CHAPTER 8

SYSTEM-WIDE TREATMENTS

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8.0 SYSTEM-WIDE TREATMENTS

Treatments in this chapter apply to roadway segments located within the influence of signalized intersections and intersections affected by the flow of traffic along a corridor. These treatments primarily address safety deficiencies associated with rear-end collisions due to sudden accelerating/decelerating; turbulence involved with midblock turning movements from driveways or unsignalized intersections; and coordination deficiencies associated with the progression of traffic from one location to another. The following specific treatments are examined:

1. Median treatments.
2. Access management.
3. Signal coordination.
4. Signal preemption and/or priority.
5. Automated enforcement.

8.1 MEDIAN TREATMENTS

The median of a roadway is used for left turns, pedestrian refuge, restriction of or access to properties on the other side of the road, and separation of opposing directions of travel. These purposes can conflict, and each use should be considered when design changes are proposed. Medians can be either flush or raised, each having specific operational and safety characteristics that may lead to tradeoffs in either.

8.1.1 **Description**

Median design contributes to safe and efficient operation of corridors and intersections, especially left-turn and pedestrian movements. Specifically, width, height, length, and type are key factors in median design. The median provides a location for vehicles to wait for a gap in opposing traffic through which to turn; it also separates opposing directions of travel. Medians may also provide a refuge for pedestrians. Inappropriate median design may contribute to operational or safety problems related to vehicles turning left from the major road and vehicles proceeding through or turning left from the minor road and public or private entrances.

8.1.2 **Applicability**

Operational or safety issues that could be addressed by median design changes include spillover of left-turn lanes into the through traffic stream, rear-end or side-swipe crashes involving left-turning vehicles, inappropriate use of the median, and pedestrian crashes. Medians may also form an integral part of an overall access management plan, as discussed later.

8.1.3 **Key Design Features**

Width, height, length, channelization, end type, and pedestrian treatments are key features of a median design. The elements combine to provide storage for left-turning vehicles, guide turning vehicles through the intersection, and help pedestrians cross the street.

Median Width

Medians physically separate opposing directions of travel and provide a safety benefit by helping reduce occurrence of head-on collisions. It is possible that a median can be so narrow or so wide that its safety benefit is negated by operational or safety problems created by an inappropriate width, as shown in Exhibits 8-1 and 8-2.

- **Narrow medians:** Many problems associated with medians that are too narrow relate to unsignalized intersections upstream or downstream of the signalized intersection in question. These include vehicles stopping in the median at an angle instead of perpendicular to the major road, or long vehicles stopping in the median and encroaching on major road through lanes. Additionally, pedestrians can have difficulty at signalized intersections with medians that are too narrow. At large intersections with medians, pedestrians commonly cross the street in two stages. If the median width is too narrow, pedestrians may not have sufficient room to wait safely and comfortably. Also, there may be insufficient room to provide adequate ADA-compliant detectable warning surfaces and, in some cases, curb ramps.
- **Wide medians:** Just as medians that are too narrow can pose difficulties, overly wide medians also can be problematic. At signalized intersections, wide medians increase motor vehicle and bicycle clearance time, thus adding lost time and delay to the intersection. If pedestrians are expected to cross the entire intersection in one crossing, overly wide medians result in very long pedestrian clearance times, which often lead to excessively long cycle lengths.

  Wide medians also can create visibility problems for signal displays, which often result in the use of two sets of signal indications: one mid-intersection, and one on the far side. Extremely wide medians can also cause driver confusion with respect to how motorists are to maneuver turns. Extra pavement marking, island delineation and/or signing may be needed to guide motorists. These factors increase the cost of construction and operation of the intersection.

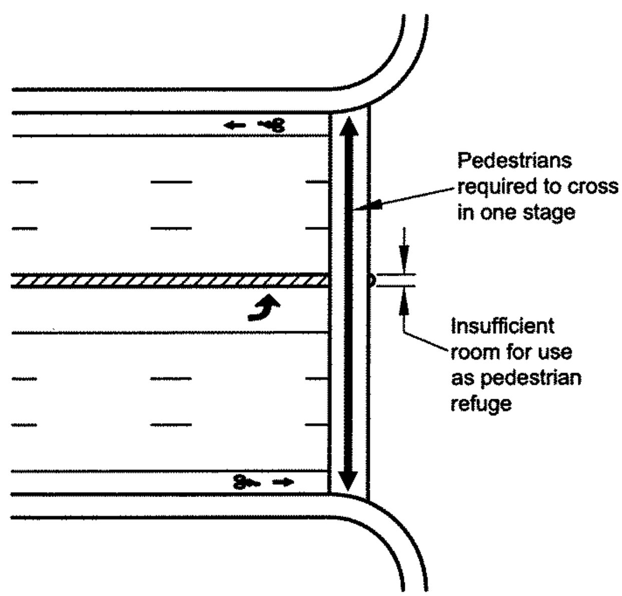


Exhibit 8-1. Issues associated with intersections with a narrow median.

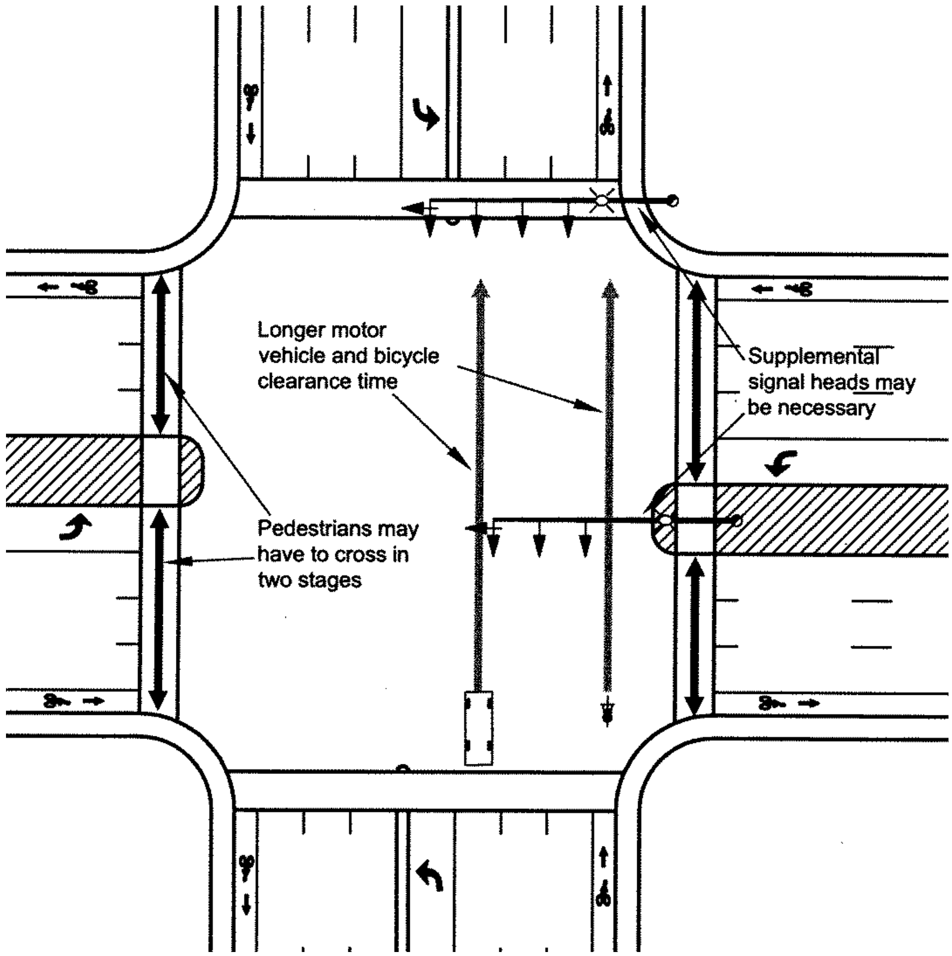


Exhibit 8-2. Issues associated with intersections with a wide median.

Median Channelization

The appropriateness of the use of raised or flush medians depends on conditions at a given intersection. Raised (curbed) medians should provide guidance in the intersection area but should not present a significant obstruction to vehicles. The design should be balanced between the desire for it to be cost effective to construct and maintain and for it to provide safe channelization. Raised medians may be delineated with reflectors, tape, or paint, in addition to the presence of lighting.

AASHTO recommends that flush medians are appropriate for intersections with:[3]

- Relatively high approach speeds.
- No lighting.
- Little development where access management will not be considered.
- No sign, signal, or luminaire supports in the median.
- Little/infrequent snowplowing operations.
- A need for left-turn storage space.
- Little or no pedestrian traffic.

Where left-turn lanes are provided in the median, raised medians should be used to separate left-turn and opposing through traffic on medians 14 to 16 ft wide or less. These raised medians should be 4 ft wide. Medians 18 ft wide or more should have a painted or physical divider that delineates the movements. It is also recommended that the left-turn lane be offset to provide improved visibility with opposing through traffic. This treatment is discussed in more detail in Chapter 11.

Median End Type

AASHTO provides the following guidance for median ends: [3, p. 701]

- Semicircular medians and bullet nose median ends perform the same for medians approximately 4 ft wide.
- Bullet-nose median ends are preferred for medians 10 ft or more wide.

A semicircle is an appropriate shape for the end of a narrow median. An alternative design is a bullet nose, which is based on the turning radius of the design vehicle. This design better guides a left-turning driver through the intersection because the shape of the bullet nose reflects the path of the inner rear wheel. The bullet nose, being elongated, better serves as a pedestrian refuge than does a semicircular median end.

Medians greater than 14 ft wide with a control radius of 40 ft (based on the design vehicle) should have the shape of flattened or squared bullets to provide channelization, though the length of the median opening will be controlled by the need to provide for cross traffic.

The median end controls the turning radius for left-turning vehicles. It can affect movement of vehicles using that leg of the intersection both to turn left from the approach and to depart from the intersection on that leg after turning left from the cross street. A median nose that does not significantly limit the turning radius will help turning vehicles proceed through the intersection at higher speeds. This could contribute to efficient vehicular operations but could also create additional safety issues for pedestrians, bicyclists, and through traffic on the opposing approach if permissive left turns are allowed.

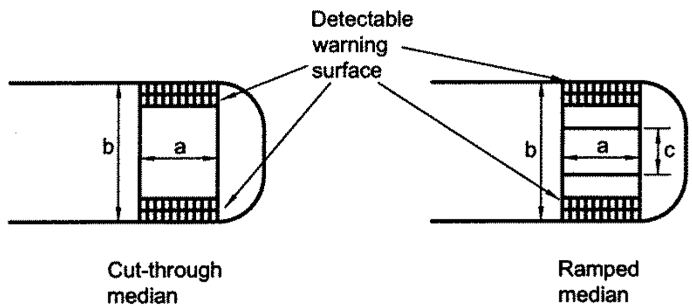
Median Pedestrian Treatments

Careful attention should be given to pedestrian treatments at signalized intersections with medians, as these intersections tend to be larger than most. Two key treatments are discussed here: the design of the pedestrian passage through the median, and the design of the pedestrian signalization.

Pedestrian treatments at medians can be accommodated in two basic ways: a cut-through median, where the pedestrian path is at the same grade as the adjacent roadway; and a ramped median, where the pedestrian path is raised to the grade of the top of curb. Exhibit 8-3 shows the basic features and dimensions for each treatment. Note that if the median is too narrow to accommodate a raised landing of minimum width, a ramped median design cannot be used. If the median is so narrow that a pedestrian refuge cannot be accommodated, then the crosswalk should be located outside the median.

Cut-through and ramped medians both provide pedestrian refuge, but cut-through medians are susceptible to hold roadway drainage and resulting debris. If space allows for ramped medians, they can provide extra visibility to pedestrians by being vertically separated from the roadway. Both cut-through and ramped medians should be designed and operated in a way that provides visibility and conspicuity of pedestrians located in the median, as well as a line-of-sight from the median to roadway users. This is especially important when median landscaping is present. The landscaping must be maintained to provide pedestrians a line-of-sight over and around the landscaping and give motorists the opportunity to detect pedestrians in the median.

Per ADAAG, all curb ramps, including those at median crossings, must have detectable warnings. Further discussion of pedestrian treatments at medians can be found in FHWA's *Designing Sidewalks and Trails for Access: Part II*.[37]

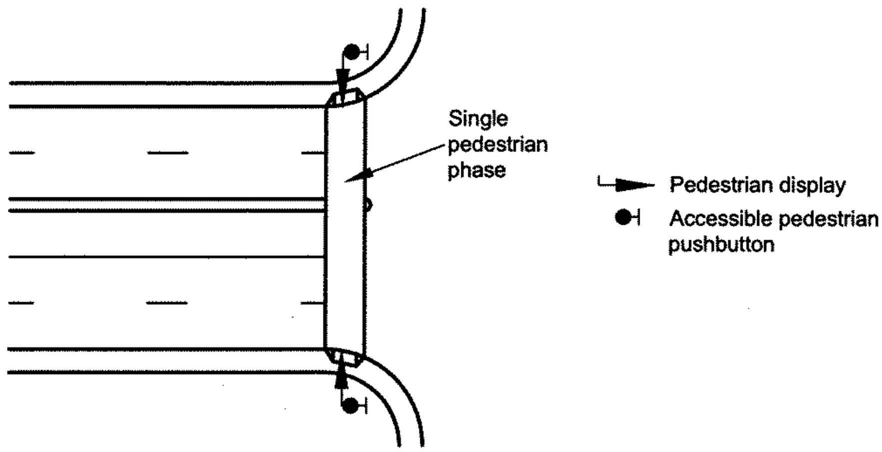


Key Dimensions: a: 915 mm (36 in) minimum, 1525 mm (60 in) preferred
b: 1.22 m (48 in) minimum, 1.83 m (72 in) preferred for one-stage crossing; 1.83 m (72 in) minimum for two-stage crossing
c: 1.22 m (48 in) minimum, 1.525 m (60 in) preferred

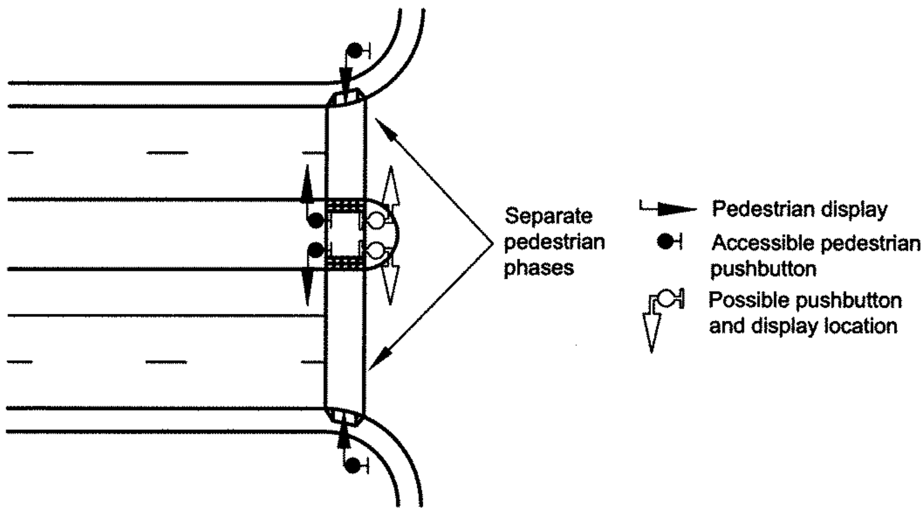
Exhibit 8-3. Median pedestrian treatments.[37]

Exhibit 8-4 summarizes pedestrian signal treatments, which also depend on the width of the median.

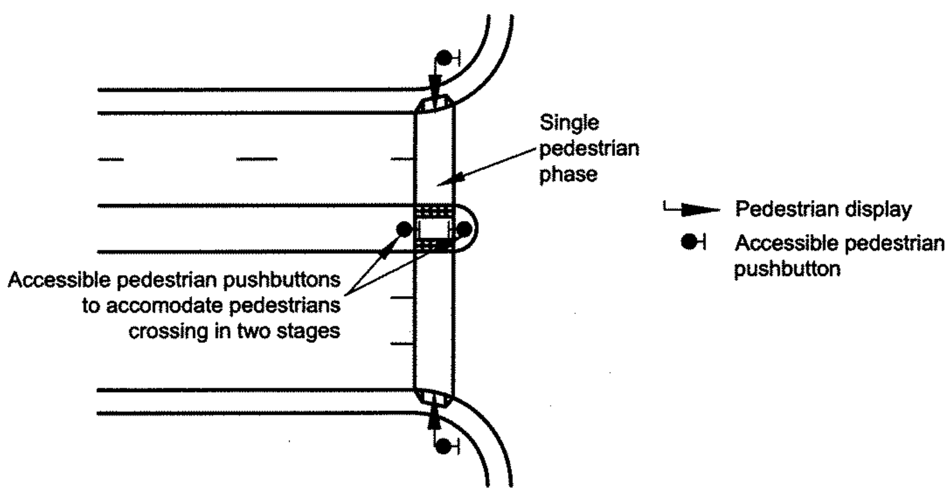
- Narrow crossings providing no refuge require a one-stage crossing using a single set of pedestrian signal displays and detectors. For this option, pedestrian clearance time needs to accommodate crossing the entire roadway.
- Wide intersection crossings with ample room for pedestrians to wait in the median (and where it is advantageous to all users to cross in two stages) require separate pedestrian signal displays and detectors for each half of the roadway. Pedestrian clearance times are set independently for each half of the roadway, as shown in Exhibit 8-5.
- A third option is for crossings where part of the pedestrian population can be reasonably expected to cross in one stage, but others need two stages. For this option, pedestrian clearance time is set to accommodate crossing the entire roadway, but a supplemental pedestrian detector is placed in the median to accommodate pedestrians needing to cross in two stages.



(a) One-stage pedestrian crossing.



(b) Two-stage pedestrian crossing.



(c) One-stage pedestrian crossing with optional two-stage crossing.

Exhibit 8-4. Pedestrian signal treatments where medians are present.

Exhibit 8-5. This refuge island enables two-stage pedestrian crossings.
Source: Michael Ronkin (*Safety Benefits of Raised Medians and Pedestrian Refuge Areas*, FHWA, 2010)

8.1.4 **Safety Performance**

Medians at intersections can provide safety benefits similar to medians between intersections. Introducing distance between opposing flows can decrease the frequency and severity of crashes. The presence of a raised median impacts motorists' ability to cross the opposing lanes, which can reduce head-on collisions. One report has shown that at urban and suburban intersections, multiple-vehicle crash frequency increases as median width increases for widths between 14 ft and 80 ft, unlike in rural areas where multiple-vehicle crash rates tend to be lower for wider medians.(82) The report also provided a summary of a study that found no statistically significant effect of median width on traffic delays and conflicts on medians between 30 ft and 60 ft wide.(83)

One study found decreasing crash rates with increasing median widths.(84) A Michigan State University study found that Michigan's boulevard roadways experienced a crash rate half that of roadways with continuous center left-turn lanes.(85) A median width of 30 ft to 60 ft was found to be the most effective in providing a safe method for turning left.

The frequency of minor collisions and vehicle damage claims may increase when raised medians are present as a result of drivers misinterpreting their distance from the raised median.

8.1.5 **Operational Performance**

Simulation of signalized directional crossovers showed they operate better than other designs (specifically, an undivided cross section with a continuous center left-turn lane and a boulevard with bidirectional crossovers). The undivided cross section has larger delays for left-turning vehicles than do boulevard roadways, even for low turn volumes. The width of the median affects the storage capacity of the crossover, so a crossover in a narrow median may not function as well as a left-turn lane. The signalized crossovers functioned more efficiently (i.e., with less time to make a left-turn) than did stop-controlled crossovers.(86)

Depending on the radius design, the presence of a raised median may impact the speed at which motorists can maneuver left turning movements. A less severe radius will allow for higher speeds of left-turning traffic, which can help clear intersections of traffic more quickly and reduce cycle lengths and delay, but may have adverse effects on pedestrian and bicycle users.

8.1.6 **Multimodal Impacts**

As noted previously, the width of the median (and the roadway in general) directly impacts the amount of time needed for pedestrians and bicycles to cross the roadway. Large intersections with no median or a median too narrow to provide a refuge force pedestrians to cross the entire street in one stage. Therefore, provision of a median with at least enough width to accommodate a pedestrian can provide the option of crossing in one stage or two. This can be a significant benefit to elderly and disabled pedestrians who cross at speeds less than the typical 4 ft/s used to time pedestrian clearance intervals.

If the median is so wide that pedestrian crossings are operated in two stages, the sequence of the stages may increase crossing time significantly. For example, if the vehicle phases running parallel to the pedestrian crossing in question are split-phased and the sequence of the vehicle phases is in the same direction as the pedestrian, crossing time is similar to that of a single-stage crossing. On the other hand, the reverse direction will result in additional delay to the pedestrian in the median area as the signal cycles through all conflicting phases.

8.1.7 **Physical Impacts**

Improvements in the median should not affect the footprint of an intersection unless a roadway is widened to provide the median to use for left-turn lanes, pedestrian refuges, and so on.

8.1.8 **Socioeconomic Impacts**

The primary socioeconomic impact of medians at signalized intersections relates more to their effect on overall access within the corridor, discussed in Section 8.2. The frequency of minor collisions and vehicle damage claims will likely increase when raised medians are installed; sometimes drivers misinterpret their vehicle's distance from the raised median.

Landscaping can play an important esthetic role at the intersection itself. The appropriate use of landscaping can visually enhance a road and its surroundings. Landscaping may act as a buffer between pedestrians and motorists and reduce the visual width of a roadway, serving to reduce traffic speeds and providing a more pleasant environment.

Landscaping must be carefully considered at signalized intersections, otherwise it will prevent motorists from making left and right turns safely because of inadequate sight distances. Care should be taken to ensure that traffic signals and signs, pedestrian crossings, nearby railroad crossings, and school zones are not obstructed. Median planting of trees or shrubs greater than 2 ft in height should be well away from the intersection (more than 50 ft). No plantings having foliage between 2 ft and 8 ft in height should be present within sight distance triangles.

Low shrubs or plants not exceeding a height of 2 ft are appropriate on the approaches to a signalized intersection, either on the median, or along the edge of the roadway. These should not be allowed to overhang the curb onto the pavement nor interfere with the movement of pedestrians. All plantings should have adequate watering and drainage systems or be drought resistant. FHWA's report *Vegetation Control for Safety* provides additional guidelines and insight.[(87)]

In addition to landscaping height considerations, AASHTO's Roadside Design Guide provides guidance to establish an enhanced lateral offset distance to signs, poles, trees, plants, and shrubbery located within the median. Specifically, the enhanced lateral offset is intended to provide an additional level of protection for roadway users at high-risk locations, such as at locations where lanes merge or at driveways and medians are present. The recommended enhanced lateral offset distance is 4 to 6 ft.

8.1.9 **Enforcement, Education, and Maintenance**

Flush medians introduce little in the way of unique enforcement or education issues for motor vehicles. However, the enforcement of signalized corridors with continuous raised medians will vary from corridors with median breaks or flush medians that allow enforcement to access both directions of traffic. Practitioners should coordinate with enforcement to discuss these concerns or find locations for median opening turnarounds or flush medians. Pedestrians may need assistance through the use of signs or other methods to make them aware of one-stage versus two-stage crossings, particularly in communities that have both types of crossings at signalized intersections.

Typical maintenance procedures will apply to medians. However, consideration should be given for providing vertical guidance for snow removal operations on raised medians using delineation. The addition of a raised median will also result in a treatment located among roadway users that will require intermittent maintenance. Landscaping should be maintained so as not to obstruct sight distance.

8.1.10 **Summary**

Exhibit 8-6 summarizes issues associated with providing median treatments.

Exhibit 8-6. Summary of issues for providing median treatments.

Characteristic	Potential Benefits	Potential Liabilities
Safety	Introducing distance between opposing flows may allow for a reduction in the frequency and severity of certain crash types.	The frequency of minor collisions may increase when raised medians are present.
Operations	Signalized directional crossovers can operate more efficiently than unsignalized directional crossovers. Appropriately designed median radii can help raise speeds in turning movements and decrease intersection delay.	Narrow medians may create storage problems. For intersections where high pedestrian volumes are present, increased motorist speeds could negatively impact pedestrian safety.
Multimodal	Medians of moderate width can allow pedestrians to cross in one or two stages, depending on ability.	Overly wide medians may require all pedestrians to cross in two stages, significantly increasing pedestrian delay. Narrow medians may require long one-stage crossings.
Physical	None identified.	Changes to median width may have a substantial physical impact upstream and downstream of the intersection. Presence of a raised median requires additional roadway maintenance.
Socioeconomic	Landscaping may provide visual appeal.	Access control upstream or downstream of the intersection may create challenges. The frequency of vehicle damage claims may increase. Potential safety concern if the landscaping becomes a fixed object hazard or impedes sight distance.
Enforcement, Education, and Maintenance	None identified.	Education on the use of pedestrian push buttons in the median may be considered. Presence of a raised median and landscaping in the median will require maintenance. Enforcement methods may need to be addressed, depending on the presence of raised median between signals.

8.2 ACCESS MANAGEMENT

Practical experience and recent research indicate that controlling access on a roadway can positively impact traffic flow and safety. Access management is a key issue in planning and designing roadways so they perform according to their functional classification.

The topic of access management is growing and exceeds the space that this guide can provide. More information on access management can be found in a number of references, including AASHTO's *A Policy on Geometric Design of Highways and Streets*[3]*; NCHRP 420: Impacts of Access Management Techniques*[88]*;* ITE's *Transportation and Land Development*[89]*;* and TRB's *Access Management Manual.*[90] Many States also have extensive guidance on access management. This section focuses on the operational and safety effects of unsignalized intersections (both public streets and private driveways) located within the vicinity of signalized intersections.

For more information on Access Management, consider the following resources:

- AASHTO *A Policy on Geometric Design of Highways and Streets*
- ITE *Transportation and Land Development*
- Transportation Research Board's Access Management Manual
- FHWA's 2007 Compendium of Access Management Tools
- NCHRP 420: Impacts of Access Management Techniques
- NCHRP Synthesis 304: Driveway Regulation Practices
- NCHRP Synthesis 337: Cooperative Agreements for Corridor Management
- NCHRP Report 348: Access Management Guidelines for Activity Centers
- NCHRP Synthesis 351: Access Rights
- NCHRP Report 395: Capacity and Operational Effects of Midblock Left-Turn Lanes
- NCHRP Report 524: Safety of U-Turns at Unsignalized Median Openings
- NCHRP Report 548: Median Intersection Design for Rural High-Speed Divided Highways

8.2.1 Description

Access management plays an important role in the operation and safety of arterial streets needing both mobility of through traffic and access to adjacent properties. Studies have repeatedly shown that improvements in access management improve safety and capacity, and also that roadways with poor access management have safety and operations records worse than those with better control of access. Treatments to improve access management near intersections (within 250 ft upstream or downstream) include changes in infrastructure, geometry, or signing to close or combine driveways, provide turn lanes, or restrict or relocate turn movements.

TRB's *Access Management Manual* states that access management programs seek to limit and consolidate access along major roadways, while promoting a supporting street system and unified access and circulation systems for development. The result is a roadway that functions safely and efficiently for its useful life, and a more attractive corridor. The goals of access management are accomplished by applying the following principles [90]:

- Provide a specialized roadway system.
- Limit direct access to major roadways.
- Promote intersection hierarchy.
- Locate signals to favor through movements.
- Preserve the functional area of intersections and interchanges.
- Limit the number of conflict points.
- Separate conflict areas.
- Remove turning vehicles from through-traffic lanes.
- Use non-traversable medians to manage left-turn movements.
- Provide a supporting street and circulation system.

Access management works best when combined with land use and zoning policies. Agencies can also regulate aspects of access management through geometric design and ingress/egress spacing.

8.2.2 **Applicability**

Examples of when to improve access management at an intersection include situations where through vehicles experience delay due to vehicles turning left or right into intersections, such as from major and minor streets (signalized and unsignalized) and from driveways, and when rear-end or angle crashes occur involving vehicles entering or leaving driveways.

8.2.3 **Design Features**

Practitioners should determine the functional area of the signalized intersection, as shown in Exhibit 8-7, to understand the upstream and downstream effects of a signalized intersection on access management. The functional area is larger than the physical area of the intersection because it includes several items, as shown in Exhibit 8-8.[90]

- Distance *d1*: Distance traveled during perception-reaction time as a driver approaches the intersection, assuming 1.5 s for urban and suburban conditions and 2.5 s for rural conditions.
- Distance *d2*: Deceleration distance while the driver maneuvers to a stop upstream of the intersection.
- Distance *d3*: Queue storage at the intersection.
- Distance immediately downstream of the intersection so that a driver can completely clear the intersection before needing to react to something downstream (stopping sight distance is often used for this).

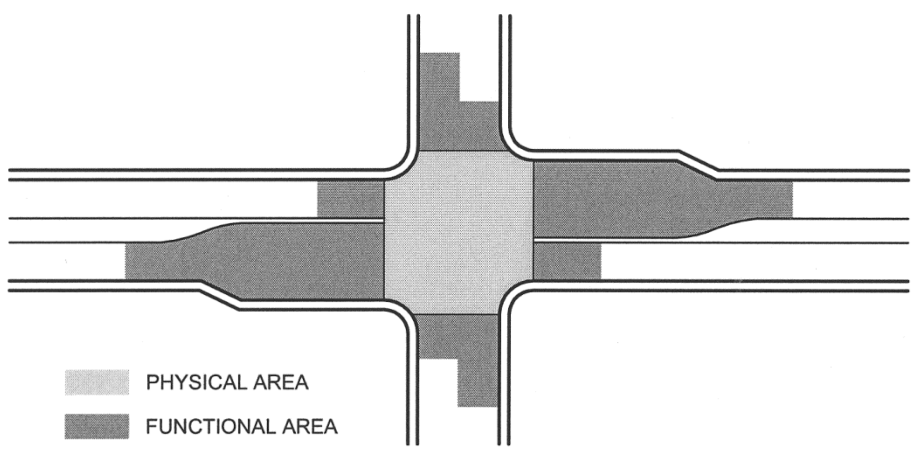


Exhibit 8-7. Comparison of physical and functional areas of an intersection.[90]

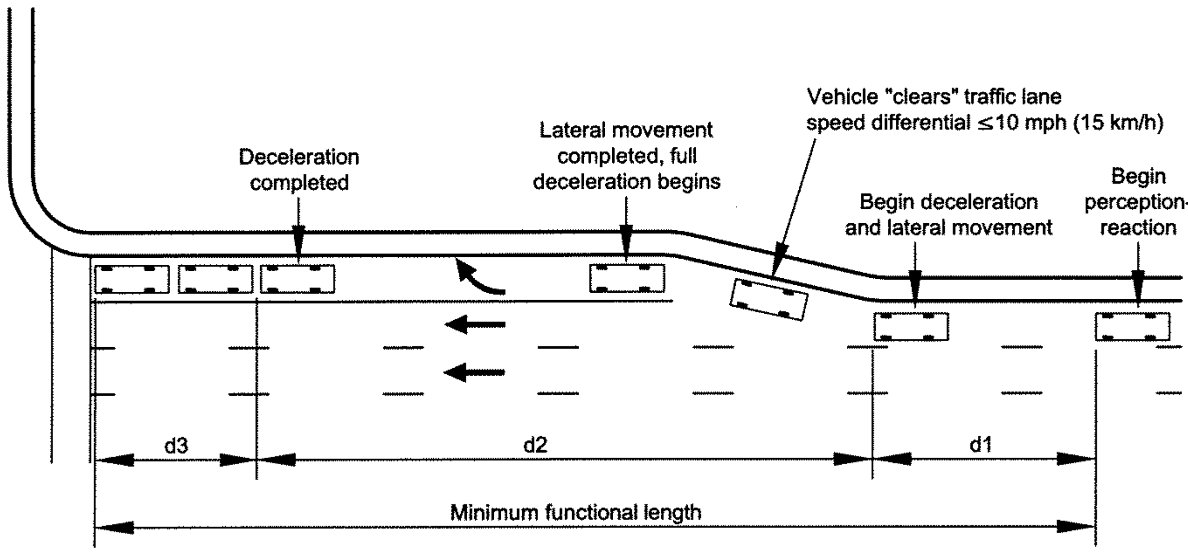


Exhibit 8-8. Diagram of the upstream functional area of an intersection.[90]

Consider overlapping functional areas' varying levels of access when addressing two proximal signalized intersections. Exhibit 8-9 shows how the functional areas of nearby signalized intersections affect the location and extent of feasible access. Ideally, driveways with full access should be located outside of the functional areas of both signalized intersections. However, signalized intersections are often located close enough to each other that the downstream functional area of one intersection overlaps with the upstream functional area of the other. In these cases, there is no clear area between the two intersections where a driveway can operate without infringing upon the functional area of one of the signalized intersections. As such, practitioners should apply sound engineering judgment regarding where and if to allow a driveway. Some important considerations in the evaluation include:

- The volume and type of traffic using the driveway.
- The type of turning maneuvers that will be most prominent.
- The type of median present and potential conflicts with and proximity to other driveways.
- The types and severity of existing crashes in the vicinity.
- The volume of traffic on the major street.

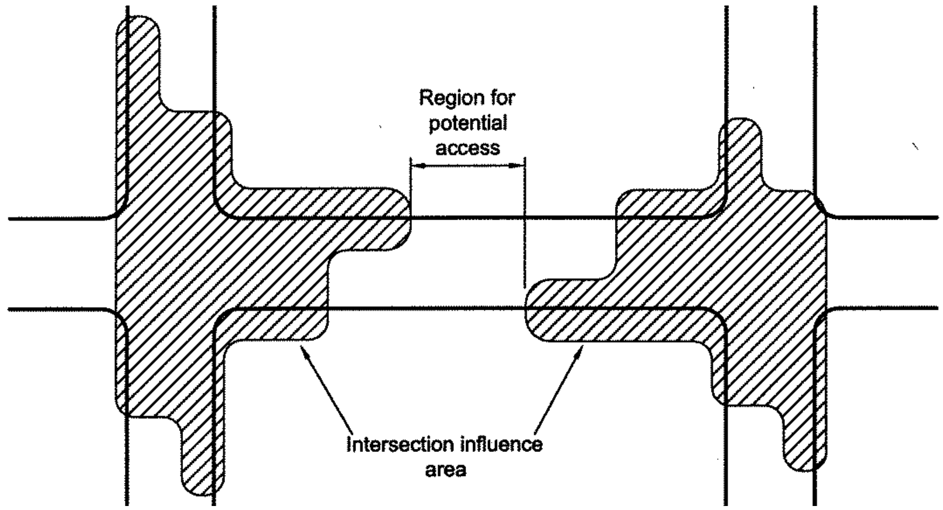
Access points clear of only one of the two signalized intersections would likely perform best from a safety perspective if restricted to right-in, right-out operation. However, in urban areas, this may not always be practical or may create other problems at downstream intersections, so again it is important to apply sound engineering judgment. In some cases, the two signalized intersections may be so close together that any access would encroach within the functional area of the intersections. These situations are likely candidates for either partial or full access restriction. It is important to note that driveways should not be simply eliminated based on general guidelines but rather should be evaluated on a case-by-case basis with consideration of the broader system effects. When driveways are closed without any regard to the system effects, there is a high potential that the problem will be transferred to another location. Finally, as a general guideline, the functional area of an intersection is more critical along corridors with high speeds (45 mph or greater) and whose primary purpose is mobility. If the corridor has a two-way left-turn lane design and driveways are placed indiscriminately, there is a high likelihood for angle crashes, and safety becomes the driving factor.

Improvements to the current access to properties adjacent to an intersection area can be implemented by:

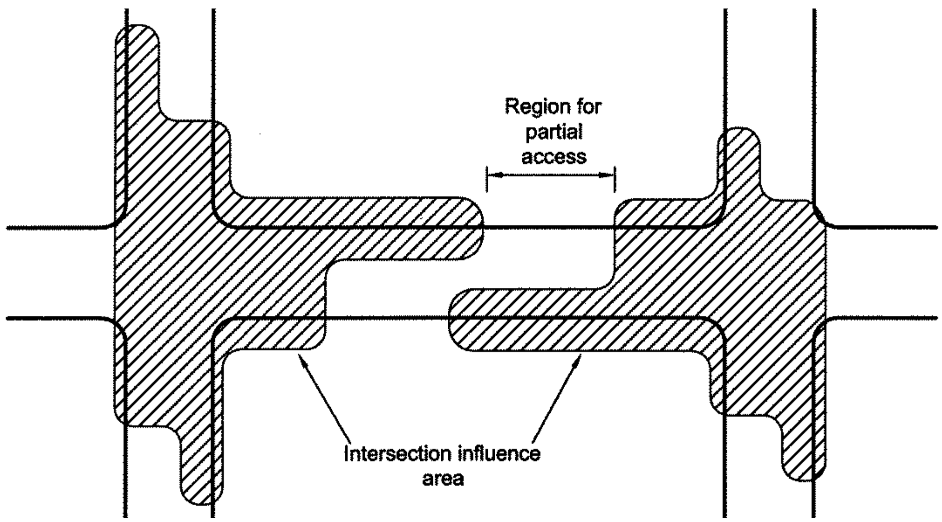
- Closing, relocating, or combining driveways.
- Restricting turning movements through the use of median treatments, using driveway treatments, and/or the installation of signing.

As discussed previously, where access is restricted, the redirection of driveway traffic needs to be considered. Two of the more typical options are:

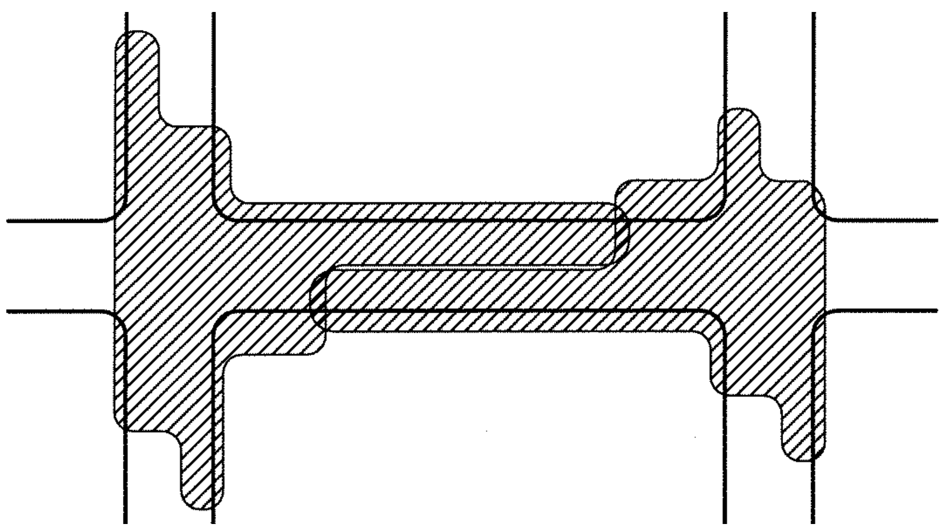
- Require drivers to make a U-turn at a downstream, signalized intersection (Exhibit 8-10). This requires adequate cross-section width to allow the U-turn and sufficient distance to the downstream intersection to weave across the through travel lanes. In addition to increasing the traffic volumes at the signalized intersection, U-turns also decrease the saturation flow rate of the left-turn movement. These combined effects potentially decrease the available capacity at the signalized intersection if the affected left-turn movement is a critical movement at the intersection.
- Create a midblock opportunity for drivers to make an unsignalized U-turn maneuver via a directional median opening (Exhibit 8-11). A study in Florida evaluated the safety effect of these directional median openings on six-lane divided arterials with large traffic volumes, high speeds, and high driveway/side-street access volumes.(91) This study found a statistically significant reduction in the total crash rate of 26.4 percent as compared with direct left turns.



(a) Minimal amount of potential adverse effects due to adjacent signalized intersections.



(b) Moderate amount of potential adverse effects due to adjacent signalized intersections.



(c) Substantial amount of potential adverse effects due to adjacent signalized intersections.

Exhibit 8-9. Access points near signalized intersections.(adapted from 90, figure 8-15)

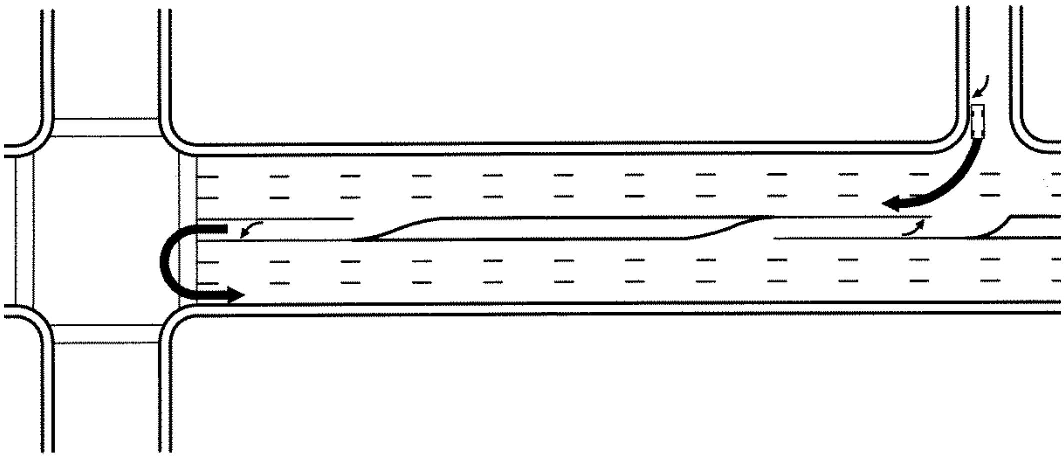


Exhibit 8-10. Access management requiring U-turns at a downstream signalized intersection.

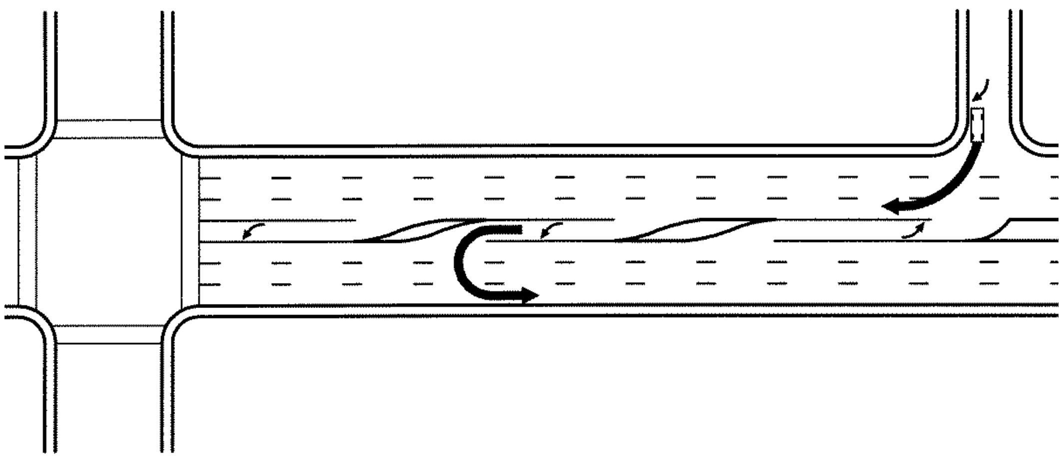


Exhibit 8-11. Access management requiring U-turns at an unsignalized, directional median opening.

Note that the conversion of an existing full-access point to right-in/right-out operation has both advantages and disadvantages. The advantages of right-in/right-out operation include:

- Removal of movements from the functional area of the signalized intersection. This reduces conflicts near the signalized intersection and improves capacity by minimizing discord in driver maneuvers.
- Better operation for the driveway. Eliminating left turns out of the driveway generally reduces delays for the driveway movements.

Disadvantages include:

- Increase in U-turn movements at signalized intersections or at other unsignalized locations. This may reduce the available capacity at the intersection and increase delay. This may also increase the potential for left-turn crashes at the location of the U-turn.
- Increase in arterial weaving. This may happen as the driveway movement attempts to get into position to make the U-turn.
- Potential for increased demand for left turns at other driveways serving the same property.

As with other access management treatments, involvement of property owners in the decision-making and design process is key to the success of the project.

8.2.4 Safety Performance

In general, an increase in the number of access points along a roadway correlates with higher crash rates. Specific relationships vary based on specific roadway geometry (lane width, presence or absence of turn lanes, sight distance, etc.) and traffic characteristics.

Exhibit 8-12 presents a summary of the relative crash rates for a range of unsignalized intersection access spacing. As can be seen, doubling access frequency from 10 to 20 access points per mile increases crash rates by about 40 percent. An increase from 10 to 60 access points per mile would be expected to increase crash rates by approximately 200 percent. Generally, each additional access point per mile along a four-lane roadway increases the crash rate by about 4 percent (see also references 92 and 93).

Exhibit 8-12. Relative crash rates for unsignalized intersection access spacing.*

Unsignalized Access Points Spacing**	Average Spacing***	Relative Crash Rate****
10 per mi	1056 ft	1.0
20 per mi	528 ft	1.4
30 per mi	352 ft	1.8
40 per mi	264 ft	2.1
50 per mi	211 ft	2.4
60 per mi	176 ft	3.0
70 per mi	151 ft	3.5

*Source: Reference 90, as adapted from 88.

**Total access connections on both sides of the roadway.

*** Average spacing between access connections on the same side of the roadway; one-half of the connections on each side of the roadway.

**** Relative to the crash rate for 10 access points per mi.

Removing or limiting access to restrict specific movements, such as right-in/right-out access, both have positive impacts to crash severity, congestion, and operational speeds. In *Safe Access is Good for Business*, FHWA states that where access is well-managed operating speeds are 15-20 mph higher. Restricting movements may require adding horizontal and vertical features, such as raised islands, which may contribute to an increase in fixed object crashes.[199]

8.2.5 **Operational Performance**

Reducing access along an arterial street can improve traffic operations. For example, urban arterials with a high degree of access control function 30 to 50 percent better than the same facility with no control.(94) Improved access management also has been shown to improve LOS.(95) Controlling the flow of traffic through restricting and managing accesses can reduce delay.

Access points close to a signalized intersection can reduce the saturation flow rate of the signalized intersection. Research has determined that the amount of reduction depends on the corner clearance of the driveway, the proportions of curb-lane volume that enter and exit the driveway, and the design of the driveway itself.(96)

However, as indicated earlier, practitioners should evaluate the impact of access control on the upstream and downstream intersections, which may experience a significant increase in U-turns or other types of turning movements. For example, eliminating left-turn movements and converting them to U-turns at signalized intersections could degrade arterial operational performance if adequate capacity to accommodate the turning movements at midblock access driveways exists, because less green time will be available for through traffic. This could substantially reduce capacity and increase delay at the signalized intersection.

8.2.6 **Multimodal Impacts**

Access treatments that reduce the number of driveways or restrict turning movements at driveways also reduce the number of potential conflicts for pedestrians and bicycles near a signalized intersection. In addition, a median treatment used as part of an overall access management strategy also provides the opportunity for a midblock signalized or unsignalized pedestrian crossing. Practitioners should evaluate whether the considered access treatments would result in a significant increase in operating speed on the facility, as increases in speed have a negative impact on both pedestrians and bicyclists that should be considered in the evaluation.

8.2.7 **Physical Impacts**

Several solutions exist for access management that can affect the footprint of the intersection area. The addition of U-turn lanes for property access will increase the roadway width of the intersection area. Turn restrictions may affect the physical size of an area if a vertical element is added to the intersection (for example a raised curb, median barrier, or flexible delineators used to prohibit left turns). In order for these not to present difficulties for pedestrians with mobility impairments, it may be necessary to provide a cut through.

8.2.8 **Socioeconomic Impacts**

Literature review indicates inconsistency in the socioeconomic effects of access management. Surveys conducted in Florida reported a relatively low rate of acceptance of access management: most drivers felt that the inconvenience of indirect movements offset the benefits to traffic flow and safety. Businesses also were unsupportive: 26 percent reported a loss in profits, and 10 to 12 percent reported a large loss.(97) Conversely, experience in Iowa indicates rapid growth in retail sales after access management projects were completed. An opinion survey conducted among affected motorists indicated that a strong majority supported all projects but one.(95) In *Safe Access is Good for Business,* FHWA states that, where access is managed properly, operating speeds are 15 to 20 mph higher, which yields an increased exposure to more potential customers. The publication also states that "before and after" studies of businesses in Florida, Iowa, Minnesota, and Texas along highways where access has been managed found that the vast majority of businesses do as well or better after the access management projects are completed.

The reactions of drivers, property owners, pedestrians, and others concerned with access to properties adjacent to intersections vary widely. Access management strategies should be considered in the context of a roadway corridor with the approval and backing of those affected or if significant safety and operational enhancements can be achieved. A decrease in crashes and traveler delay from applying access management principles can result in considerable societal savings.

Redesign, relocation or closing of driveways should be part of a comprehensive corridor access-management plan. The optimal situation is to avoid driveway conflicts before they develop. This requires coordination with local land use planners and zoning boards in establishing safe development policies and procedures. Avoidance of high-volume driveways near congested or otherwise critical intersections is desirable.

Highway agencies should also understand the safety consequences of driveway requests. The power of a highway agency to modify access provisions is derived from legislation that varies in its provision from State to State. Highway agencies generally do not have the power to deny access to any particular parcel of land, but many do have the power to require, with adequate justification, relocation of access points. Where highway agency powers are not adequate to deal with driveways close to intersections, further legislation may be needed.

8.2.9 **Enforcement, Education, and Maintenance**

Periodic enforcement may be needed to ensure that drivers obey restrictions at driveways where such restrictions cannot be physically implemented with raised channelization, such as signed prohibitions. If raised channelization is used corridor-wide, it may be necessary to team with enforcement to provide openings for emergency turnarounds.

Education other than appropriate signing should not be needed when implementing changes to access unless major changes to access management are made along a corridor, requiring a fundamental shift in driver behavior.

8.2.10 **Summary**

Exhibit 8-13 summarizes issues associated with providing access management.

Exhibit 8-13. Summary of issues for providing access management.

Characteristic	Potential Benefits	Potential Liabilities
Safety	Fewer access points generally result in a lower crash rate along a corridor. Physical segregation of opposing traffic flows if barrier or curb is used as an access management strategy.	Turn restrictions may require adding horizontal and vertical features to driveways, which may contribute to an increase in fixed object crashes.
Operations	Fewer access points generally result in an increase in LOS and capacity.	An increased number of U-turns at a signalized intersection due to access management may reduce the overall capacity of the intersection. An increase in weaving as vehicles entering the highway attempt to turn left at signalized intersections.
Multimodal	Fewer access points reduce the number of potential conflicts for bicycles and pedestrians.	Potential increases in operating speed along the arterial may negatively impact safety relative to bicycle and pedestrian modes.
Physical	None identified.	Turn restrictions may require adding horizontal and vertical features to driveways.
Socioeconomic	Socioeconomic benefits are mixed, with some studies reporting economic improvement and others reporting economic losses. Societal cost savings attributed to decreased crashes and travel delay.	Both economic improvement and economic losses have been reported.
Enforcement, Education, and Maintenance	None identified when raised channelization is used.	Periodic enforcement may be needed where signs are used instead of raised channelization. May be necessary to educate motorists on access options if corridor wide improvements are made, and provide emergency turnarounds for enforcement. Additional costs may be incurred for maintenance with the installation of physical barriers preventing access.

8.3 SIGNAL COORDINATION

8.3.1 Description

The primary objective of signal coordination is smooth flow of traffic along an arterial, street, or a highway to improve mobility, safety, and fuel consumption. This can be achieved by synchronizing the signal timings at multiple intersections along a major street to improve traffic flow in one or more directional movements. Examples include arterial streets, downtown networks, and closely spaced intersections like diamond interchanges. Intersections should be coordinated when they are in close proximity to each other (i.e., 0.5 miles or less) and there is a significant amount of traffic on the street being coordinated.[66] Coordination can also improve travel time reliability; reduce travel time, stops and delay; and improve air quality.[201]

Coordination also has other benefits. Drivers may have occasional difficulty making permissive turns at signalized intersections because of lack of acceptable gaps in the opposing through traffic. This can contribute to both operational and safety problems. Providing coordination can create platooning of through traffic, resulting in availability of more acceptable gaps to left-turning traffic. Increasing acceptable gaps can improve intersection capacity and safety.

8.3.2 **Applicability**

Signal coordination may be applicable for intersections where:

- Lack of coordination is causing unexpected and/or unnecessary stopping of traffic approaching from adjacent intersections.
- Congestion between closely spaced intersections is causing queues from one intersection to interfere with the operation of another.
- Rear-end conflicts/collisions are occurring due to the higher probability of having to stop at each light.

8.3.3 **Safety Performance**

Apart from its operational benefits, signal coordination reduces vehicle conflicts along corridors with coordinated traffic signals. This reduces the number of rear-end conflicts, as vehicles tend to move more in unison from intersection to intersection.

Studies have proven the effectiveness of signal coordination in improving safety. The ITE *Traffic Safety Toolbox: A Primer on Traffic Safety* cites two studies of coordinated signals with intersection crash frequencies that dropped by 25 and 38 percent.[98] One study showed a decrease in crash rates for midblock sections as well. A study on the effectiveness of traffic signal coordination in Arizona concluded that there is a small but significant decrease in crash rates on intersection approaches after signal coordination.[99] Crashes along the study corridor decreased 6.7 percent. Another study of the safety benefits of signal coordination carried out in Phoenix compared coordinated signalized intersections to uncoordinated signalized intersections citywide. The coordinated intersections were found to have 3 to 18 percent fewer total collisions, and 14 to 43 percent fewer rear-end collisions.[100]

Exhibit 8-14 shows selected findings of safety benefits associated with signal coordination.

Treatment	Finding
Signal Coordination[100]	3 to 18% estimated reduction in all collisions along corridor 14 to 43% estimated reduction in rear-end collisions along corridor
Provide Signal Progression[101]	10 to 20% estimated reduction in all collisions along corridor

Exhibit 8-14. Selected findings of safety effects associated with signal coordination or progression.

8.3.4 **Operational Performance**

The potential benefits of coordination directly relate to the traffic characteristics and spacing of intersections. Coordinated operation works best when traffic arrives in dense platoons. These platoons occur more frequently when the intensity of traffic volume between intersections increases and distance between intersections decreases, to a practical limit. Selection of the system cycle length defines the relationship that allows coordinated operations between the intersections, while the offset represents the difference in start or end times for the through green at adjacent intersections.

The primary parameters to implement coordination are cycle lengths, splits, offsets and phasing sequences. Coordination requires a fixed background cycle length for all intersections within a specific coordination plan. Selection of an appropriate cycle length for a system is crucial for two reasons. First, the cycle length should be able to service the expected vehicle and pedestrian demand on all movements by selecting the appropriate split (time allocated to service each movement). Second, the cycle length should facilitate good progression along the major street. Coordination is then achieved by adjusting the offsets (a function of start or end of a major street green with respect to the start or end of major street green for the adjacent intersection). These offsets are fine-tuned in the field to ensure that any residual queues are cleared before the arrival of platoons for smooth progression. Finally, progression can sometimes be further improved by modifying the signal phasing for left turns (e.g., implementing a lead-lag sequence).

A key to success in signal coordination is the appropriate spacing of the signals. Signals within a half-mile (or sometimes even more if platooning can be maintained) of each other should be coordinated. Dispersion of platoons can occur if signals are spaced too far apart, resulting in inefficient use of signal coordination and loss of any operational benefit. Operations on cross streets may be negatively impacted. The Colorado Access Demonstration Project concluded that 0.5-mi spacing could reduce vehicle hours of delay by 60 percent and vehicle-hours of travel by over 50 percent compared with signals at one-quarter mile intervals with full median openings between signals.(90, adapted from reference 102)

Grouping the signals into a system to be coordinated is an important aspect of the design of a progressive system. Factors that should be considered include geographic barriers, v/c ratios, and characteristics of traffic flow (random versus platoon arrivals). When systems operating on different cycle lengths are adjacent to or intersect each other, changes to provide a uniform cycle length appropriate for both systems should be considered so that the systems can be unified, at least for certain portions of the day.

Coordination is effective in improving throughput along a major thoroughfare. However, during oversaturated conditions the objective typically changes from providing progression to managing queues. The traffic engineer needs to identify the period of oversaturated conditions and select the appropriate cycle length, splits, offsets, and phasing sequences to ensure smooth movement of traffic under such conditions by management of queues.

Dependent on the spacing between signalized intersections, prevalence of certain movements, or a disparity in ideal cycle lengths of each signalized intersection, it may be beneficial to consider half or double cycles, respective of other cycle lengths that appear on the corridor. Double cycles allow an intersection to cycle twice as frequently as a major intersection, while half cycles have half the cycle length of a major intersection along the corridor. According to FHWA's *Traffic Signal Timing Manual*,(66) half cycles can often produce substantially lower delays at the minor intersections where double cycling is employed. However, it may become more difficult to achieve progression in both directions along the major arterial, which may result in more arterial stops than desired.

8.3.5 **Multimodal Impacts**

Progression along a transit route can reduce travel time and improve travel time reliability of transit vehicles. The transit agency should also play a role. They can design their stops appropriately with respect to traffic signals to take advantage of the progression being provided along the corridor.

8.3.6 **Physical Impacts**

Signal coordination may require overhead or underground installation of wire, fiber, or radio equipment if direct connection type of coordination is employed.

8.3.7 **Socioeconomic Impacts**

Signal coordination will also reduce fuel consumption, noise, and air pollution, by reducing the number of stops and delays. If traffic signals are retimed and maintained properly, we would see a reduction in harmful emissions (carbon monoxide, nitrogen oxides, and volatile organic compounds) of up to 22 percent.(202) According to the Surface Transportation Policy Project, motor vehicles are the largest source of urban air pollution.(203) In addition, the EPA estimates that vehicles generate 3 billion pounds of air pollutants annually.(204)

8.3.8 Enforcement, Education, and Maintenance

Signals working in coordination should reduce excessive speed, as motorists realize that they cannot “beat” the next traffic signal. Incidents of aggressive driving should be reduced as well.

Signal timing plans need to be updated as traffic volumes and patterns change. This should be factored into periodic maintenance of the traffic signal.

8.3.9 Summary

Exhibit 8-15 summarizes the issues associated with providing signal coordination.

Characteristic	Potential Benefits	Potential Liabilities
Safety	Fewer rear-end and left-turn collisions.	May promote higher speeds.
Operations	Improves traffic flow.	Usually longer cycle lengths.
Multimodal	May reduce pedestrian-vehicle conflicts.	May result in longer pedestrian delays due to longer cycle lengths.
Physical	No physical needs.	None identified.
Socioeconomic	Reduces fuel consumption, noise, and air pollution.	None identified.
Enforcement, Education, and Maintenance	May result in less need for speed enforcement.	Signal timing plans need periodic updating.

Exhibit 8-15. Summary of issues for providing signal coordination.

8.4 SIGNAL PREEMPTION AND/OR PRIORITY

8.4.1 Description

Signal preemption and signal priority are terms describing treatments for special needs (e.g., drawbridge, railroad crossing), special vehicle classes or vehicles with multiple users, relative to automobile traffic at the intersection. Signal preemption is the higher order of the two treatments and involves transferring the intersection’s signal controller into a special operating mode designed to clear the intersection, if necessary, and then service the special vehicle type or need. The two most common types of signal preemption are emergency vehicle preemption and railroad preemption.

Priority is defined as the preferential treatment of one vehicle class (such as a transit vehicle, emergency service vehicle, or a commercial fleet vehicle) over another vehicle class at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations. Priority may be accomplished by a number of methods, including changing the beginning and end times of greens on identified phases, changing the phase sequence, or including special phases, all without interrupting the general timing relationship between specific green indications at adjacent intersections.

8.4.2 Emergency Vehicle Preemption

A specific vehicle often targeted for signal preemption is the emergency vehicle. Signal preemption allows emergency vehicles to disrupt a normal signal cycle to proceed through the intersection more quickly and under safer conditions. The preemption systems can extend the green on an emergency vehicle’s approach or replace the phases and timing for the whole cycle. The MUTCD discusses signal preemption, standards for the phases during preemption, and priorities for different vehicle types that might have preemption capabilities.[1]

Several types of emergency vehicle detection technologies are available. These include the use of light, sound, pavement loops, radio transmission, and push buttons to detect vehicles approaching an intersection:

- Light—an emitter mounted on emergency vehicles sends a strobe light toward a detector mounted at the traffic signal, which is wired into the signal controller.
- Sound—a microphone mounted at the intersection detects sirens on approaching vehicles; the emergency vehicles do not need any additional equipment to implement signal priority systems.
- Pavement loop—a standard pavement loop connected to an amplifier detects a signal from a low frequency transponder mounted on the emergency vehicle.
- Push button—a hardwire system is activated in the firehouse and is connected to the adjacent signal controller.
- Radio—a radio transmitter is mounted on the vehicle and a receiver is mounted at the intersection.

Many of these systems have applications in transit-vehicle priority as well as signal preemption for emergency vehicles. Some jurisdictions use signs that alert drivers of a police pursuit in progress.

8.4.3 **Railroad Preemption**

When located in close proximity to rail-highway grade crossings, signalized intersections can use railroad preemption to ensure that vehicles safely clear the crossing prior to train arrival. Operation of the grade crossing's active warning devices (flashing lights or flashing lights with gates) can be synchronized with the traffic signal display such that any active vehicular or pedestrian phases that conflict with the phase(s) servicing the intersection leg with the grade crossing are safely terminated, and then the phase(s) clearing vehicles from the grade crossing are activated with sufficient time to clear the crossing before train arrival.

The signal initiating railroad preemption originates from the track circuit and train detection equipment provided by the railroad for actively-controlled grade crossings. Variations exist in the design of the preemption interconnect circuit and track detection and warning system, but all share the purpose of providing adequate warning time of train arrival to both approaching motorists and the traffic signal controller. In special cases, advance preemption is used to alert the traffic signal controller about the impending arrival of a train before the grade crossing's active warning system (i.e., flashing lights with or without gates) begins operation. Proper design of signal timing for preemption operation is covered in the ITE *Preemption of Traffic Signals Near Railroad Crossings: An ITE Recommended Practice*.[205]

8.4.4 **Transit Vehicle Priority**

Unlike preemption, traffic signal priority operates within the context of a signal's routine operational mode. Also, while the immediacy of preemption requests allows the shortening of pedestrian walk and clearance intervals, these changes to routine signal operation are not allowed with signal priority. A variety of methods can be used to provide priority to buses or light rail vehicles, including extending green on identified phases, altering phase sequences and including special phases without interrupting the coordination of green lights between adjacent intersections.[66]

Several different technologies are available for generating a priority request for the transit vehicle on approach to a signalized intersection. Pavement loops and radio (which can also be used for emergency vehicle preemption) can be employed in transit detection and signal interconnection, and even train detection circuits for light rail transit can be used. One emerging technology uses global positioning system (GPS) technology in accordance with the transit agency's automatic vehicle location (AVL) system to transmit a priority request signal in conjunction with a roadside reader near the signal controller or remotely using the Internet and communication between the transit and road authority. Whether a priority request is granted and can be accommodated by the traffic signal controller can be affected by the current controller state and whether or not the transit vehicle is behind schedule at the time the priority request is received.

8.4.5 **Applicability**

Preemption/priority is considered where:

- Normal traffic operations impede a specific vehicle group (i.e., emergency vehicles).
- Traffic conditions create a potential for conflicts between a specific vehicle group and general traffic.

8.4.6 **Safety Performance**

No known research addresses the safety implications of emergency vehicle preemption, although it is expected that the number of conflicting movements associated with an emergency vehicle having to run a red light would be reduced.

Installation of signal preemption systems for emergency vehicles decreases response times. A review of signal preemption system deployments in the United States shows decreases in response times between 14 and 50 percent for systems in several cities. In addition, the study reports a 70 percent decrease in crashes with emergency vehicles in St. Paul, MN, after deploying the system.[(103)]

Signal preemption has also been considered for intersections at the base of a steep and/or long grade. These grades create a potentially dangerous situation if large trucks lose control and enter the intersection at a high speed. Preemption can reduce the likelihood of conflicts between runaway trucks and other vehicles.

8.4.7 **Operational Performance**

Preemption of signals by emergency vehicles will temporarily disrupt traffic flow. Congestion may occur, or worsen, before traffic returns to normal operation. Data gathered on signal preemption systems in the Washington, DC, metropolitan area suggested that once a signal was preempted, the coordinated systems took anywhere between half a minute to 7 minutes to recover to base time coordination. During these peak periods in more congested areas, vehicles experienced significant delays. Agency traffic personnel indicated that signal preemption seems to have more impacts on peak period traffic in areas where the peak periods extend over longer time periods than it does where peak periods are relatively short.[(103)]

8.4.8 **Multimodal Impacts**

Priority for transit vehicles can enhance transit operations, reducing delays and allowing for a tighter schedule, with minimal impacts to pedestrians and bicyclists. A study in King County, Washington showed that transit signal priority coupled with signal timing optimization resulted in a 40 percent reduction in transit signal delay and a 35 to 40 percent reduction in travel time variability. In Portland, Oregon, transit signal priority improved travel time by 10 percent and reduced travel time variability by 19 percent.[(206)]

8.4.9 **Physical Impacts**

The key to success is ensuring that the preemption system works when needed by providing clear sight lines between emergency vehicles and detectors. Also, practitioners should ensure that vehicles from a variety of jurisdictions can participate in the signal preemption program.

Light-based detectors need a clear line of sight to the emitter on the vehicles; this line could become blocked by roadway geometry, vehicles, foliage, or precipitation. Also, systems from different vendors may not interact well together. Other alarms, such as from nearby buildings, may be detected by a sound-based system.

8.4.10 **Socioeconomic Impacts**

Reduction in response time by emergency services and more predictable transit services benefit society. However, the costs, particularly when applied to an entire road network, can be significant.

8.4.11 **Enforcement, Education, and Maintenance**

Preemption directly benefits emergency vehicles, although most police agencies do not use signal preemption. Preempted signals that stop vehicles for too long may encourage disrespect for the red signal, although this has not been reported.

8.4.12 **Summary**

Exhibit 8-16 summarizes the issues associated with providing signal preemption and/or priority.

Characteristic	Potential Benefits	Potential Liabilities
Safety	Quicker response time for emergency vehicles. On steep grades, preemption could be used to minimize conflicts between runaway trucks and other vehicles.	None identified.
Operations	None identified.	Can be disruptive to traffic flow, particularly during peak hours.
Multimodal	Delay to transit vehicles and travel time variability is reduced.	None identified.
Physical	None identified.	Requires a clear line of sight between the emergency vehicle and the transmitter; other nearby radio systems may be affected or interfere.
Socioeconomic	Lower emergency service response time. More reliable transit service.	Can be costly.
Enforcement, Education, and Maintenance	Improves emergency vehicle response time.	None identified.

Exhibit 8-16. Summary of issues for providing signal preemption and/or priority.