Movable Concrete Barrier Approach to the Design and Operation of a Contraflow HOV Lane

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A 5-mi-long contraflow lane is being constructed on East R.L. Thornton Freeway (IH-30) in Dallas, Texas. This is a joint project of the Texas Highway Department and Dallas Area Rapid Transit. The lane will provide high-occupancy vehicles (HOV) a travel time savings of up to 10 min compared with traffic operating in the congested mainlanes. This priority treatment project is unique because it uses a movable concrete barrier system in the design and operation of the contraflow lane. The movable barrier system, which consists of a barrier transfer vehicle and a continuous concrete barrier, will provide greater safety by physically separating HOVs from the opposing traffic in the general-purpose lanes. Although contraflow lanes have traditionally been restricted to buses and authorized vanpools for safety reasons, this relatively new technology will permit carpools to safely use the lane as well. The decision to use the movable barrier system instead of pylons to designate the priority lane essentially doubled the capital and operating costs of the project; however, the carpool demand also doubled the number of passenger-hours of travel time saved. The greater safety, attraction of carpools, greater perception of utilization, and ability to move more people in the peak period made the barrier system an attractive demonstration project. This paper discusses design and operational issues associated with using the movable barrier system for a contraflow HOV lane. Elements requiring special attention were the access locations design, barrier end treatment, equipment storage and maintenance, set-up and take-down techniques, and enforcement procedures.

The Texas State Department of Highways and Public Transportation (SDHPT) and Dallas Area Rapid Transit (DART) identified four freeway corridors in the Dallas area to be evaluated for determining the short-term feasibility of implementing high-occupancy vehicle (HOV) lane projects.

The Texas Transportation Institute (TTI) researched the feasibility of HOV alternatives in these corridors. The most favorable project was determined to be a contraflow lane on East R.L. Thornton Freeway (IH-30) that used a movable concrete barrier to separate the HOV traffic from the opposing general-purpose traffic in the off-peak direction *(1)*.

The East R.L. Thornton Freeway contraflow lane is the first demonstration project on HOVs in Dallas undertaken by DART and SDHPT. This project will also demonstrate the use of a movable barrier system in an HOV application. The movable concrete barrier has not yet been used in a permanent application in the United States; however, there have been several construction projects that have used the movable barrier to separate construction zone activities from traffic, some requiring daily operation.

During the past year, TTI has been reviewing the detailed design of the contraflow lane, in developing the performance specification for the movable barrier system, and in developing the operations plan and operating manual for the contraflow lane. The purpose of this paper is to explain some of the design and operational issues that must be considered in designing an HOV facility that uses a movable barrier system. This paper also discusses advantages and disadvantages of a movable barrier system when applied in the design and operation of a contraflow lane.

DESCRIPTION OF IH-30 CORRIDOR

East R.L. Thornton Freeway is a major 8-lane radial freeway located on the east side of Dallas (Figure 1). The freeway primarily serves commuters destined for the central business district or employment centers to the north and west of the district. The presence of significant volumes of commuting traffic results in a high directional split during the peak periods. Approximately 70 percent of peak-hour traffic is traveling in the peak direction.

East R.L. Thornton Freeway experiences recurring congestion during both peak periods. In the morning, average vehicle speeds are less than 30 mph for more than 1 hr in a section that extends for 5 mi. In the evening, average vehicle speeds are less than 30 mph for more than an 1.5 hr in a section that extends for a little more than 3 mi.

There are geometric design features in this corridor that present constraints in designing short-term improvements. Near the downtown there is an elevated freeway section approximately 1 mi long, and the eastbound and westbound mainlanes are on two separate structures at different elevations. Also, there is a bridge structure over the White Rock Creek that has no inside shoulder for the half-mile length of the bridge.

ALTERNATIVE SELECTION

The Texas SDHPT has plans to build additional mixed-flow capacity in the IH-30 corridor by 1995. DART and SDHPT were interested in short-term improvements that would increase the capacity of the freeway for buses and carpools.

The possible alternatives for the HOV facility were identified as follows: *(a)* an exclusive HOV facility in the median;

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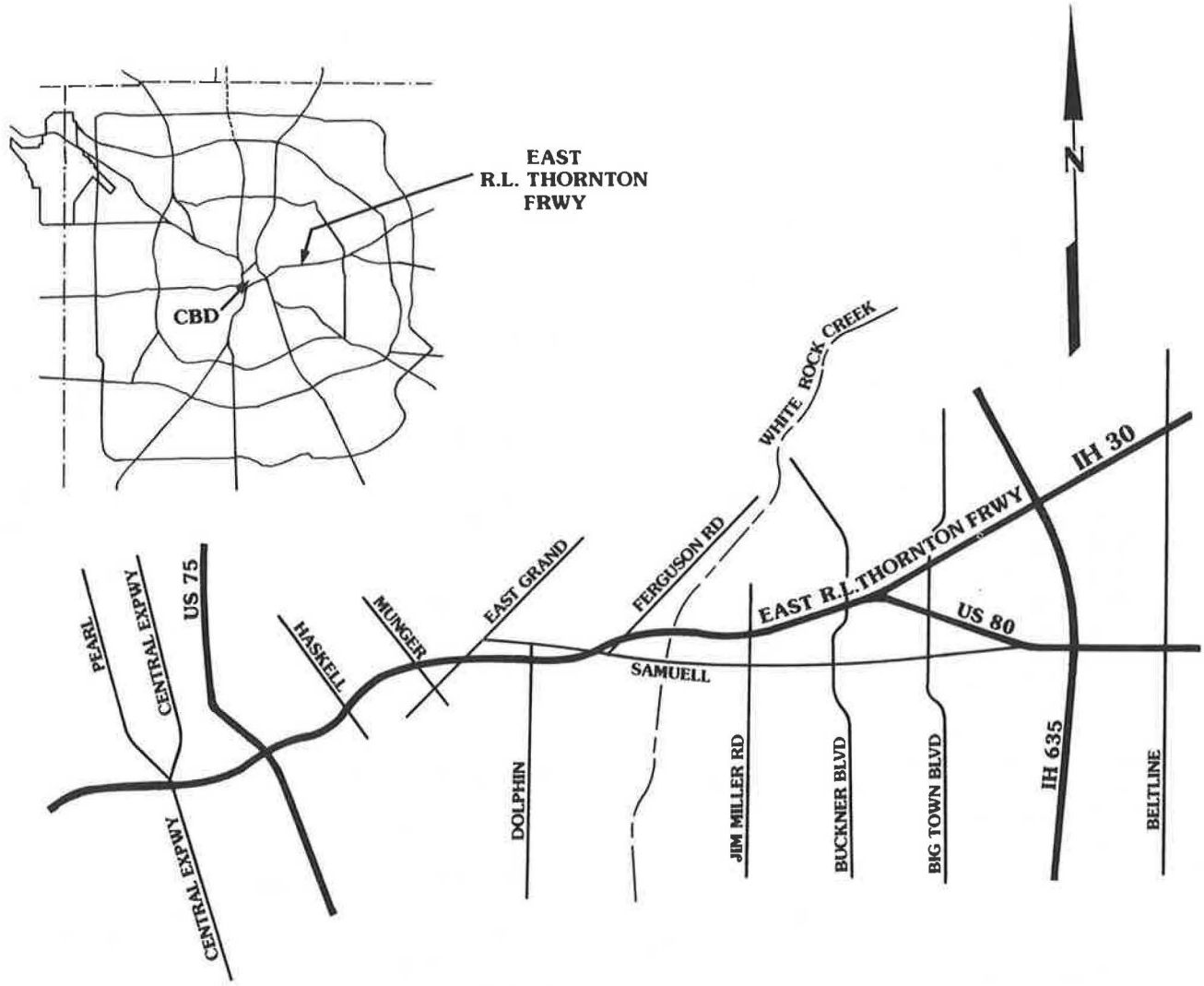


FIGURE 1 Study corridor.

(b) a concurrent-flow HOV facility on the inside shoulder; or *(c)* a contraflow HOV facility using a lane in the off-peak direction. The intent of the intermediate facility was to provide a cost-effective improvement that could be operating in 18 to 24 months.

The bridge structures at different elevations near downtown eliminate the short-term feasibility of an at-grade facility in the median. An elevated structure would be required over the bridge sections. These structures could not be designed and built in the 18- to 24-month time frame.

The inside shoulder is not continuous, thus making a concurrent flow lane infeasible. Two sections, near IH-45 and over White Rock Creek, essentially have no inside shoulder. A 10-ft inside shoulder exists for the remainder of the freeway corridor, but long sections of the shoulder have significant cross slopes that require extensive retaining walls. Even with considerable reconstruction and narrowing of the general-purpose lanes, a desirable buffer zone between the concurrent flow HOV facility and the congested general-purpose lanes does not exist. Furthermore, a concurrent flow lane without a shoulder does not allow adequate enforcement. Considering experience in other cities, many vehicles use an HOV lane illegally if enforcement is not visible, effective, and safe. High violation rates on the first HOV project in this area would be detrimental to future projects.

The contraflow HOV lane can be designed and operated on the inside freeway lane of the off-peak direction. This requires no additional construction over the bridge structures and only minimal construction at the access-egress points. The controlled-access points aid in enforcement by limiting the number of locations vehicles can enter the lane. Use of the inside lane of the off-peak direction also allows the contraflow lane to have a shoulder for incidents and enforcement.

A primary constraint with contraflow operation is the traffic volume in the off-peak direction. Operation of the contraflow lane can only continue as long as general-purpose lane traffic volumes in the off-peak direction are low enough to operate with one less lane available for general-purpose traffic. East

R.L. Thornton Freeway has relatively low traffic volumes in the off-peak direction. A more detailed discussion of the estimated life of the project is presented subsequently.

HIGH-OCCUPANCY VEHICLE DEMAND

Peak-period traffic counts were conducted to determine the existing bus volumes, carpool volumes, and occupancy rates. There are approximately 70 DART buses in the peak hour within the corridor, all having destinations in the downtown area. The peak-hour person volumes in buses are slightly over 2,500 persons. There are also approximately 800 total carpools in the peak hour on the freeway; 660 are two-occupant carpools and 130 are three-or-more occupant carpools (vanpools are included in the 3+ occupant carpools). These carpools carry an estimated 1,800 persons in the peak hour.

The bus volume in this corridor is one of the largest in the Dallas area. However, almost half of the potential HOV market is carpools. A project serving buses only would be missing a large population that could benefit from an HOV facility.

Future HOV demand was estimated from the North Central Texas Council of Governments' traffic assignment model *(2)*. By 1991, when any project could be operational, the expected bus volumes were projected to be 80 buses in the peak hour moving 2,800 persons and more than 1,300 carpools moving over 2,800 persons; 1,110 will be two-occupant carpools and 220 will be three-or-more occupant carpools. This would equate to a daily vehicle volume of almost 6,500 vehicles and a daily person volume of almost 24,000 persons. These demand projections represent total demand in the corridor and do not account for the actual volumes that could be served by an HOV facility based on access-egress locations and origin-destination patterns.

A selected link analysis was performed at various locations in the corridor to determine the destinations of the trips on IH-30. Three locations (at 4 mi, 6 mi, and 11 mi from the downtown) were analyzed. The data indicate a significant number of long distance trips in this corridor. Between 32 and 36 percent of trips at each of the selected link locations were destined for locations beyond (to the west and north of) the downtown. It was also determined that 34 percent of the trips were destined for the downtown. The remaining 30 percent were destined for areas spread out within the corridor and south of the downtown and would not be well served by the final design of the contraflow HOV facility. It is very important for a successful project that markets destined both for downtown and for locations beyond downtown be served by the HOV facility to capture enough ridership to justify the cost of the project.

BENEFITS AND COSTS

The benefits evaluated in this study were limited to: *(a)* the travel time saved by passengers able to travel in the contraflow lane at 55 mph as compared with the existing congestion and *(b)* lower operating costs of buses operating under free-flow conditions. The value of time used was $9 per person hour for 250 operating days per year *(3)*. If only buses were allowed to use the contraflow lane, the benefits were estimated to be $1.9 million per year. If carpools were added, then the total benefits for users increased to $3.6 million per year. There are other benefits realized from this type of project; however, not all are easily quantified.

The cost of building a contraflow lane with pylon separation (no movable barrier) included construction at the access points, restriping the freeway, signing, support vehicles to place pylons, and operating costs. The annualized cost was estimated to be $1.3 million per year (capital costs were amortized over the four year life of the project and added to the annual operating costs). This resulted in a benefit-cost ratio of 1.5. This pylon-separated contraflow lane would be limited to buses and vanpools only for safety reasons.

However, if a movable barrier system were to be implemented, carpools could also operate in the contraflow lane. The addition of the movable barrier and the barrier transfer vehicles increases the annualized cost of the contraflow lane to $1.9 million per year. (It was assumed that the barrier system will have a residual value equal to 30 percent of the initial cost after 4 years of operation.) Including 2+ occupant carpools in the benefit estimation and the cost of the movable barrier system, the benefit-cost ratio of the barrier-separated project was calculated to be 1.9.

Both projects were relatively equal in cost-effectiveness. The ability to offer a time savings to carpoolers, move more people in the peak period, enhance the perception of utilization, and test a new technology all led to the decision to use the movable barrier system contraflow lane.

MOVABLE CONCRETE BARRIER SYSTEM

The movable concrete barrier system consists of a barrier transfer vehicle and a movable concrete barrier. The main advantage of the movable concrete barrier is the ability to provide a solid, physical separation between opposing flows of vehicles. A graphical representation of how the movable barrier system operates is shown in Figure 2.

The movable barrier system being used on East R.L. Thornton Freeway is the Quickchange Movable Concrete Barrier System developed by Quick-Steel Engineering Pty, Ltd., of Botany, New South Wales, Australia. Barrier Systems Incorporated (BSI) of Sausalito, California, is the North American licensee for the system.

Movable Concrete Barrier

The movable concrete barrier consists of pinned, hinged sections of concrete safety-shaped barrier 1 m long. The sections are 2-ft wide at the base and 32-in. high. The continuous sections of movable barrier can be transferred laterally across a lane or lanes of traffic by the barrier transfer vehicle.

The movable barrier manufactured by BSI was crash tested in a federally funded research project initiated by Caltrans. Caltrans conducted the crash test, collected and analyzed data, and reported the findings *(4)*. The movable concrete barrier demonstrated its ability to retain and redirect a vehicle under a variety of impact conditions. Vehicle redirection was smooth in all tests. There was no tendency for the barrier to pocket or trap the impacting vehicles. In these tests there was no evidence of structural distress of the barrier segments.

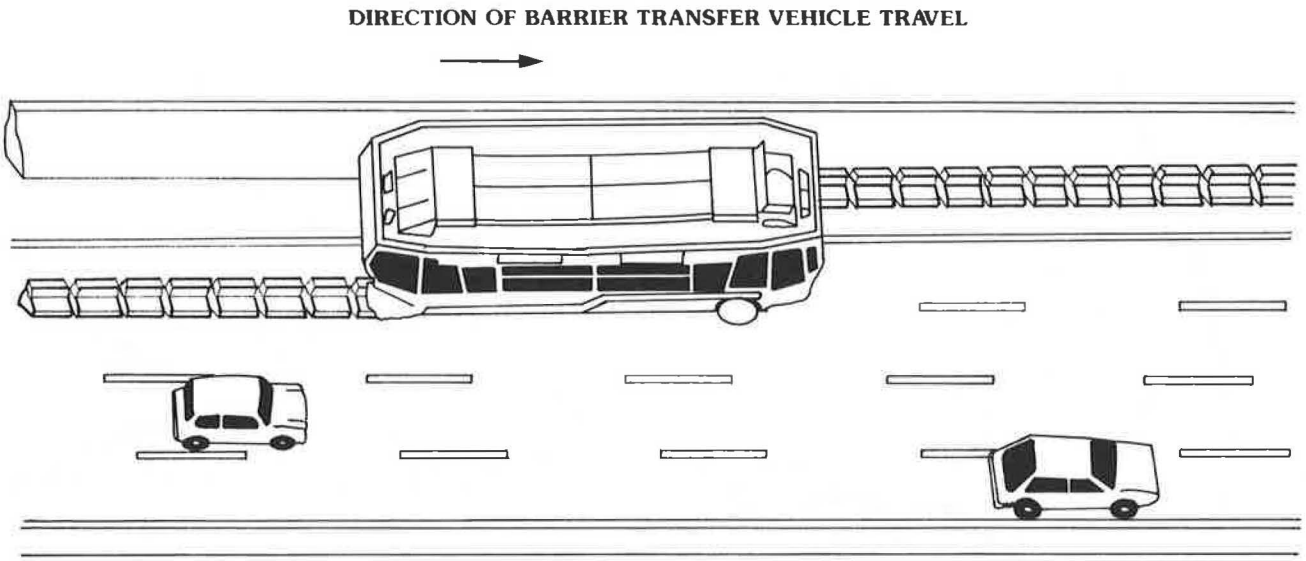


FIGURE 2 Movable concrete barrier system.

Barrier Transfer Vehicle

The barrier transfer vehicle is self-propelled with an S-shaped conveyor assembly mounted to the underside. Closely spaced urethane conveyor wheels roll under the flanges of the T-shaped cap of the movable barrier. The wheels lift the sections off the pavement, guide them along the S-shaped conveyor to the desired position, and lower the sections back down to the pavement. As the barrier transfer vehicle moves forward, the barrier is transferred from the median to the lane stripe between the first and second lanes, minimizing the exposure of the barrier transfer vehicle to traffic.

Other Applications of the Movable Barrier System

One of the first projects that used the movable barrier system for daily operation was in Paris, France. A 5-lane bridge was configured for 3 lanes inbound and 2 lanes outbound in the morning, 3 lanes outbound and 2 lanes inbound in the evening, and 2 lanes in both directions in the off-peak periods. This project has been successful. Recent construction project in Washington, D.C., and Canada use the movable barrier system everyday to maintain capacity in the peak hours and additional construction area during the off-peak hours.

At the time this paper was being prepared, there were other projects in the United States being designed that will use the movable barrier system on an everyday basis for a more permanent application, but this project should be the first to be implemented in this country.

OVERVIEW OF CONTRAFLOW LANE PROJECT

The East R.L. Thornton Freeway contraflow lane is designed to allow priority vehicles to bypass traffic congestion through the use of a barrier-separated contraflow lane. This lane is constructed on the inside freeway lane in the off-peak direction by using the movable barrier. The limits of the project conform to the traffic congestion patterns of the corridor as well as locations of safe, efficient, and enforceable access points. The contraflow lane will be constructed in the median and on the inside freeway lane between downtown and Jim Miller Road. The morning operation extends westbound from Jim Miller Road to the Pearl-Central Expressway interchange, and the evening operation extends in the eastbound direction from the Pearl-Central Expressway interchange to Dolphin Road (Figure 3).

The contraflow lane is designed to have a movable barrier on each side of the fixed-median barrier. In the morning, the barrier on the eastbound lanes is moved into position by the downtown barrier transfer vehicle that moves east out to Jim Miller Road, reducing the off-peak direction (eastbound) to three general-purpose lanes (two lanes between Pearl-Central Expressway and IH-45). The inside lane and shoulder are separated to form the contraflow lane for commuters destined for downtown and beyond. In the evening, the process is reversed to create a barrier-separated contraflow lane on the westbound general-purpose lanes for eastbound commuters leaving downtown. A second barrier transfer vehicle, stored in the Dolphin Road median, moves west to the Pearl-Central Expressway interchange, moving the barrier along the westbound lanes, reducing the westbound general-purpose lanes to three lanes (two lanes between Pearl-Central Expressway and IH-45).

Jim Miller Road Access Point: A.M. Operation

Jim Miller Road serves as an entrance to the contraflow lane in the morning peak period (Figure 4). Contraflow lane vehicles traveling westbound into downtown may enter the contraflow lane west of Jim Miller Road. The movable barrier separates the off-peak (eastbound) general-purpose lanes from the contraflow lane.

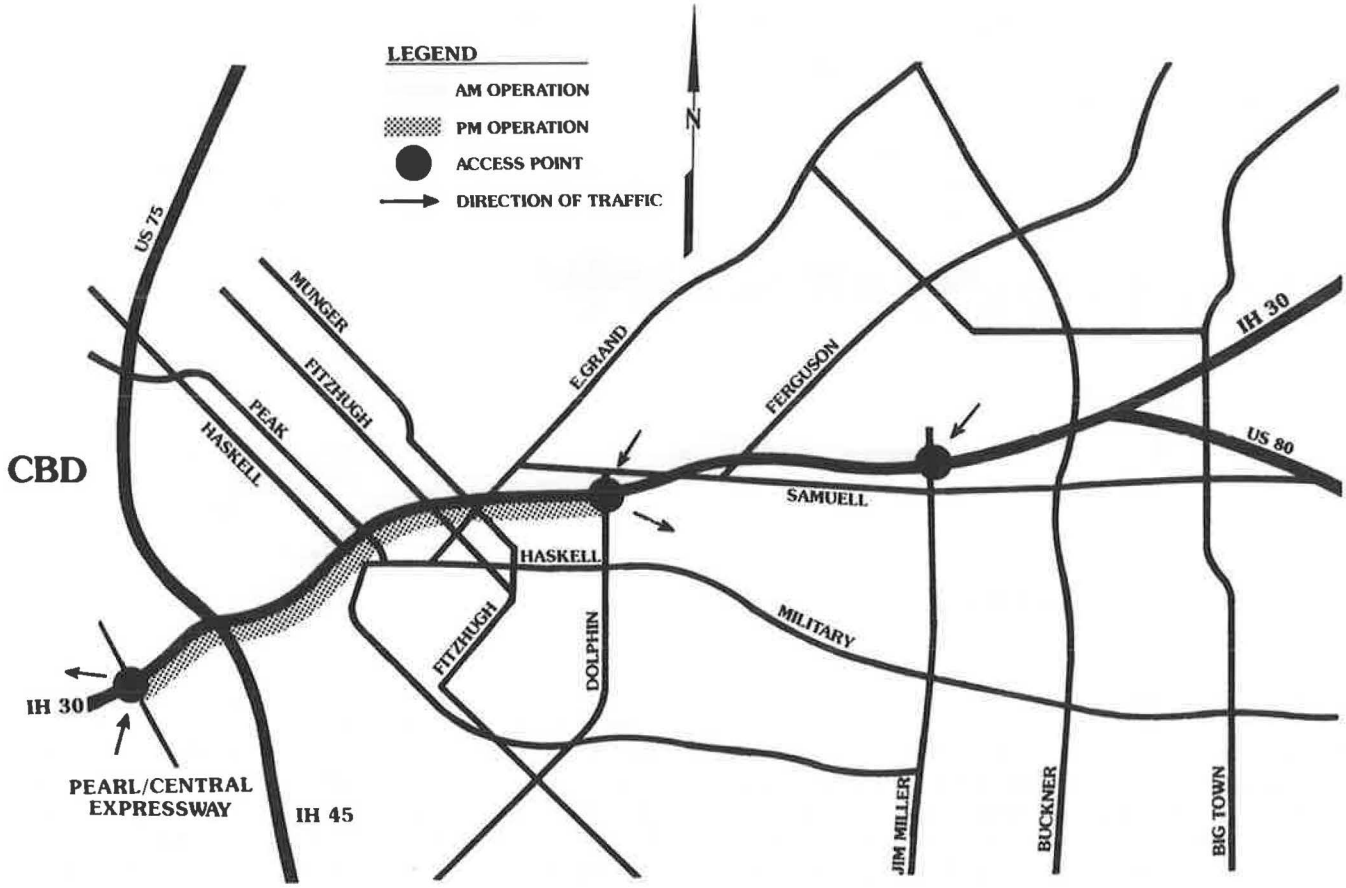


FIGURE 3 Limits of contraflow lane and access point operation.

A short section of concurrent flow lane precedes the entrance, allowing contraflow lane vehicles to bypass any congestion that may extend to Jim Miller Road and also allowing the enforcement officer to monitor vehicles entering the lane.

The HOV lane makes a transition from the concurrent flow lane on the inside shoulder of the westbound lanes across the median and onto the inside lane of the eastbound lanes. The contraflow lane is 14-ft wide through the entrance, and pavement markings delineate the path through the median. The end of the fixed barrier is protected with a crash attenuator. The remainder of the contraflow lane is 12-ft wide with a 10-ft shoulder. The general-purpose lanes are reduced to 11-ft except for the lane adjacent to the movable barrier, which is 12-ft wide with the barrier in place. This is consistent over the length of the contraflow lane in both the westbound and eastbound directions.

When the contraflow lane is not in operation, the Jim Miller Road entrance is closed by the movable barrier (Figure 5). The movable barrier is positioned against the fixed barrier on the inside shoulder of the eastbound lanes. The short section of concurrent flow lane is closed through the use of pylons and signing. When the contraflow lane is not in use in either peak period, the outside two general-purpose lanes are 11-ft wide and the inside two lanes are 13-ft wide for both the westbound and eastbound directions.

Dolphin Road Access Point: A.M. Operation

The next access point in the morning peak period is located just west of Dolphin Road (Figure 6). Vehicles are guided through the crossover with the use of pylons and dashed white edge lines. An acceleration lane is provided on the inside shoulder of the eastbound mainlanes to allow entering contraflow lane vehicles to merge safely with the contraflow vehicles on the lane from Jim Miller Road. To protect wrong-way maneuvers in the morning, the leg of the crossover used by vehicles in the P.M. operation is closed off on one side by the P.M. movable barrier and by a gate on the other side. The P.M. barrier is stored on the inside shoulder of the westbound lanes and the end is protected by a crash attenuator.

Pearl-Central Expressway Access Point: A.M. Operation

The downtown egress point is located just east of the ramps to Pearl-Central Expressway. In the morning, the downtown is the only egress point (Figure 7). The left-handed exit to Pearl-Central Expressway from the westbound general-purpose lanes is limited to only HOV traffic from the contraflow lane. Contraflow lane vehicles destined for downtown exit to Pearl-Central Expressway. The remaining HOV traffic

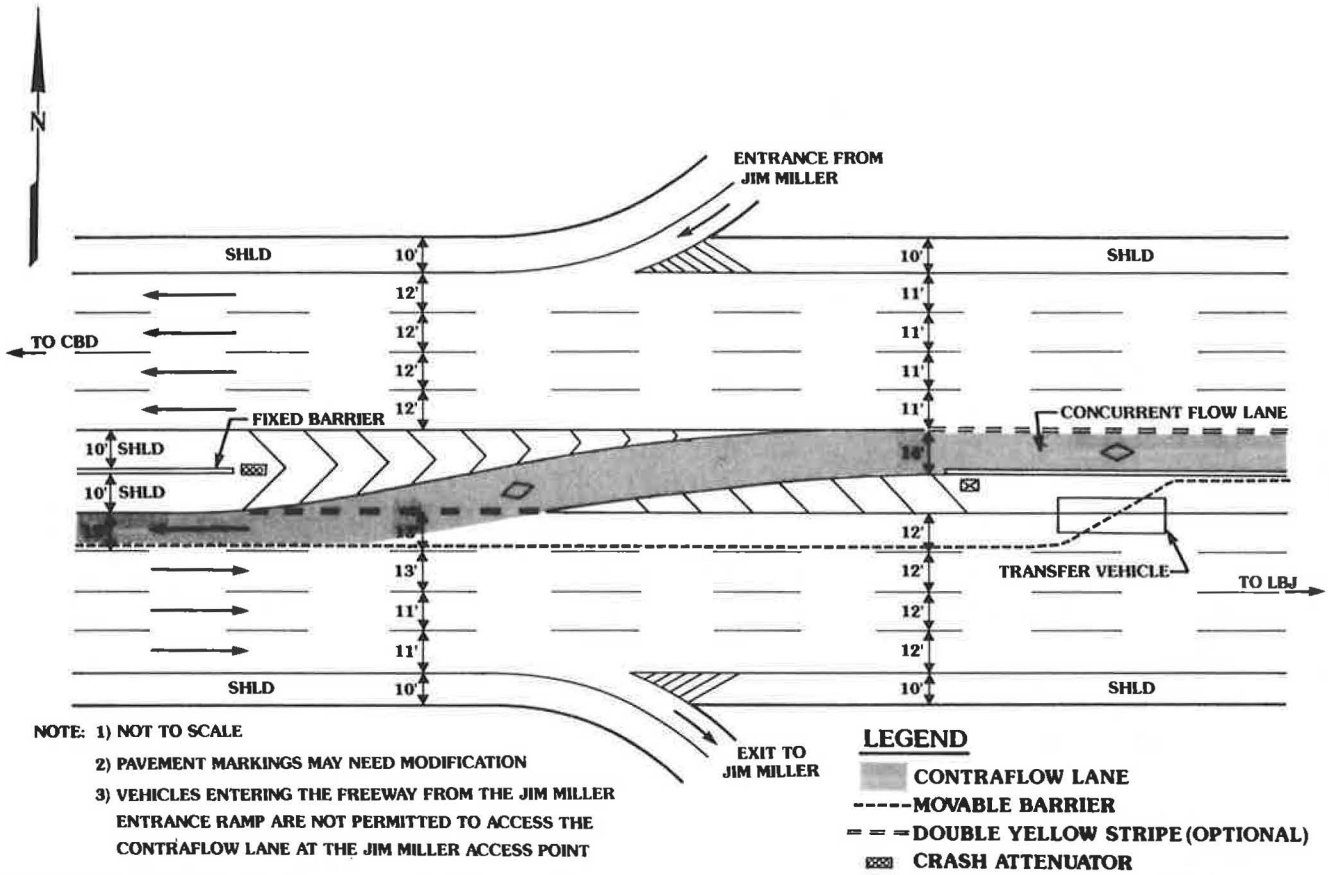


FIGURE 4 Jim Miller Road access point, A.M. operation.

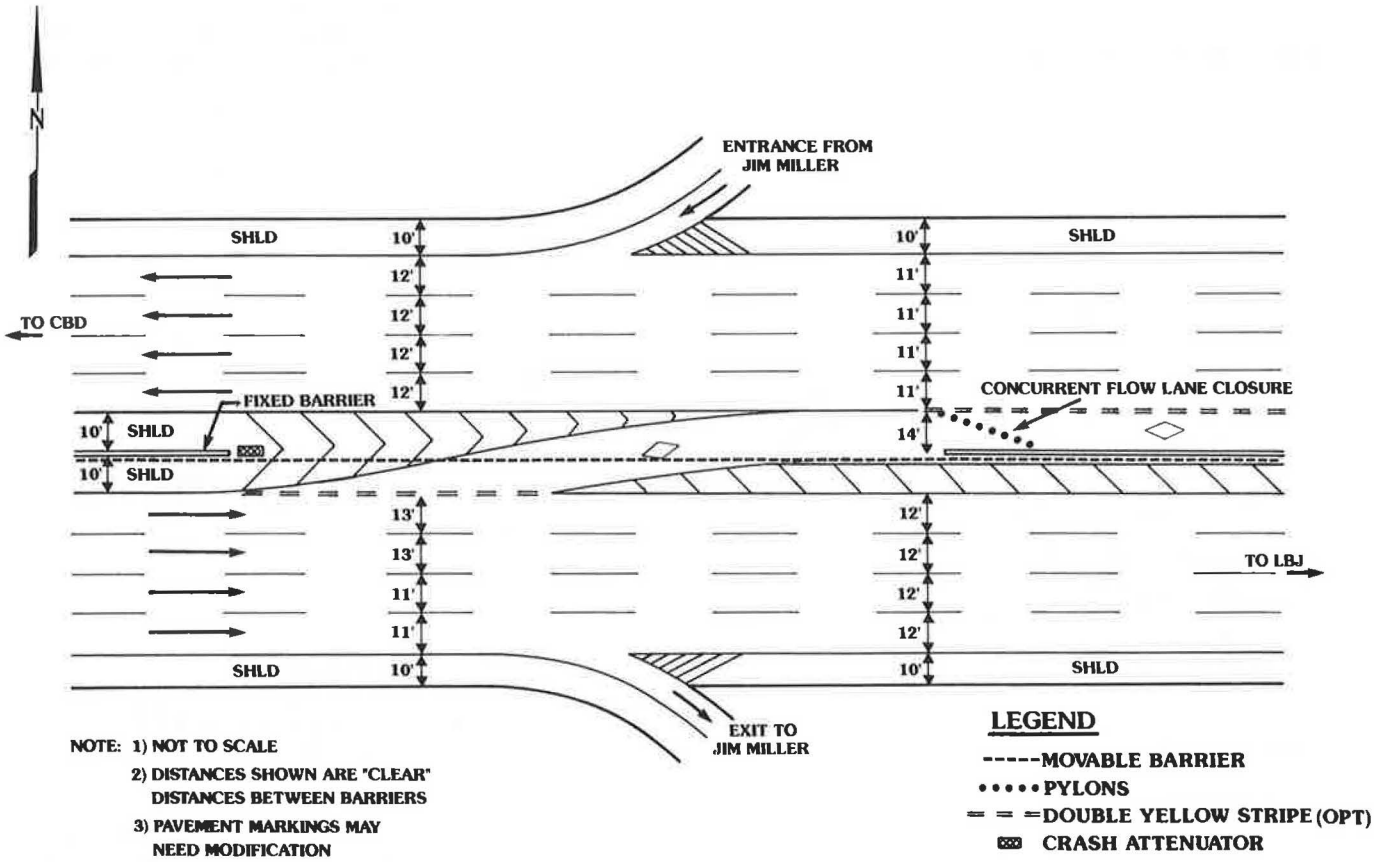
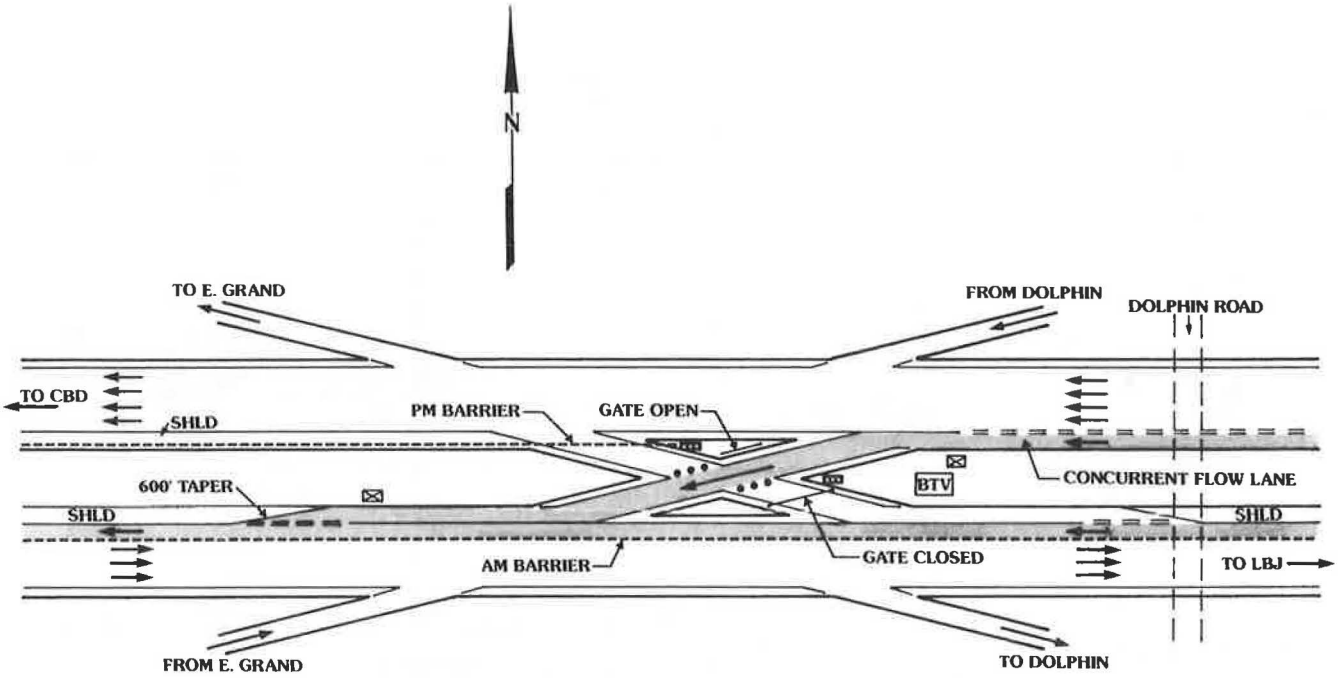


FIGURE 5 Jim Miller Road access point, non-operation.



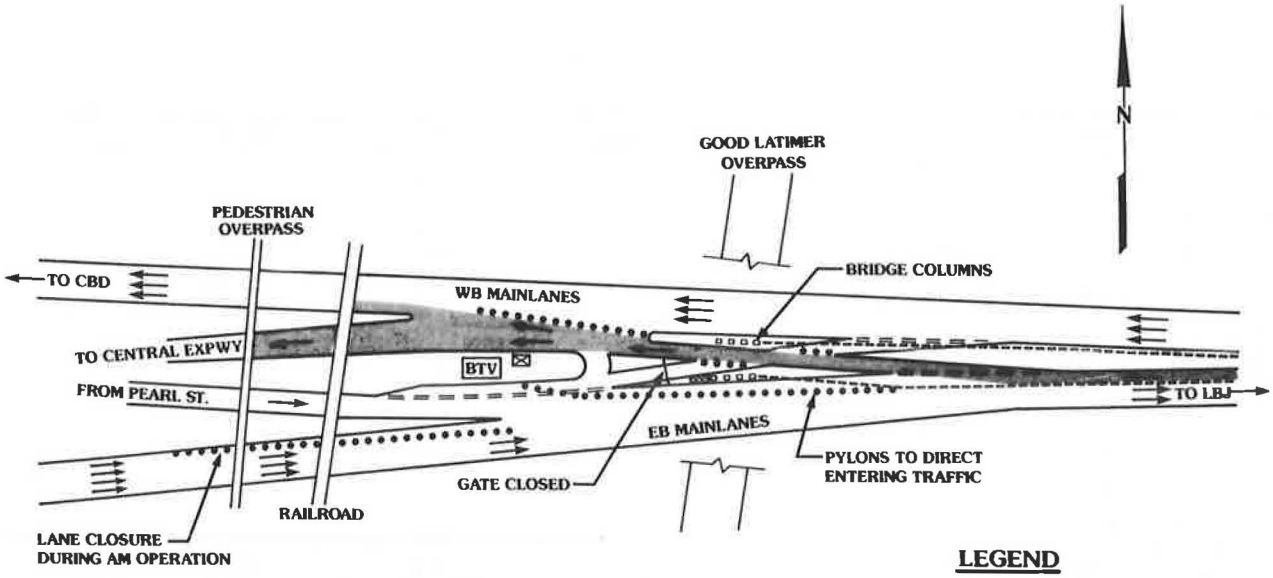
NOTE: 1)NOT TO SCALE

2)VEHICLES ENTERING THE FREEWAY FROM THE DOLPHIN ENTRANCE RAMP ARE NOT PERMITTED TO ACCESS THE CONTRAFLOW LANE

LEGEND

- CONTRAFLOW LANE
- ---- MOVABLE BARRIER
- • • • • PYLONS
- ⊠ ENFORCEMENT LOCATION
- CRASH ATTENUATOR
- = = = DOUBLE YELLOW STRIPE (OPT)
- BTV TRANSFER VEHICLE STORAGE

FIGURE 6 Dolphin Road access point, A.M. operation.



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- BTV TRANSFER VEHICLE STORAGE

FIGURE 7 Downtown terminus point, A.M. operation.

destined for locations beyond the downtown are allowed to reenter the freeway. Traffic analysis indicates the Pearl-Central Expressway exit ramp can be closed to freeway traffic in the morning peak period. This is a low-volume ramp, and general-purpose traffic currently using Pearl-Central Expressway can use the next left-handed exit ramp 1,000 ft downstream.

The eastbound general-purpose lanes in this section of the freeway are reduced from three lanes to two lanes in the morning to allow for the contraflow lane. With use of pylons and signing, the inside freeway lane is closed before the movable barrier. Also, pylons are provided to direct entering traffic from Pearl-Central Expressway in the eastbound direction to merge with the two lanes on IH-30.

The downtown crossover is closed during the off-peak periods (Figure 8). The entrance from the Pearl-Central Expressway entrance ramp is closed with use of pylons and a gate. The barrier transfer vehicle is stored in a building located west of the crossover.

Pearl-Central Expressway Access Point: P.M. Operation

In the evening, the downtown access point is the only entrance to the contraflow lane (Figure 9). The Pearl-Central Expressway entrance ramp is restricted to only HOV traffic destined for the contraflow lane. General-purpose traffic destined for IH-30 is diverted to the upstream entrance ramp. Contraflow lane vehicles from beyond the downtown are provided access to the contraflow lane from the inside lane of IH-30.

Vehicles using the contraflow lane in the evening are guided through the crossover by pylons and dashed white edge lines. The ends of both movable barriers are located behind fixed barriers to protect the contraflow lane users in the P.M. operation, and a crash attenuator is provided at the bridge columns.

Dolphin Road Access Point: P.M. Operation

In the evening, the Dolphin Road access point operates as the exit for the contraflow lane (Figure 10). The contraflow lane operates on the inside lane of the westbound general-purpose lanes and contains the 10-ft inside shoulder.

To allow egress back to the general-purpose lanes, there must be a "break" in the A.M. movable barrier. The movable barrier is being manufactured with a hinged connection to allow the barrier to be separated and moved to create the egress location for the evening operation. The end of the A.M. barrier is protected behind a crash attenuator. The contraflow lane vehicles are guided through the crossover by pylons and dashed white edge lines. There is an acceleration lane on the inside shoulder of the eastbound general-purpose lanes to allow proper merging between the contraflow vehicles and the mixed-flow vehicles.

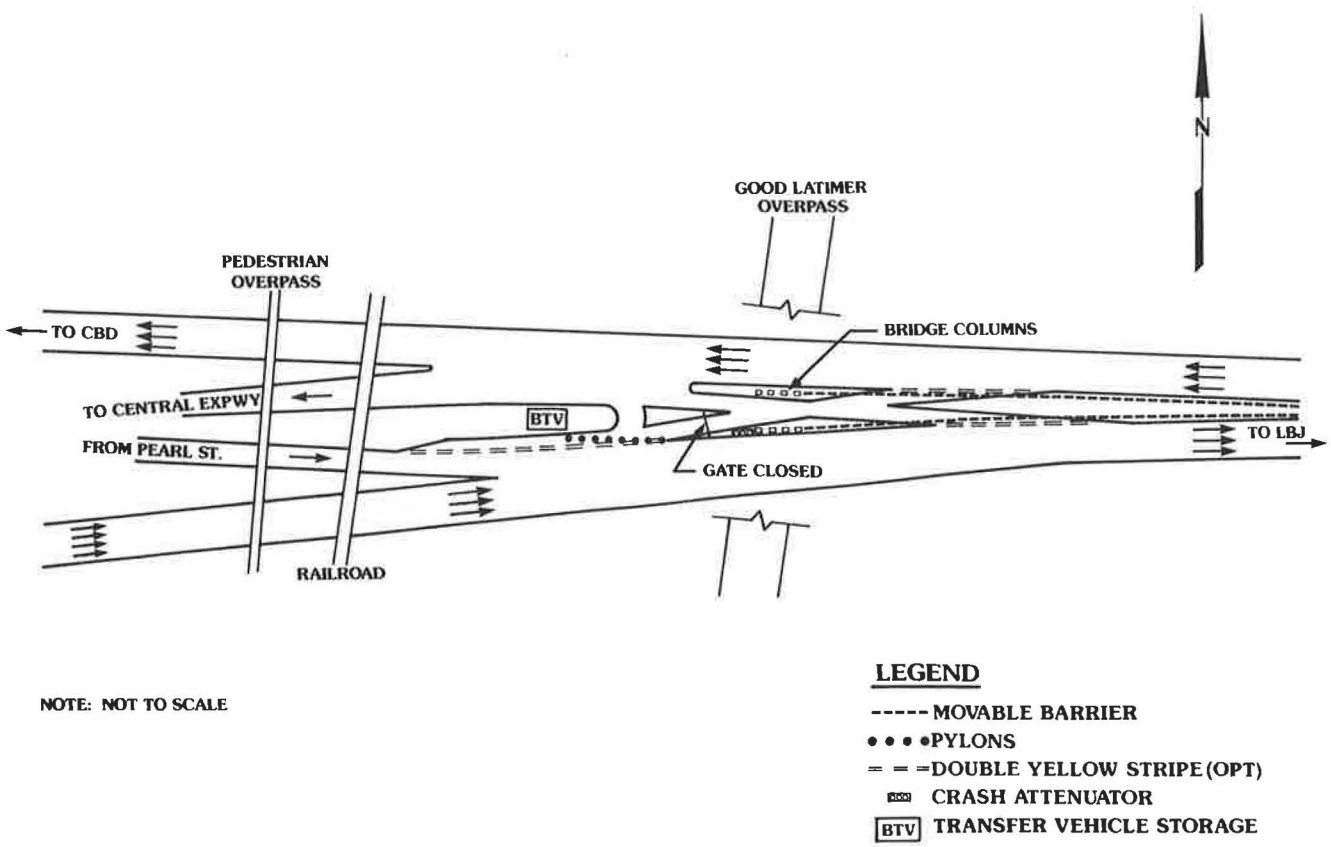


FIGURE 8 Downtown terminus point, non-operation.

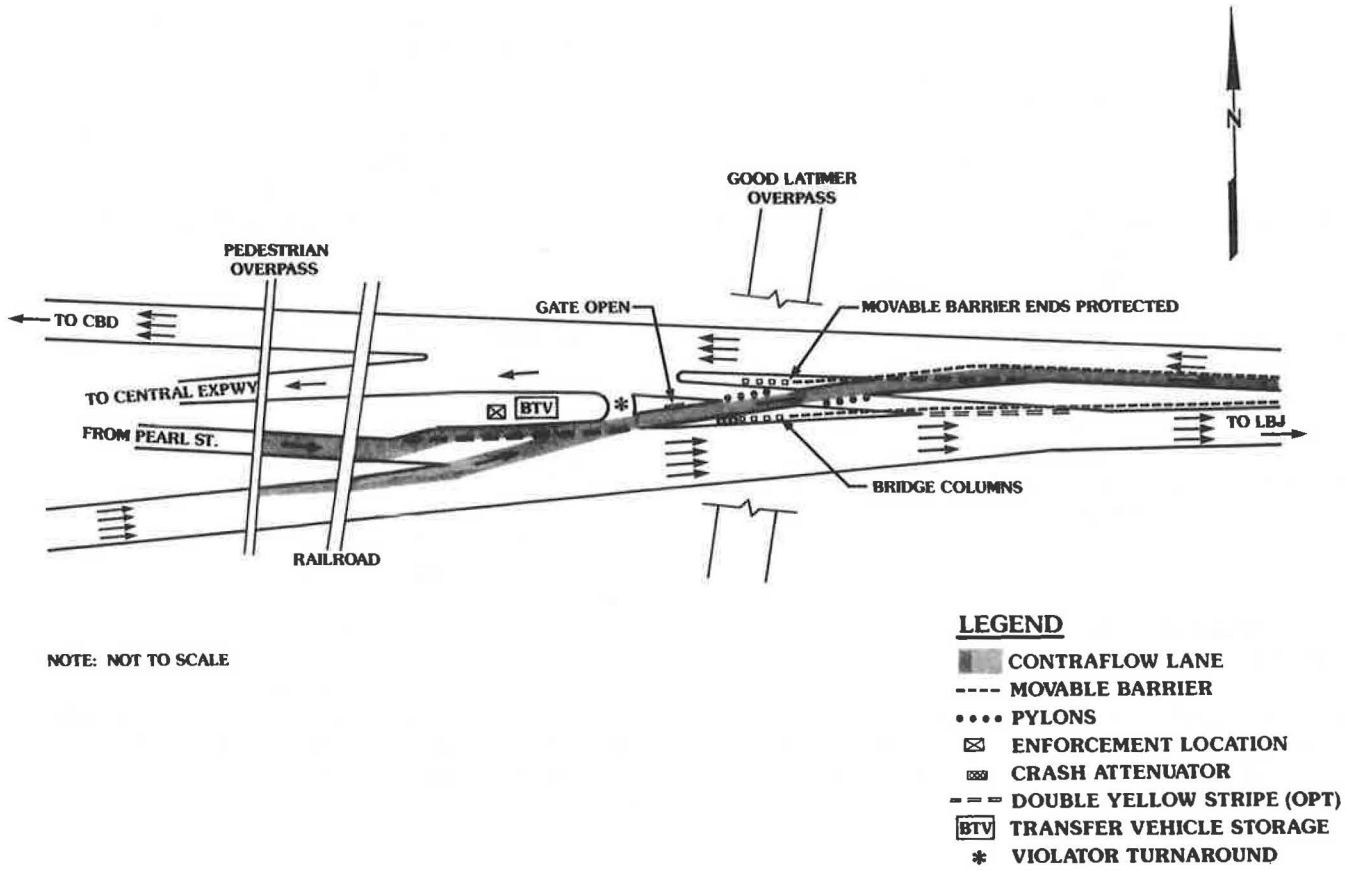


FIGURE 9 Downtown terminus point, P.M. operation.

In advance of the contraflow lane operation, the inside lane of the *westbound* general-purpose lanes must be closed to allow for the contraflow lane; this is accomplished with pylons. There is a closed gate at the morning contraflow lane entrance to prevent general-purpose vehicles traveling in the westbound direction from entering the crossover from the wrong direction.

The crossover is closed off to *all* traffic during off-peak periods (Figure 11). The movable barrier closes off three of the four legs of the crossover and there is a gate closing off the last leg. The concurrent flow lane preceding the contraflow lane entrance in the westbound direction is also closed with pylons. The barrier transfer vehicle used for the evening operation is stored in a building located near the Dolphin Road overpass.

DESIGN ISSUES

Once the project was approved for construction, a detailed design of the contraflow lane was initiated. Many design elements were identified at the conceptual stage as needing a more detailed investigation once the project was funded. The following discussion highlights these issues.

Cross Section

The typical existing cross section is shown in Figure 12. Generally, the 8-lane freeway has 10-ft inside and outside shoulders with 12-ft mainlanes. The proposed cross section is also shown in Figure 12.

During off-peak periods when the movable barrier system is not in operation, the movable barrier is on the inside shoulder. This reduces the inside shoulder by 2 ft and results in 8-ft inside shoulders during the off-peak periods.

In order to accommodate the 2-ft-wide movable barrier between the inside lanes during operation, the freeway needs to be restriped as shown in Figure 12. The 2 outside lanes are 11-ft wide and when the barrier is in operation the two inside lanes on either side of the movable barrier are 12-ft wide. When the barrier is not in operation the two inside lanes are 13-ft wide.

Vertical and Lateral Transfers of the Barrier

The movable barrier system must transfer the movable barrier across the inside shoulder and inside freeway lane. In the East R.L. Thornton Freeway corridor, the inside shoulder has variable width, a different slope than the mainlanes, and in some areas a curb. To accomplish this move the barrier transfer vehicle must be designed to lift the movable barrier 22 in. to clear the crown of the curb and must also be able to laterally move the movable barrier between 15 and 22 ft.

The barrier transfer vehicle is specially designed in order to meet these requirements. The cost to manufacture a machine that can accomplish these requirements was greater than originally estimated. The vehicle has hydraulic drive and

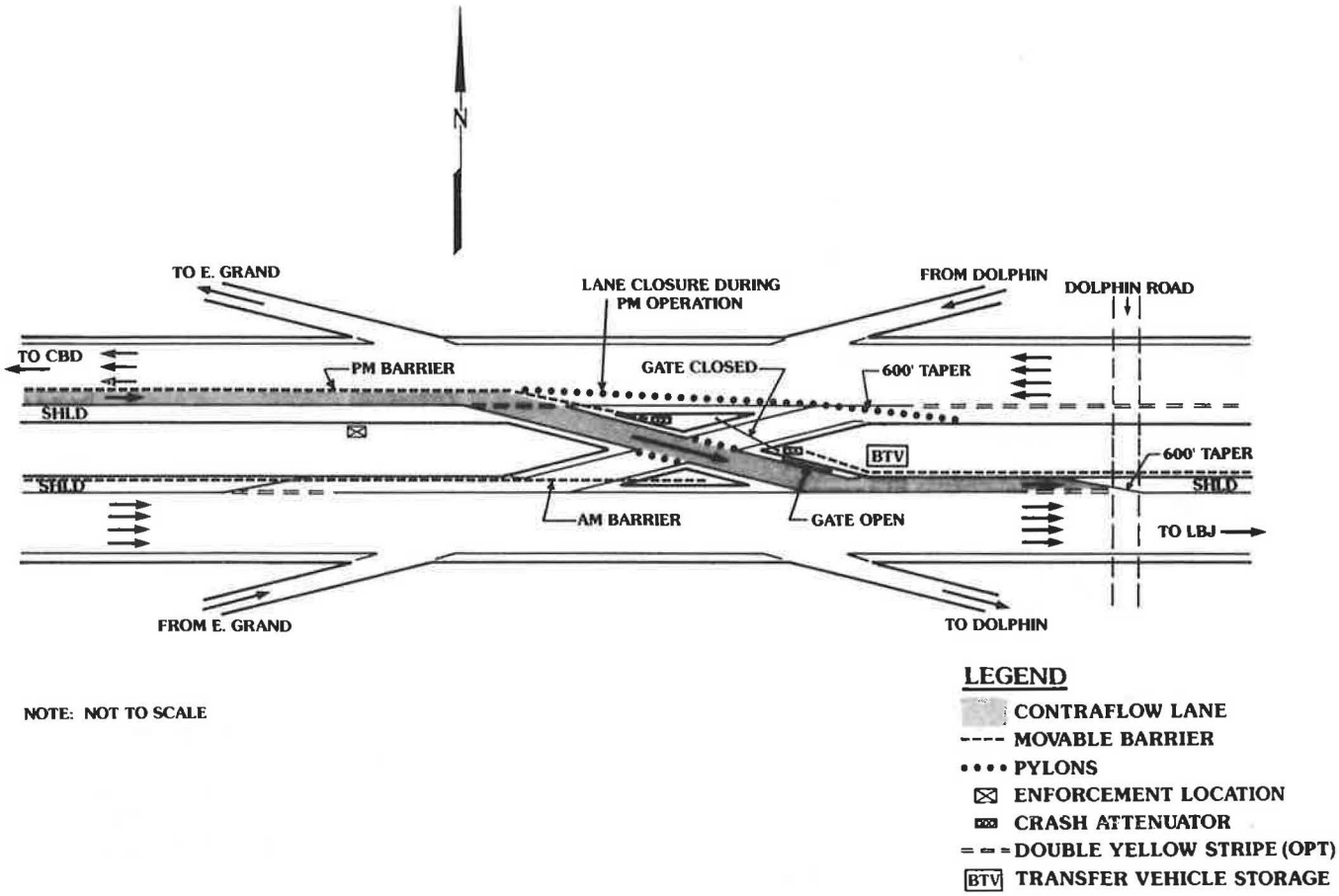


FIGURE 10 Dolphin Road access point, P.M. operation.

steering, and each wheel can be independently raised and lowered. This enables the vehicle to accomplish variable vertical lifts. In some areas, the inside shoulder will be leveled to reduce the difference in elevation.

The barrier transfer vehicle executes the variable lateral transfers with its ability to "crab." The movable barrier and barrier transfer vehicle are shown in Figure 13. The vehicle can rotate about its axis and increase or decrease the width of the machine, which in turn changes the lateral transfer of the movable barrier.

These special design features increase the cost of the barrier transfer vehicle from the initial estimate of $300,000 to the final cost of $450,000. Providing for substantial vertical and lateral transfers can decrease the operating speed of the vehicle and put additional strain on the vehicles that have to perform the operation four times per day for the life of the project.

Barrier End Treatments

The movable barrier system increases safety to motorists by physically separating the opposing traffic flows. However, at the limits of the project and at intermediate access points, the ends of the barrier must be protected so as not to introduce a blunt end that may be struck by vehicles. This problem has been noted by other agencies using the barrier system in construction zones.

The treatment for protecting the ends of the barriers varies depending on the application. This project will be in operation for many years; and, therefore, a more permanent treatment using a combination of fixed guardrail and crash attenuators is being installed at the access points to protect the ends of the barriers. The barrier transfer vehicle can place the movable barrier within a few inches of any permanent crash attenuator, and then the barrier can be located behind the positive protection mechanically or manually. Currently, BSI is designing a mechanical device that will pull the barrier behind the crash attenuator or push it into place for transfer by the barrier transfer vehicle. BSI has also demonstrated that the movable barrier can be manually moved short distances by one person with a crow bar *(4)*.

Barrier Transfer Vehicle Storage

Storage of the barrier transfer vehicle is an important design element that also influences the overall operation of the contraflow lane. In this corridor there are sections with wide medians that create the opportunity to construct storage facilities, which is convenient since the movable barrier operation is concentrated in the median. If the machines had to cross four lanes of traffic from the median to any storage facility located on the outside of the freeway, freeway operations would be disrupted. However, retaining walls are needed to provide level areas for the storage building in the median.

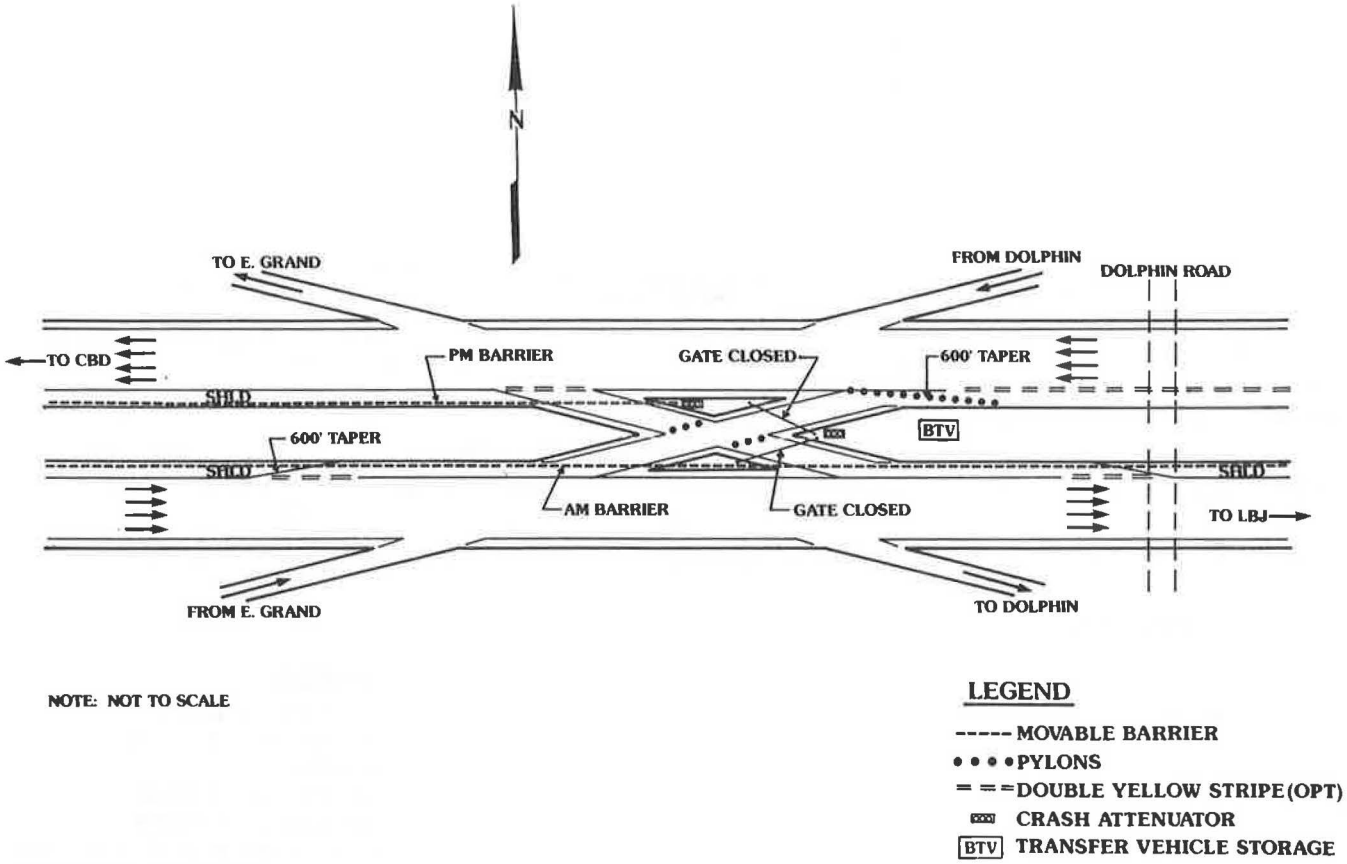


FIGURE 11 Dolphin Road access point, non-operation.

Additionally, plans to pave all sections in the median where the transfer vehicle must operate are recommended to improve operation for a project that operates daily over several years.

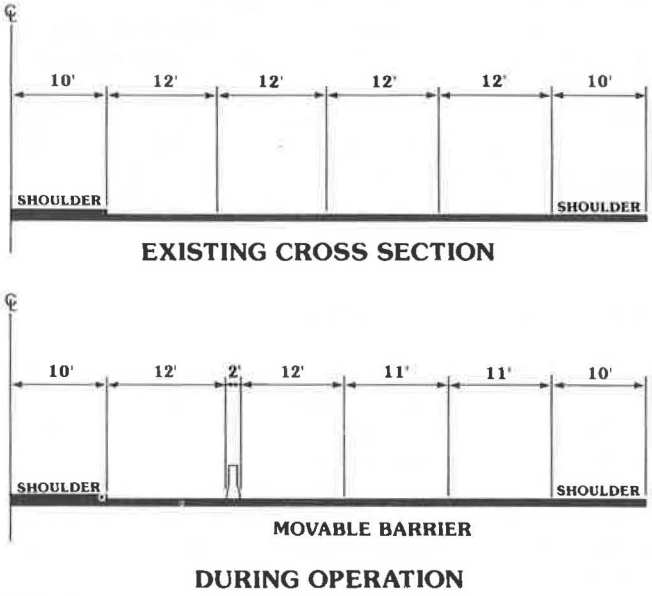


FIGURE 12 Typical contraflow lane cross section.

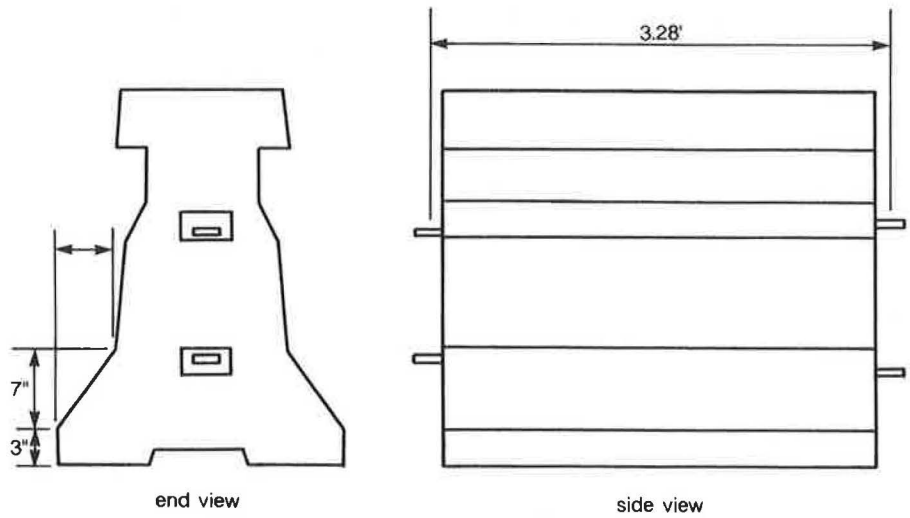
OPERATIONAL ISSUES

Many operational issues need to be considered to guarantee that the project is successful with the movable barrier system. Because the barrier transfer vehicles are not suited for driving long distance or at high speeds, all equipment and support operations must be set up within the freeway corridor.

Life of Project

The life of the contraflow HOV facility is determined by the traffic growth in the off-peak direction. A contraflow facility takes a lane away from the off-peak direction and reserves that lane for priority vehicles. When the off-peak direction general-purpose traffic begins experiencing unacceptable congestion because of the capacity restraint, the operating methods must be reevaluated.

The section of IH-30 just east of IH-45 is the section with the highest off-peak volumes in the afternoon peak period. The existing volumes were projected using the historical growth rate of 2.4 percent and the section was estimated to reach the flow rate capacity in 1994. If a higher growth rate were to occur or operation were continued beyond 1994, there would be significant congestion between the Munger entrance ramp and the Haskell entrance ramp in 1994. The congestion would mean a loss in travel time to the off-peak direction of approximately 45 sec per vehicle and an average speed drop



MOVABLE CONCRETE BARRIER

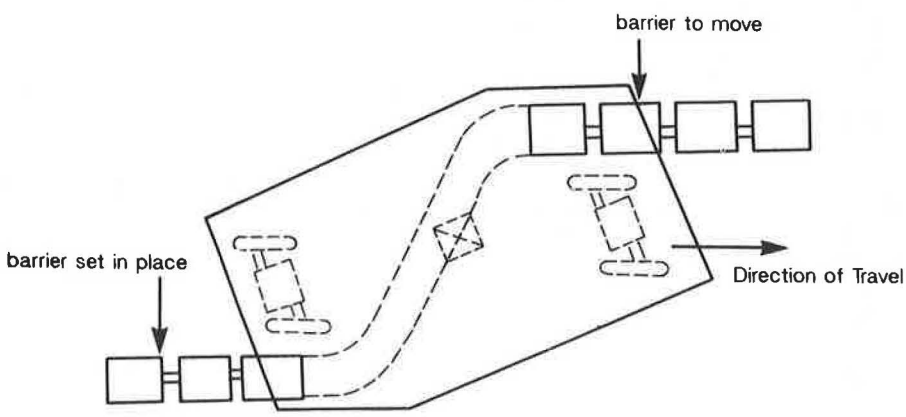


FIGURE 13 Movable concrete barrier transfer vehicle.

from 55 mph to 30 mph for a section of a slightly less than one mile.

However, there are measures that can be taken to alleviate the congestion in this section. Similar to the experience in Houston *(5)*, entrance ramps prior to the congested section could be metered or closed during the operation of the contraflow lane. Approximately 8 percent of the traffic in the off-peak direction would have to be diverted. This would reduce the volumes expected in this section and possibly divert some of the local traffic to use the arterial system close to downtown, which has some reserve capacity.

By implementing the measures outlined above, it appears that operation of the contraflow facility can be maintained past 1994 for another 3 to 4 years. Because the off-peak volumes and the life of the project are very important to the cost-effectiveness of the contraflow facility, these variables need to be monitored during the construction and operation of such a facility.

Movable Barrier Operations

The operations plan addressing the movable barrier system has recently been completed. The major concerns are: *(a)* the A.M. and P.M. movable barriers must be moved into position starting at the west and east ends of the project, respectively, *(b)* the A.M. movable barrier on the eastbound lanes must be disconnected to allow the P.M. egress maneuver at Dolphin Road, and *(c)* the movable barriers must be placed accurately and on time.

Two different barrier transfer machines will be used to set up the different configurations for the two peak periods. The barrier transfer vehicle used for the morning operation will be stored at the downtown in the freeway median. This machine will drive along the inside shoulder of the eastbound lanes approximately to the Jim Miller Road bridge and park on the inside shoulder during operation of the contraflow lane.

Afterwards, the machine will close the lane by replacing the movable barrier in the median and return to the storage building downtown.

The barrier transfer vehicle used for the evening operation will be stored in the wide median at Dolphin Road. This machine will drive along the inside of the westbound lanes from Dolphin Road to the downtown access point and park there during operation of the contraflow lane. At the end of lane operation, the machine will close the lane and return to the Dolphin Road storage facility. The plan to have two machines each responsible for separate operations simplifies the operation of the barrier system, reduces the additional travel of one machine to get into position to begin operation, and allows for a back up if either machine should experience mechanical difficulties. However, two machines significantly increase the cost of the project.

Another concern is that the provision for a midpoint access location creates the need for a "break" in one of the movable barriers. By having different lengths of operation during the morning and evening, the number of conflicts is reduced to one. The evening egress maneuver must pass through a "break" in the A.M. movable barrier.

This gap in the A.M. barrier is created with minimum effort using two machines. The machine used in the A.M. operation moves the A.M. barrier to the shoulder. The barrier is manually unhinged at the midpoint location. The machine used in the P.M. operation attaches to the barrier and moves the barrier the additional 20 ft to create the egress location for the P.M. operation. The ends of the barrier are protected behind crash attenuators.

The last operational concern is the accurate placement of the barrier. To ensure proper placement of the movable barrier, a guide wire is embedded in the pavement. The machines are able to detect the signal in the wire and are guided to properly align the movable barrier.

With the aid of the guidance system, the movable barrier set-up or take-down operation is estimated to take 45 min in the morning and 30 min in the evening at an average speed of 7 mph. This time difference reflects the varying lengths of the two operations. This is a critical concern because the length of time there is a lane reduction in the off-peak direction needs to be kept to a minimum.

Providing this guide wire presented two problems. First, saw cuts in the pavement are needed for the entire length of the project on both sides of the freeway. Second, the guide wire consists of many half-mile loops. Each loop requires a power generator to be located in the freeway median. The design of this application has not been tested.

Operating Crews

Two crews, one in the morning and one in the evening, are planned to operate the contraflow lane. The morning crew consists of two barrier transfer vehicle operators, two persons to set up all access-egress points, and a wrecker operator to remove stalled vehicles and incidents. The barrier transfer vehicle operators are responsible for the pre-operation maintenance and the operation of the barrier system. Two operators are required because both machines must be operated to handle the break in the A.M. barrier. The contraflow lane personnel are responsible for the placement of the pylons, opening and closing gates, and activating the signing system. The wrecker operator must be on location during set up in case the barrier transfer vehicle breaks down and during operation of the lane in case of an incident.

The evening crew only consists of four persons (one barrier transfer vehicle is needed, requiring only one operator). The duties are the same as those listed above.

Enforcement

Enforcement is critical to the successful operation of an HOV facility. Because the contraflow lane is barrier-separated and has limited access points, violation rates can be kept to a minimum with sufficient enforcement.

The contraflow lane is the first project of its type in Dallas. Therefore, the access locations are designed to give ample distance to divert violators (whether deliberate or accidental) out of the contraflow lane and back into the general-purpose lanes.

Each access point is designed with a section of concurrent flow lane on the inside shoulder of the access point. This short section of concurrent flow lane has two purposes: *(a)* it allows the enforcement officer to screen the vehicles entering the HOV lane for correct occupancy, and (b) the HOV traffic is able to bypass any congestion in the general-purpose lanes.

The concept for the enforcement plan is shown in Figure 14. In the morning, enforcement officers are stationed on the westbound lanes at Jim Miller Road and Dolphin Road. These officers are responsible for monitoring the traffic entering the contraflow lane. Ample distance is provided upstream of the contraflow lane entrances to motion noneligible vehicles out of the lane. There is a fixed barrier located at each of these enforcement locations to protect the officers.

An officer is also stationed at the downtown egress location of the contraflow lane in the median area. Most noneligible vehicles will have been signaled by enforcement officers at Jim Miller and Dolphin roads to vacate the contraflow lane before the entry points to the lane. Drivers violating these warnings are pulled over and given a citation by the officer downstream at the downtown egress location of the contraflow lane.

In the evening, the main enforcement is handled at the Dolphin Road egress point. An area to pull vehicles over and issue citations is provided at the crossover. The officer stationed at this enforcement area monitors all vehicles traveling in the lane and issues citations as necessary. There are also officers located at the downtown entrance. The downtown entrance can be accessed by the eastbound mainlanes or the Pearl entrance ramp that has been converted to HOV-only operation. This conversion will cause some motorist confusion during the initial period of operation, and having an officer at the entrance will aid in operation.

During the first months of operation, all access-egress points need strict enforcement to ensure the proper operation of the contraflow lane. As both contraflow lane users and general-purpose lane drivers become familiar with the lane, some reduction in the number of locations of enforcement may be acceptable.

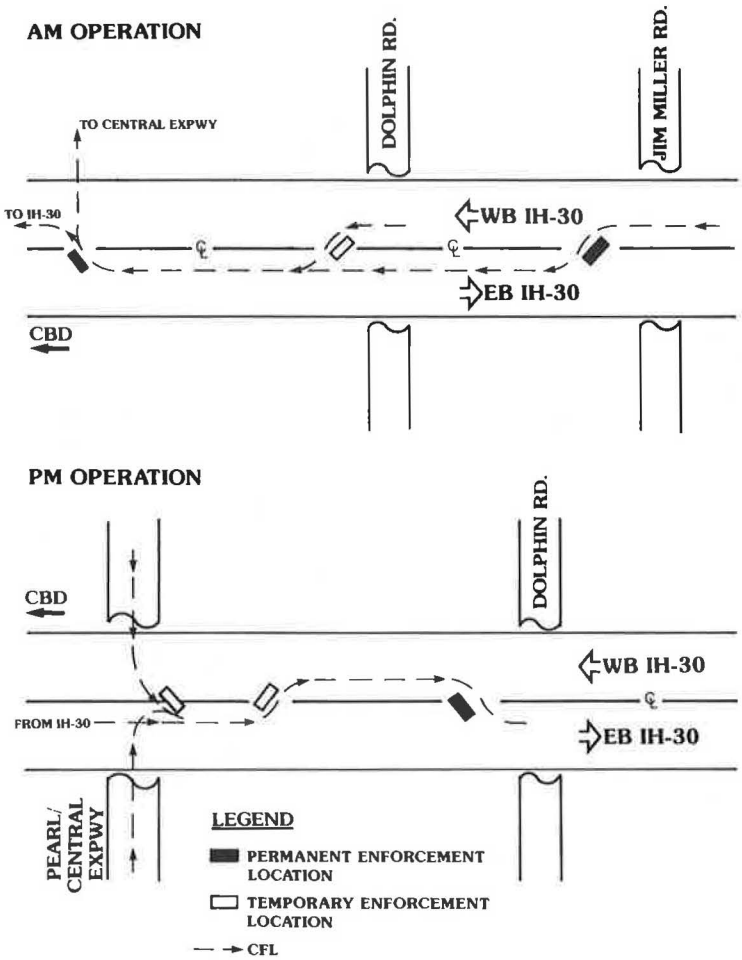


FIGURE 14 Concept for enforcement plan.

Maintenance

There are some maintenance items necessary to keep efficient operation. To aid in the set up of both morning and evening operation, the pathways on which the barrier transfer vehicle operates are to be paved for less wear and tear on the machine and better traction in rainy weather. The storage buildings in which the machines are kept are equipped with electricity in order for preset-up maintenance and routine repairs and maintenance to be conducted. There is no space to store fuel tanks; therefore, mobile fuel trucks will have to refuel the machines every few days.

During set up and operation of the contraflow lane, provisions must be made for breakdowns and incidents. If the barrier transfer vehicle should fail during setup or take down of the movable barrier, a DART tow truck used for standard buses can complete the set up by towing the barrier transfer vehicle the remaining distance. There will always be a tow truck reserved for such incidents. The tow truck will also be able to remove stalled vehicles on the lane prior to, or during, operation.

IMPLEMENTATION

The contraflow lane project has been jointly funded by DART and SDHPT. The agencies are dividing the costs. DART has received UMTA funding for a portion of the project cost.

SDHPT is purchasing the movable barrier and the barrier transfer vehicles, and DART is reimbursing SDHPT for the preliminary engineering and the construction of the access points. DART will assume the cost of enforcing, operating, and maintaining the lane.

Soon after the preliminary feasibility study was completed, BSI revised their estimates of the movable barrier and the barrier transfer vehicles. Even with these increased costs, the project was still cost effective.

As of November 1990, the contract with BSI was signed and the construction contract for the contraflow lane was awarded. The revised cost estimates from BSI were accurate for the cost of the barrier system. The construction contract was higher than first estimated because of the greater required length of retaining walls and a more complex signing system that was added in the late design stages. The project remains cost effective based on these new numbers. The benefit-cost ratio has decreased from 1.9 two years ago in the feasibility study to 1.2 today.

It should be reiterated that the East R.L. Thornton Freeway contraflow lane is a demonstration project. All agencies realized the marginal cost effectiveness. However, the ability to test for acceptance of HOV facilities, improved regional mobility, and indirect benefits such as air quality gave merit to proceeding with this project.

The East R.L. Thornton Freeway contraflow lane is scheduled to start operating in May 1991. To monitor the operation of the contraflow lane, a continuing evaluation program has been initiated. As this demonstration project proceeds, it will be important to monitor the contraflow lane in order to make adjustments to assure better operation, safety, and efficient movement of people during the peak periods.

CONCLUSION

The movable barrier system offers distinct advantages in a contraflow HOV lane application. There is improved safety between HOV traffic and opposing mixed-flow traffic with the addition of a physical barrier. The protection provided by the movable barrier allows passenger cars with two-or-more occupants to take advantage of the travel time savings a contraflow lane offers. The addition of carpools increases the person movement during the peak period and increases the cost effectiveness of the lane and greatly enhances the public perception of lane utilization.

There is a significant increase in marginal cost in going from a traditional pylon-separated contraflow lane to a movable barrier-separated contraflow lane. However, if a carpool market exists, the additional cost can be offset by the benefits provided in time savings to contraflow lane users, as well as the improved safety.

There are also additional design and operational issues that arise with the use of a movable barrier system. The movable barrier system equipment must be designed to conform to the application and the environment in which it will be operating. The design of the access locations must provide access-egress maneuvers for the HOV traffic, maneuverability and operation of the barrier transfer vehicle, and the storage of the movable barrier. The operation of the barrier system during setup and take down of the lane must be designed to minimize conflicts with mixed-flow traffic and provide efficient use of the equipment. Also, attention must be given to the treatment of the ends of the movable barrier by either extending the ends beyond the clear zone or by protecting them with crash attenuators.

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Publication of this paper sponsored by Committee on High-Occupancy Vehicle Systems.