Managed Lane Weaving, Ramp and Design Issues

Engineers should consider several elements, criteria, and controls in the design process. In many cases, right-of-way limitations and roadway constraints may make it difficult to meet all desirable design standards. Many groups have an interest in how a facility is designed and operated, and these interests may require compromises during the testing phase.

Unless a facility is being developed as part of a new project or major reconstruction of an existing facility, some compromise in design may need to be considered. Desirable criteria include all the preferred design elements. Desirable designs generally reflect those associated with a permanent or new facility and meet American Association of State Highway and Transportation Officials (AASHTO) and other standards.

Designs with reduced features reflect the inability to meet the desirable criteria due to lack of available rights-of-way or other significant limitations. Reduced designs do not reflect those associated with permanent facilities, and consideration of reduced designs should be given on a case-by-case basis based on sound engineering practices. However, practitioners should use desired values whenever practical.

General Design Issues

The design and operational components of a managed lane facility must be considered simultaneously. Right-of-way constraints will normally dictate the extent of design that is possible. A full design requires fewer operational treatments. When reduced design standards are implemented, the operations component of the managed lane development becomes increasingly important. Table 1 lists examples of the operational treatments needed for full and reduced designs on a managed lane. Reduced designs must be decided by each local area and situation and acceptable to the Federal Highway Administration, Federal Transit Administration (FTA), Department of Transportation (DOT), transit agency, city, and others with a stake in the facility.

***Design Vehicle* –** The physical and operating characteristics of eligible vehicles will influence the design of managed lane facilities. Standard and articulated buses, as well as carpools and vanpools, are often part of the allowed vehicle mix on these types of facilities. Designers should use the typical dimensions and turning radii for design vehicles included in the AASHTO *Green Book (1)* and National Cooperative Highway Research Program (NCHRP) Report 414 *(2*), which will also accommodate vanpools and carpools, to assist with the design of managed lane projects on freeways.

The design vehicles should be used to control the geometrics of the different managed lane facility design elements. Acceleration and deceleration lanes and corner radii should be based on a bus or other large design vehicle while alignment geometry is based on the stopping sight distance of a passenger car driver, which is lower to the ground. Larger design vehicles are

Table 1. Operational Treatments Needed for Full and Reduced Design Standards (Adapted from Reference *2*).

Design Standards	Level of Operational Treatments	Example Operational Treatments
Full	Low	• Minimal enforcement • Visual detection by police, bus operators, motorist assistance patrols, or agency personnel • Calls from motorists using cellular telephones • Reports from roadside call boxes • Information from commercial traffic reporters • Flow metering not required • Consistent speed limit
Reduced	High	• Items noted above for full standards • Automatic vehicle identification (AVI) or inductance loop detectors for vehicle detection • Closed-circuit television cameras • Full advanced transportation management systems or integrated transportation management systems • Dedicated tow trucks with limited turning radius for narrow managed lane width • Changeable message signs (CMSs) • Entry ramp metering • Significant enforcement effort • Lower speed limits at constricted points

not usually used in alignment design because the higher eye height of their drivers allows them to see objects from a longer distance. Larger design vehicles, however, should be used for vertical alignment design when sight restrictions occur on long downgrades. In these situations, the speed of a bus may exceed that of a passenger car *(3)*. If the managed lane will be used for general-purpose vehicles during off-peak periods or during incident management situations, consider using a semitrailer truck as the design vehicle (e.g., WB-67). Further, for these situations and/or when the facility will be opened to truck traffic, it is important to ensure that the entire facility, including all ingress/egress locations and horizontal curvature, is designed for the semitrailer truck design vehicle.

Design Speed – In most cases, the design speed of managed lanes will be the same as that used on the adjacent general-purpose lanes. However, there may be limited instances where the design speed of the managed lanes is lower than the adjacent general-purpose lanes, due to the geometrics of the managed lane facility or other limitations. The designated design speed of the facility should relate to the maximum speed the facility is expected to accommodate. Further, the design speed should accommodate the vast majority of users (e.g., the anticipated 85th percentile speed), and consider the use of on-line and off-line stations, gradients, and local conditions.

Horizontal Clearance – For horizontal clearances, 5 ft (1.5 m) is the desired clearance; however, as a minimum, at least a 2-ft (0.6 m) lateral clearance should be provided to adjacent barriers, signing columns, or other obstructions for both managed lanes and general-purpose traffic lanes. Exceptions to this minimum should be considered only in temporary situations, such as construction or reconstruction of a facility where speeds are reduced or for very short distances where other options do not exist.

Vertical Clearance – Structures over the mainlanes of interstate or controlled-access highways must meet minimum vertical clearance requirements. In some locations, the height of the tallest vehicle anticipated to operate in the managed lane facility is used to determine the vertical clearance. Buses are usually the tallest vehicle using a managed lane and are commonly used to determine the vertical clearance. If the managed lane will include trucks, the vertical clearance of the truck design vehicle may govern. In the case of managed lanes on freeways, the standard of 16.5 ft (5 m) used for the adjacent freeway lanes will also be used for the managed lane *(1)*. In situations of restricted vertical clearance, a minimum of 14.5 ft (4.4 m) is acceptable per the AASHTO *Green Book*, which includes an allowance of 6 inches (0.2 m) in anticipation of future resurfacing *(1)*. This may also be an issue where an overcrossing road is widened; the cross slope on the wider road will result in clearance at the edges of the roadway.

Stopping Sight Distance – The design of a managed lane facility should provide adequate stopping sight distance (SSD) for all vehicle types (e.g., bus, truck, van, car) using the facility. Due to the driver's eye height, the automobile is usually used as the design vehicle for determining stopping sight distance. The stopping sight distances should be checked if barriers are used as they may restrict the available sight distances *(1)*.

Superelevation – Superelevation rates on managed lanes must be applicable to curvature over a range of design speeds. Designers must give consideration to the higher center of gravity for buses, vans, and trucks, which will result in superelevations slightly higher than otherwise justified *(4)*.

Cross Slope – The cross slope of a managed lane facility should generally follow the adjacent freeway, which is commonly 2 percent. However, for a facility located in a median that straddles the crown of the roadway, it is acceptable to crown the facility with a 2 percent crossfall to either side if drainage requirements permit. For typical sections with five or more lanes, the uniform cross slope of 2 percent may not be sufficient and the outside lane(s) cross slope may require modification. For concurrent-flow facilities, the designer should extend the existing crossfall of the freeway mainlanes.

Minimum Turning Radius – Generally, a 50-ft (15.2-m) minimum radius (inner wheel path) is considered desirable at low speeds (10 mph [16 km/h]); this will accommodate most urban transit buses. For a radius below this value, the designer should consider the possibilities of a compound curve or approach and departure tapers to avoid increasing the outside radius and resulting in vehicle overhang. This condition is likely to be encountered at managed lane ramp intersections with local streets and possibly at ramp intersections with the mainlane facility. These recommended radii might differ if the managed lane facility is designed to accommodate semitrailers *(3)*.

Horizontal Curvature – The horizontal alignment of a managed lane should be designed to ensure that all design vehicles, including buses and semitrailers, if applicable to the managed lane facility design, may safely negotiate all curves. Values for minimum radii for horizontal curvature should be used only where the cost of incorporating desirable radii is inconsistent with the benefits *(2, 3, 4)*.

Managed lanes on curves should provide additional lateral width for maneuvering and for the overhang of various parts of a bus. Likewise, ramps on curves must also have sufficient width to accommodate the bus wheel path and allow passing of stalled vehicles. Designers should consider providing extra lane width on curves to accommodate semitrailers on a full- or part-time basis *(2, 3, 4)*.

Vertical Curvature – Managed lanes on freeways typically follow the existing vertical curvature of the facility. For busways and managed lane facilities on separate rights-of-way or new construction, K-factors are used to determine the necessary vertical curvature and are determined by applicable design speeds. For design on independent facilities outside the freeway right-of-way, K-factors (distance divided by the percentage change in algebraic difference of grades) should be used to calculate the recommended minimum length of vertical curvature. These calculations assume a driver eye height of 3.5 ft (1080 mm) (passenger cars being the most critical vehicles), object height of 2.0 ft (0.6 m), parabolic curvature, and the presence of fixed-source lighting for an urban environment. K-factors for sag vertical curvature based on comfort are about 50 percent of that required to satisfy the headlight sight distance requirement for the normal range of design conditions *(1)*. Therefore, it is important that fixed-source lighting exists along the managed lane facility to apply the sag vertical curvature values. If the fixed-source lighting does not exist or is not adequate, the headlight sight distance requirement should be used in the design of the sag vertical curvature.

Gradients – Recommended gradients should reflect current AASHTO practice to ensure both safety and uniformity of operation along with the capabilities of the vehicles authorized on the managed lane facility. Consideration must be given to maximum and minimum grades. Gradients exceeding the recommended maximum may be considered in special or extreme situations only. The designer can enhance operation by providing flatter grades of adequate length at starting and stopping locations. The maximum length of grade should be such that vehicles are not slowed by more than 10 mph (16 km/h) considering the length and percentage of the grade.

A minimum longitudinal grade of 0.35 percent is controlled by the need to provide adequate drainage and to prevent water retention (i.e., ponding) on the roadway surface. For median facilities retrofitted at grade, the minimum grade follows the existing freeway gradient *(3, 4)*.

Managed Lanes Weaving

A primary consideration for managed lanes is access for users. Can intended users access the facility efficiently and safely? Weaving across general-purpose lanes to access managed lanes may present a problem if the access is at-grade. Three typical weaving scenarios, as illustrated in Figure 1, may include:

- weaving within managed lanes;
- merging and diverging at managed lanes access points;
- freeway weaving from a freeway entrance to a managed lane entrance, or
- intra-freeway vehicle stream separation of vehicles destined for managed lane access.

Typical managed lane design guidelines specify either minimum (500 feet) and desirable (1000 feet) weaving distances per lane, or a preferred minimum distance (2500 feet) between a freeway entrance or exit and a managed lanes facility entrance or exit. A recommended weaving distance application table is provided Table 2, which updates and places some conditions on these generic guidelines *(5)*. As shown in Table 2, these minimum weaving distances are a function of mainlane design year volume levels, allowable speed reduction for those users accessing the managed lanes, and the presence of intermediate ramp/ramps between the freeway entrance/exit and the managed lanes entrance/exit. As more of these factors impact the access design, the more weaving distance needs to be provided for at-grade access to a managed lanes facility.

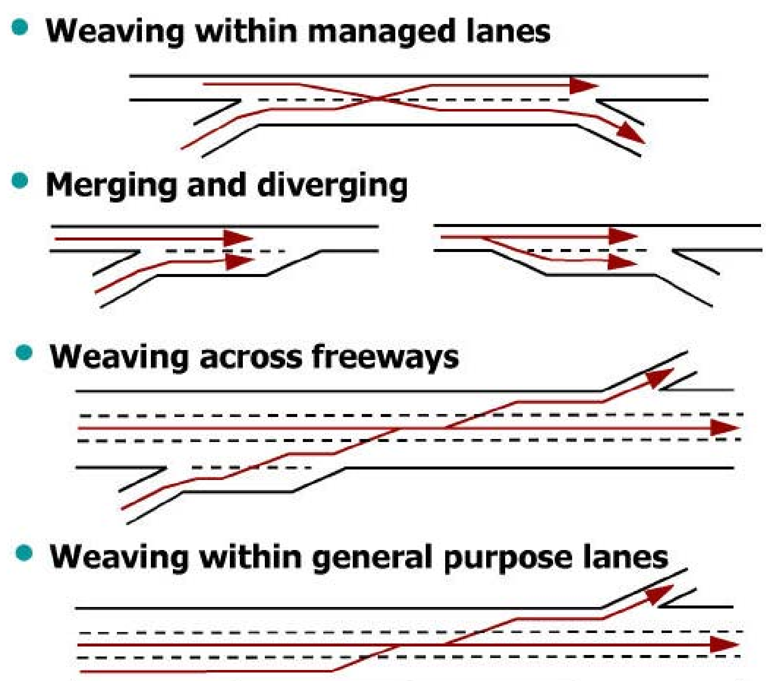

Figure 1. Complex Managed Lanes Weaving.

For general managed lane planning purposes, the recommended minimum and desirable distances between a freeway entrance/exit ramp and a managed lanes entrance/exit are 2500 feet and 4000 feet, respectively. The minimum distance applies in cases where a speed reduction of up to 10 mph is acceptable and freeway volumes are moderate. For high freeway volumes, especially in cases where an intermediate ramp is present between the freeway entrance/exit and the managed lanes entrance/exit, 4000 feet of cross-freeway weaving distance is appropriate.

Table 2. Weaving Distances for Managed Lane Cross-Freeway Maneuvers *(5)*.

Design Year Volume Level	Allow up to 10 mph Mainlane Speed Reduction for Managed Lane Weaving?	Intermediate Ramp (between freeway entrance/exit and managed lanes entrance/exit)?	Recommended Minimum Weaving Distance Per Lane (feet)
Medium (LOS C or D)	Yes	No	500
		Yes	600
	No	No	700
		Yes	750
High (LOS E or F)	Yes	No	600
		Yes	650
	No	No	900
		Yes	950
Note: The provided weaving distances are appropriate for freeway vehicle mixes with up to 10% heavy vehicles; higher percentages of heavy vehicles will require increasing the per lane weaving distance. The value used should be based on engineering judgment, though a maximum of an additional 250 feet per lane is suggested.			

To preserve freeway quality of service in the vicinity of managed lanes entrance and exit ramps, it is recommended that for moderate freeway volumes in the design year, a transition distance of 1 mile be allowed for vehicles to selectively maneuver from their initial position in any freeway lane to the leftmost (or rightmost) freeway lane so that they can access a managed lane facility. Under high volume freeway conditions in the design year, a transition distance of 1.5 to 2 miles is appropriate. For both moderate and high volume freeway conditions, the presence of ramps within the transition distance requires that the given value be increased.

One important point to remember is that these distances are those needed once drivers have already determined whether or not they are candidates for the managed facility. Sign locations should be designed based on driver perception and decision distances that are added onto the values given here. Also note that the transition distance values given here provide sufficient upstream warning so that mainlane speeds are not significantly impacted by the selective separation weaving vehicles; if lesser transition distances are used, mainlane and weaving vehicle speed will be reduced.

Direct Connect Ramps for Managed Lanes

Another factor to consider when designing managed lanes facilities is the effect of ramp spacing on freeway operations and managed lanes access. When do you consider a direct ramp between the managed lanes and a generator or surface street system? Grade separated or direct access ramps are desirable. They provide access for eligible vehicles where high vehicle volumes are anticipated or where additional time savings and operational efficiencies can be gained. Direct-access ramps are usually found with exclusive managed lanes, but they may be used with any type of lane. They may be used at the start, end, or intermediate locations along a managed lanes facility and can be the most efficient means of managing conflicting movements at locations where there is substantial congestion and they facilitate enforcement.

Table 3 provides general threshold values for considering a direct connect ramp for a managed lanes facility *(6)*. Under moderate volume freeway conditions (i.e., LOS C or D), a maximum weaving volume of 450 vehicles per hour is recommended between any given freeway entrance and the next downstream managed lanes entrance or for any given managed lanes exit and the next, downstream freeway exit. Under high volume freeway conditions, this number drops to 350 vehicles per hour. In corridors where managed lanes-related weaving volumes exceed these values, it is recommended that direct access from park and ride/transit facilities to the managed lanes be provided.

Table 3. Maximum Weaving Volumes for Direct Access Consideration *(6)*.

Freeway Volume	Maximum Weaving Volume (before considering direct managed lane access ramps)
Moderate (LOS C or D)	450 vehicles/tour
High (LOS E or F)	350 vehicles/hour

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2. Texas Transportation Institute, Parsons, Brinckerhoff, Quade, and Douglas, and Pacific Rim Resources. NCHRP Report 414: HOV Systems Manual. TRB, National Research Council, Washington, D.C., 1998.
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4. J.M. Mounce, and R.W. Stokes. *Manual for Planning, Designing, and Operating Transitway Facilities in Texas*. Publication No. FHWA/TX-871425-2. Texas State Department of Highways and Public Transportation, Austin, Texas, September 1985.
5. Venglar, S., D. Fenno, S. Goel, and P. Schrader. *Managed Lanes – Traffic Modeling*. Report No. FHWA/TX-02/4160-4. Texas Transportation Institute, College Station, Texas, 2002.
6. Fitzpatrick, K., M. Brewer, and S. Venglar. *Managed Lane Ramp and Roadway Design Issues*. Report No. FHWA/TX-03-4160-10. Texas Transportation Institute, College Station, Texas, 2003.

For More Details . . .

Related Reports:
Report 4160-4, *Managed Lanes – Traffic Modeling*
Report 4160-10, *Managed Lane Ramp and Roadway Design Issues*

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