 (Seattle)

Pros

- Easy installation
- Low installation cost
- Easy access for emergency vehicles since there is no physical separation
- Easy for EL traffic to vacate the lanes in case of an emergency or incident in the lanes
- Easy adjustment of access points after initial installation
- Easy to operate in mixed mode during non-peak times
- No right of way typically needed for installation

Cons

- No physical separation to deter drivers from leaving or entering EL when they are not supposed to
- Illegal lane changes are not deterred
- No location for overhead sign structure uprights within area separating GPL & EL, which results in longer sign structure spans
- Hard to enforce illegal maneuvers and other infractions because enforcement areas are hard to establish
- GPL traffic may have to merge with EL traffic for left exits
- More opportunity for GPL and EL side swipes
- Vehicles in the GPL are not physically separated from EL if an incident does occur
- Operating speeds within the Express Lanes are typically lower than posted during congested times because no physical separation is present

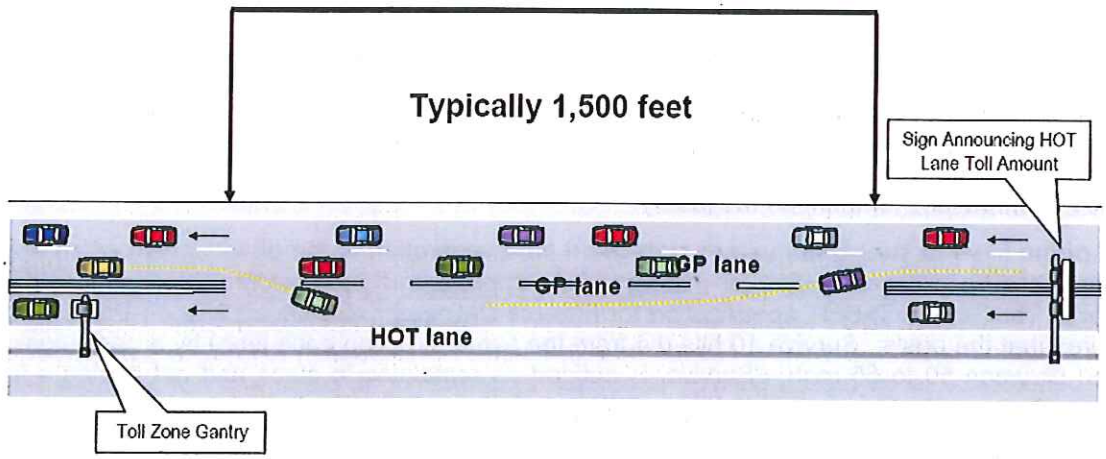
Considerations

- Good for EL with multiple access points
- Good for EL conversions from HOV lanes where similar application were used
- Good for short trip systems due to the ability to provide more access points

Industry Experiences

Since the deployment of Express Lanes within the United States, there have been numerous "lessons learned" and study results received from the industry. Some of these have direct impacts to the selection of separation types and are included below.

- The 95 Express in South Florida initially installed white flexible delineators, spaced at 20' centers, when they were transitioning from GPL to HOV. At the time of this conversion, before tolling was added, there were numerous accidents caused by driver confusion. After much analysis, the Florida Department of Transportation changed the white delineators to orange to improve visibility. But the biggest impact was that the delineator spacing was reduced to 10' centers since there were numerous vehicles weaving in-and-out of the 20' spaced devices. As a result of this change, FHWA revised the delineator spacing requirements to state that 20' is the maximum spacing to be used for separation of delineators instead of their original requirement of 20' spacing as the minimum. And as a result of the spacing change in the field, accidents were reduced significantly.
- A research effort was conducted by TTI on pylon-delineator experience which included an analysis on the use of these devices as lane separation techniques for managed lanes. During a webinar to share lessons learned on these devices based upon this research, a question was asked about the maintenance experience with the delineators on the I-95 Express project. The answer revealed the fact that research had shown that other agencies were experiencing a replacement rate of 115% per year for the delineators and that the I-95 Express project was right on track with that research result.
- The WsDOT HOT/HOV Lane Buffer and Mid-Point Access: Design Review Report provides some information regarding the SR-91 experience with pylons: The HOV/HOT lanes are separated from the general-purpose lanes by double yellow lines. The distance of the buffer from edge of lane line is 4 feet. Between the lane lines is a flexible barrier of tubular pylons. The pylons are placed 6 feet on center. The cross-section used as described from the median barrier is a 4-foot inside shoulder, two 12- foot HOT lanes, and a 4-foot buffer between the HOV lanes and general-purpose lanes. Even with the pylons, the Orange County Transportation Authority (OCTA) have a number of drivers violate the access requirements of the express lanes either by trying to avoid the toll and enforcement areas or by using the lanes for shorter trips, creating their own access points through the pylons. OCTA replaces 1,000 pylons per month. The cost of maintaining the pylons is high; however, the barrier is essential to successful operation of the facility. Without the pylons, enforcement would be impossible.
- TTI completed a research project entitled *Intermediate Access to Buffer-Separated Managed Lanes* in March 2007 (17). The objective of this TxDOT research project was to develop guidance materials on full intermediate access point design to a buffer-separated toll lane.



Volume counts for 5-minute periods were associated with each maneuver. Key findings of the data analysis included that:

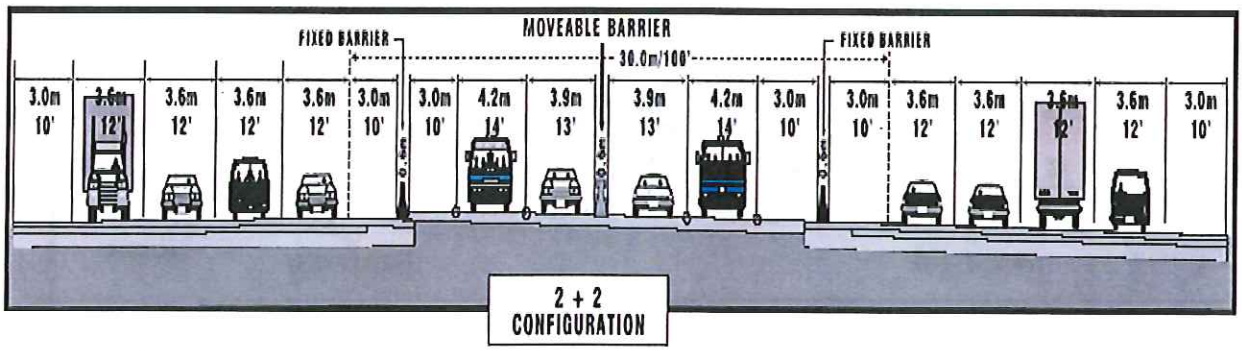
- Approximately 9 percent of the vehicles crossed the solid white markings (i.e., were not in compliance with the pavement markings);
- Compliance was better for the longer access opening length (1500 ft) as compared to the 1160-ft access opening length;
- A surprisingly large number of maneuvers at the intermediate access openings (over 7 percent) involve vehicles passing slower-moving vehicles; and
- At the two sites with the larger quantity of data between 40 and 80 percent of the passing vehicles involved a vehicle leaving the managed lane to pass a slower-moving managed lane vehicle; and findings from one field site demonstrated that when presented with the opportunity to enter a managed lane that is located very close to an entrance ramp, drivers will attempt to cross multiple lanes to do so.

- Based on findings from a single site, researchers observed that vehicles appear to be shifting their position within the HOV lane and in some cases the lane adjacent to the HOV lane in response to the existing pavement markings. The transition from broken line to solid double lane lines includes a point (see photo) that may be drawing the driver's attention. To minimize that potential, the researchers recommended that the solid lane lines end without having the point and that the broken lane line continues from the solid lane line that is closest to the general purpose lane.

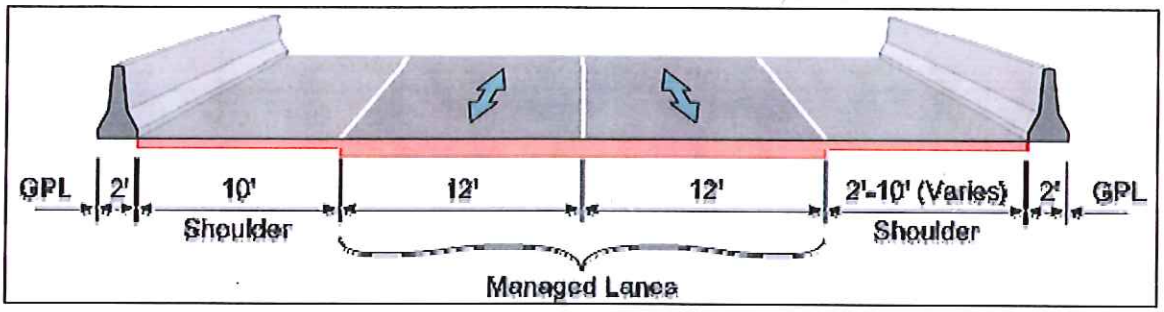
- According to a TTI report in 2006, previous studies regarding the safety of concurrent flow, buffer separated HOV and/or HOT lane facilities regarding safety have been relatively inconclusive. Some studies have concluded that buffer-separated concurrent flow lanes are as safe as other types of HOV lane projects, while others have indicated a safety concern with these types of projects". The same report cites an increase in injury crash rates since installation of buffer separated HOV lanes on two corridors in Dallas, Texas. The report cites that increases in injury crashes were likely due to the speed differential between HOV lanes and the general-purpose lanes. [TTI *Crash Data Identify Safety Issues for High-Occupancy Vehicle Lanes in Selected Texas Corridors*, 2004. Project Summary Report 04434S]. In contrast, a section of the Interstate 394 (I-394) in Minneapolis, Minnesota converted its concurrent flow HOV lanes to HOT facilities with a two foot buffer separation between the HOT lanes and adjacent general purpose lanes. The HOT lanes include multiple mid-point access locations. Since opening the facility in May 2005, the I-394 HOT lanes had not experienced an increase in accidents within the corridor – in fact they saw a marked decrease in the number of accidents along the corridor. Transportation officials also noted that transit operators say that having designated access points (for the I-394 HOT lanes) have improved operations for them on the facility.

- One of the keys to successful use of curb-pylon lane separation is the development of an appropriate performance-based specification for managed lane application that considers the likelihood of frequent impacts. The current TxDOT specification for Flexible Delineator and Object Marker Posts (DMS-4400) requires that the posts: Survive 10 hits (hit from the same direction each time) by a passenger car, at a speed between 50 to 55 mph. ('Survive' is defined as remaining in place and not having a list in any direction from vertical of more than 20°.). With the Katy Freeway Managed Lane project, the delineator hits appear to be less frequent than normal and it is believed that this is due primarily to the large shoulder offsets between the GPL and EL from the delineators. This offset gives drivers time to recover if inadvertent lane departures occur.

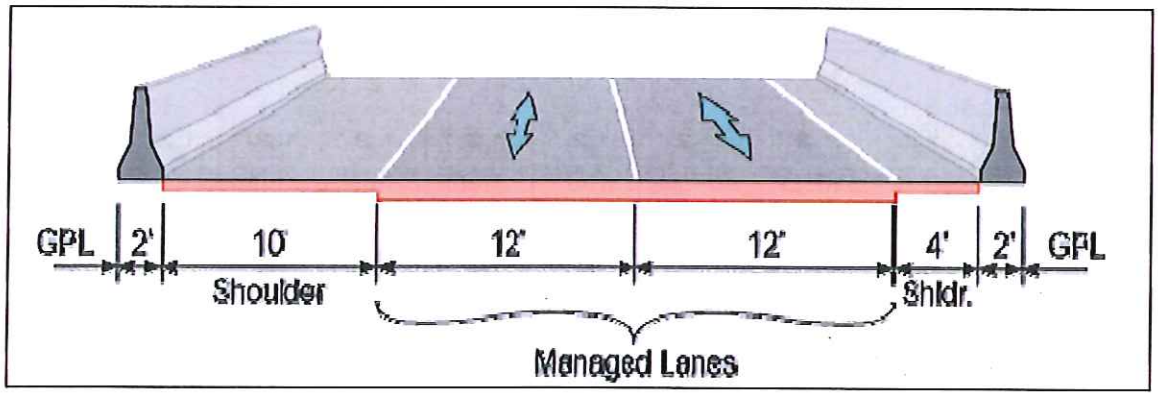
Cross Section Diagrams – Rigid Barriers



I-15, San Diego

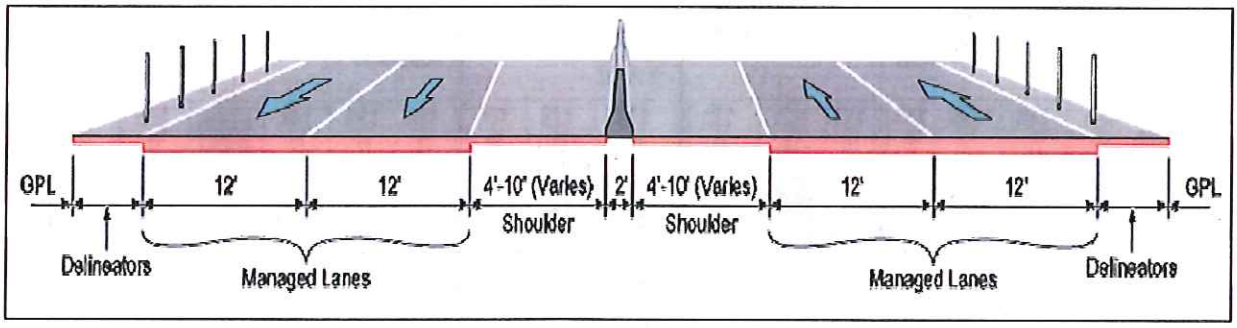


I-394 Reversible HOT Lanes, Minneapolis

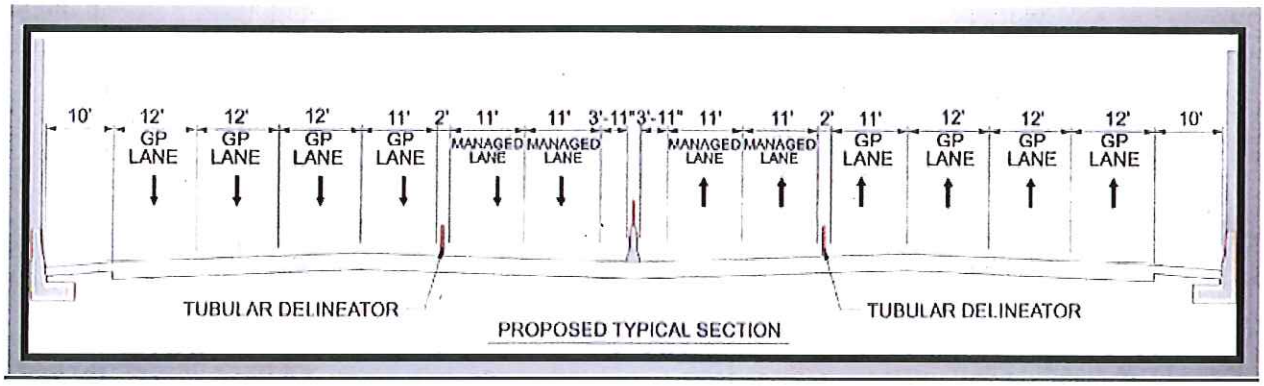


I-25, Denver

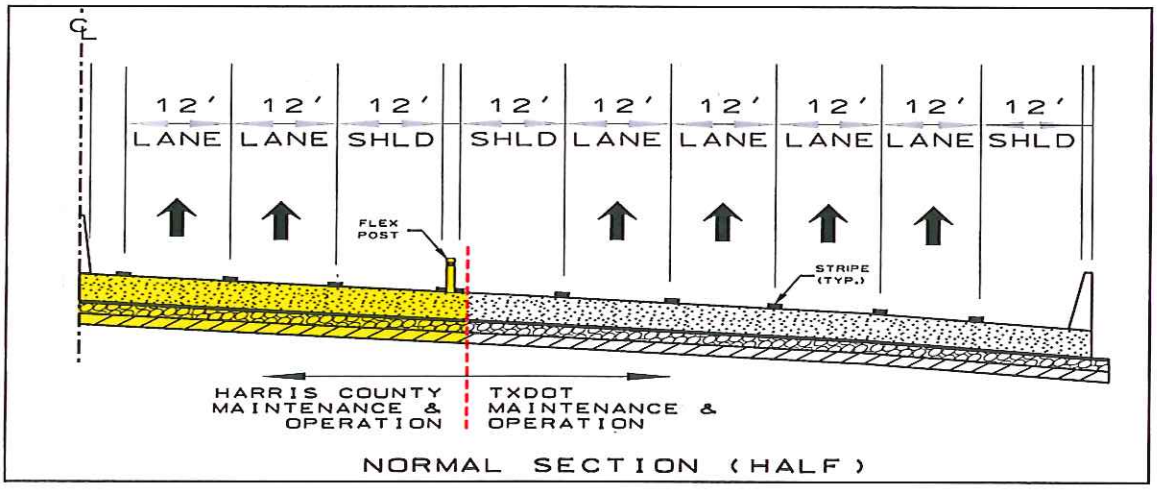
Cross Section Diagrams – Flexible/Tubular Delineators



SR 91, Orange County, CA.

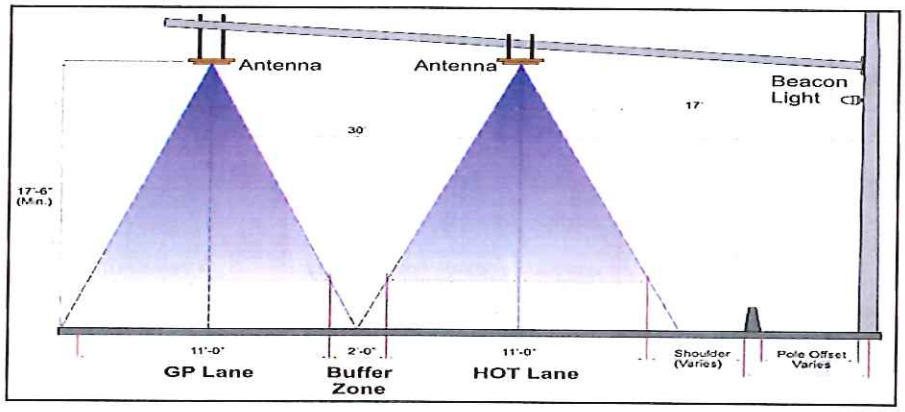


95 Express, South Florida

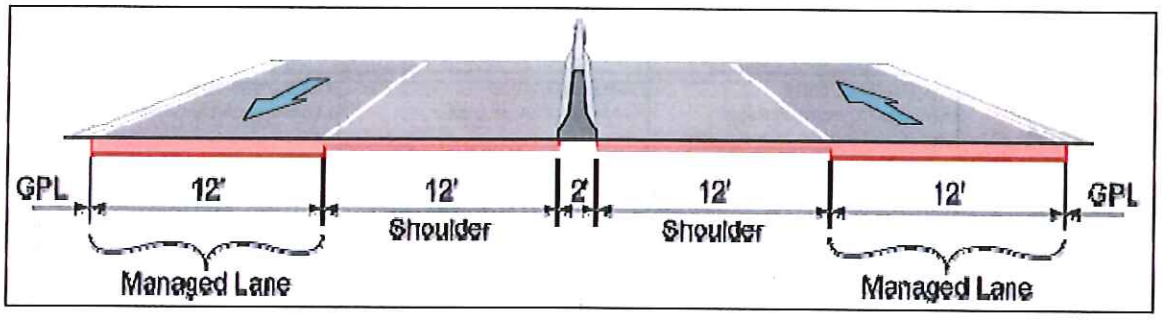


Katy Managed Lanes, Houston

Cross Section Diagrams – Pavement Markings

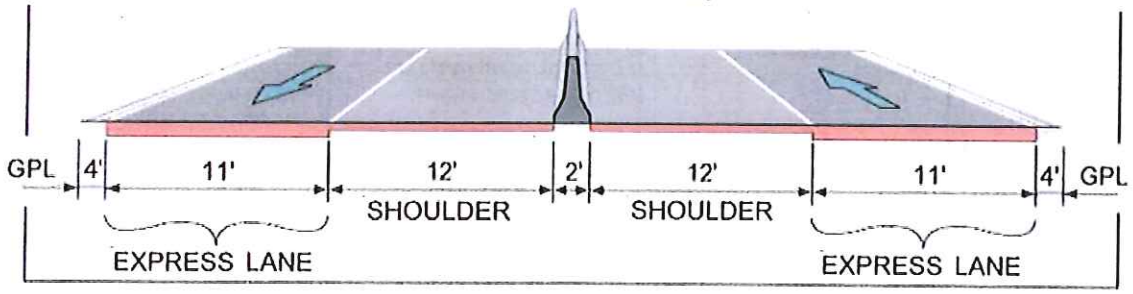


SR 167, Seattle



I-394 HOT Lanes, Minneapolis

I-35W HOT Lanes, Minneapolis



I-15 HOT Lanes, Salt Lake City

Comparison Table

Separation Type		Rigid Barriers	Delineators	Pavement Markings
Safety	Pros	• Reduces General Purpose Lane and Express Lane side swipes • Express Lane traffic is separated from incidents in General Purpose Lanes	• Easier access for emergency vehicles since delineators can be driven over	• Easy access for emergency vehicles since there is no physical separation • Easy for Express Lanes traffic to vacate the lanes in case of an emergency or incident in the lanes
	Cons	• Access to lanes is restricted, therefore Incident Management response may take longer • With an incident in the Express Lanes, the impact to Express Lane traffic is high because of lane blockage • More difficult to vacate lanes in case of an emergency or incident	• Impacts to delineators can create roadway debris • Vehicles in the General Purpose Lanes are not physically separated from Express Lanes if an incident does occur	• More opportunity for General Purpose Lane and Express Lane side swipes • Vehicles in the General Purpose lanes are not physically separated from Express Lanes if an incident does occur
Right-of-Way	Pros	*None*	• No right of way typically needed for installation	• No right of way typically needed for installation
	Cons	• Right of way typically needed for access points installation	*None*	*None*
Cost	Pros	• Low maintenance • Allows for overhead sign structure uprights to be placed within barrier, which reduces sign structure spans	• Easy installation • Low installation cost	• Easy installation • Low installation cost
	Cons	• Higher cost for installation than other methods	• High maintenance costs due to frequent replacement of delineators that are hit by vehicles • No location for overhead sign structure uprights within area separating General Purpose Lane & Express Lane, which results in longer sign structure spans	• No location for overhead sign structure uprights within area separating General Purpose Lane & Express Lane, which results in longer sign structure spans
Express Lane Roadway Features and Operational Characteristics	Pros	• Allows for higher operating speeds in Concurrent Flow operations • Reduces toll avoidance • Better enforcement areas due to limited access points	• Provides some physical separation which can help reduce toll avoidance • Reduces illegal lane changes	• Easy to operate in mixed mode during non-peak times
	Cons	• When installed within existing roadway cross sections, design constraints may be involved • Mixed mode operations in non-peak times are not applicable • Special openings or devices may be needed for emergency vehicles during incident responses	• Hard to operate in mixed mode during non-peak times • Easily traversed • Hard to establish enforcement areas • Operating speeds may be lower than posted because of limited physical separation • Frequent maintenance on delineator replacements	• Illegal lane changes are not deterred • Hard to enforce illegal maneuvers and other infractions because enforcement areas are hard to establish • Operating speeds within the Express Lanes are typically lower than posted during congested times because no physical separation is present
Access Points	Pros	• Access points are controlled by physical separation making them easier to enforce and limits violators	• Easy adjustment of access points after initial installation • Access points are controlled by visual/soft separation limiting violators	• Easy adjustment of access points after initial installation
	Cons	• Possible flyovers or extra ramps required for General Purpose Lane left exits	• General Purpose Lane traffic may have to merge with Express Lane traffic for left exits	• General Purpose Lane traffic may have to merge with Express Lane traffic for left exits

Lead Author:

Michael Davis, PE, DBIA
Atkins
482 South Keller Road
Orlando
FL 32810-6101
michael.davis@atkinsglobal.com
407-806-4401

Support:

Atkins Managed Lanes Team
John Doan, PE
Tom Knuckey, PE
Chris Bausher, PE
Jennifer Tsien, PE, PMP
Samantha Soules
Julie Dillard