CHAPTER 9

INTERSECTION-WIDE TREATMENTS

TABLE OF CONTENTS

LIST OF EXHIBITS

9.0 INTERSECTION-WIDE TREATMENTS

This chapter discusses five groups of intersection-wide treatments:

- Pedestrian treatments.
- Bicycle treatments.
- Transit treatments.
- Traffic control treatments.
- Illumination.

9.1 PEDESTRIAN TREATMENTS

Accommodating pedestrians significantly affects the design and operations of a signalized intersection and should therefore be an integral part of the design process. Key actions to consider are:

- Protect crossing locations with a high number of pedestrians (where possible) from conflicting through traffic.
- Minimize crossing distances.
- Provide adequate crossing times.
- Locate pedestrian ramps within the crosswalk.
- Ensure pedestrian ramp location and design meet ADA requirements.
- Consider high visibility cross walk markings.

One common way to better accommodate pedestrians and improve their safety is to reduce their crossing distance. Reducing crossing distance decreases a pedestrian’s exposure to traffic, which may be particularly helpful to pedestrians who are disabled or elderly. It also reduces the amount of time needed for the pedestrian phase, which reduces the delay for all other vehicular and pedestrian movements at the intersection. Three common methods of reducing pedestrian crossing distance are:

- Reducing curb radius
- Extending curbs.
- Providing median crossing islands.

Traffic engineers have also modified the location of the stop line and crosswalk to try to control where motorists stop on the intersection approach and where pedestrians cross.

Traffic control improvements directly applicable to pedestrians include:

- Improving the signal display to the pedestrian through the use of redundancy, including the use of pedestrian signals, accessible pedestrian signals, and enhancements to the pedestrian signal display.
- Modifying the pedestrian signal phasing.

Each of these treatments is discussed in the following sections; median crossing islands were addressed in Chapter 8.

9.1.1 Reduce Curb Radius

Description

A wide curb radius typically results in high-speed turning movements by motorists, increasing the opportunity for right-turning vehicle conflicts with pedestrians. Existing guidelines recommend reconstructing the turning radius to a tighter turn to reduce turning speeds, shorten the crossing distance for pedestrians, and improve sight distance between pedestrians and motorists. Exhibit 9-1 demonstrates that increasing the curb radius increases pedestrian crossing distance. Tighter turning radii are even more important where street intersections are not at right angles.[104]

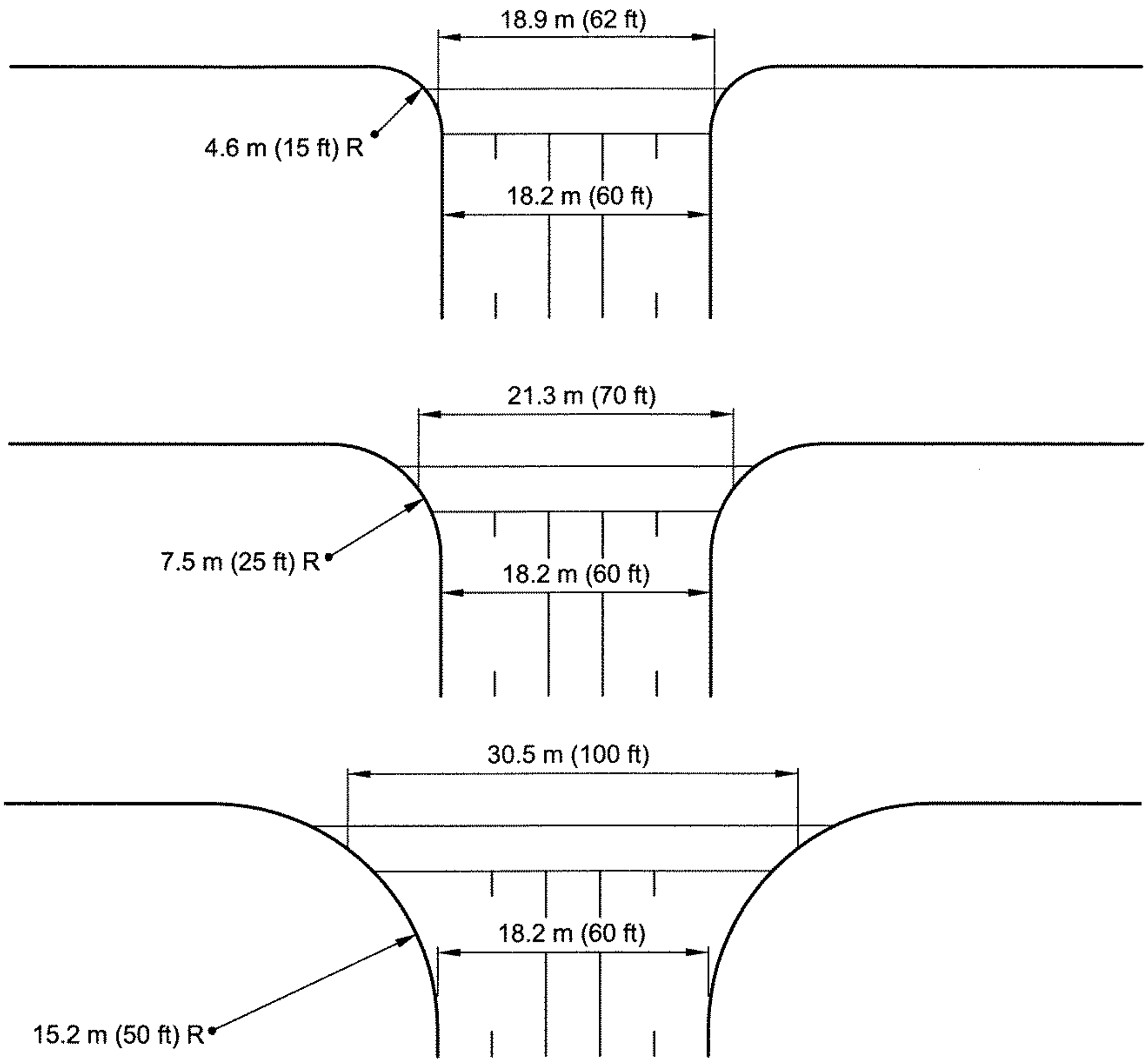


Exhibit 9-1. A curb radius increase from 15 ft to 50 ft increases the pedestrian crossing distance from 62 ft to 100 ft, all else being equal.

Applicability

Consider reducing the curb radii at any signalized intersection with pedestrian activity. Note that the need to accommodate the design vehicle may limit how much the curb radius can be reduced.

Safety Performance

Reducing the curb radius lowers the speed of right-turning vehicles and should reduce the frequency of pedestrian-vehicle collisions. Any remaining collisions will be less severe due to the lower speeds involved. Crash severity increases significantly between 20 and 40 mph.[105]

However, vehicles turning right will be forced to decelerate more rapidly in attempting the right turn. This could lead to rear-end conflicts with through vehicles, particularly if a separate right-turn lane is not provided and the through movements have high speeds.

Operational Performance

Reducing pedestrian crossing distance via smaller curb radii reduces the amount of time needed to serve the pedestrian clearance time. This may result in shorter cycle lengths and less delay for all users. However, a curb radius reduction may reduce the capacity of the affected right-turn movement.

Multimodal Impacts

Pedestrians benefit from a shorter crossing distance and the reduced speed of right-turning vehicles.

Larger vehicles and transit may have difficulty negotiating the tighter corner, either swinging out too far into the intersection or having their rear wheels encroach the curb onto the sidewalk. Caution should be exercised in reducing curb radius if right-turning large trucks or buses are frequent users. It may be necessary to move the stop line locations on the roadway the trucks are turning into to allow them to briefly swing wide into the opposing lanes.

Physical Impacts

Reducing the curb radius reduces the size of the intersection and allows for additional space for landscaping or pedestrian treatments. Traffic signal equipment may need to be relocated.

Socioeconomic Impacts

Depending on the degree of improvement, low to moderate construction costs will be associated with the reconstruction of the curb radius.

Enforcement, Education, and Maintenance

The effectiveness of this treatment may be enhanced by police enforcement of drivers failing to come to a complete stop on a red signal when making a right turn and/or not yielding to pedestrians in the crosswalk.

Summary

Exhibit 9-2 summarizes issues associated with curb radius reduction.

Exhibit 9-2. Summary of issues for curb radius reduction.

Characteristic	Potential Benefits	Potential Concerns
Safety	Reduction in right-turning vehicle/pedestrian collisions. Fewer right-turn-on-red violations.	May increase right-turning/through vehicle rear-end collisions due to increased speed differential. Large vehicle off-tracking.
Operations	Less overall delay due to reduced time needed to serve pedestrian movement.	Reduction in capacity for affected right-turn movement.
Multimodal	Shorter crossing distance. Facilitates the use of two perpendicular ramps rather than a single diagonal ramp.	May be more difficult for large trucks and buses to turn right.
Physical	Reduces the size of the intersection.	None identified.
Socioeconomic	Low to moderate costs.	None identified.
Enforcement, Education, and Maintenance	None identified.	Enforcement of yielding to pedestrians may be necessary.

9.1.2 Provide Curb Extensions

Description

Curb extensions, also known as “bulbouts” or “neckdowns,” involve extending the sidewalk or curb line into the street, reducing the effective street width. These are often used for traffic calming on neighborhood streets, but the technique is applicable for higher volume signalized intersections. Curb extensions improve the visibility of the pedestrian crosswalk. They reduce the amount of roadway available for illegal or aggressive motorist activities such as failing to yield to pedestrians, making high-speed turns, and passing in the parking lane. It has also been observed that motorists are more inclined to stop behind the crosswalk at a curb extension, and that pedestrians are more inclined to wait on the curb extension than in the street. An example of a curb extension is shown in Exhibit 9-3.

Curb extensions provide multiple benefits:

- Improve crosswalk visibility
- Reduce pavement for high-speed turns and passing on right.
- Motorists are more likely to stop.
- Pedestrians are more likely to wait.

Application

This treatment applies to urban intersections with moderate to heavy pedestrian traffic and/or a history of pedestrian collisions. It would not be appropriate at high-speed rural intersections, and caution should be used at intersections with a high proportion of right-turning movements. Curb extensions can be used to terminate parking lanes; care should be exercised if they are used to terminate travel lanes.

Exhibit 9-3. Intersection with curb extension in South Haven, Michigan.
Photo credit: Jeff Shaw, Federal Highway Administration

Safety Performance

Reducing the pedestrian crossing distance and subsequent exposure of pedestrians to traffic should reduce the frequency of pedestrian collisions. A New York City study suggested that curb extensions appear to be associated with lower frequencies and severities of pedestrian collisions.[106] Curb extensions should also reduce speeds on approaches where they are applied.

Operational Performance

The operational performance effects of curb extensions are similar to those for reduced curb radii. The reduction in pedestrian crossing distance reduces the amount of time needed to serve the pedestrian clearance time. This may result in shorter cycle lengths and less delay for all movements. However, the reduced curb radius resulting from the curb extension may reduce the capacity of the affected right-turn movement. If a right-turn lane is present, the curb radius reduction should not impede through movements.

Because curb extensions are essentially a traffic-calming treatment, they will likely reduce speeds and possibly divert traffic to other roads; right-turn movements would be particularly affected by this treatment. Emergency services (fire, ambulance, and police) should be consulted if this treatment is being considered.

Multimodal Impacts

Pedestrians benefit greatly from the provision of curb extensions. The curb extension can greatly improve the visibility between pedestrians and drivers. In addition, the reduction in pedestrian crossing distance reduces pedestrian exposure and crossing time.

Bicycle movements and interactions with motor vehicles need to be considered in the design of any curb extensions.

Practitioners should use caution when considering this treatment along heavy truck routes. All types of trucks and transit vehicles, in particular those needing to turn right at the intersection, would be negatively affected by this treatment.

Physical Impacts

Drainage should be evaluated whenever curb extensions are being considered, as the curb extension may interrupt the existing flow line.

Socioeconomic Impacts

Costs associated with this improvement would be low to moderate.

Enforcement, Education, and Maintenance

No specific effects have been identified.

Summary

Exhibit 9-4 provides a summary of the issues associated with curb extensions.

Characteristic	Potential Benefits	Potential Concerns
Safety	Reduction in right-turning vehicle/pedestrian collisions. Fewer right-turn-on-red violations.	May increase right-turning/through vehicle rear-end collisions due to increased speed differential. Large vehicle off-tracking.
Operations	Less overall delay due to reduction in time needed to serve pedestrian movement.	May adversely affect operation if curb extension replaces a travel lane. Right-turn movements delayed. Emergency vehicles may be significantly delayed.
Multimodal	Shorter crossing distance. Facilitates the use of two perpendicular ramps rather than a single diagonal ramp. Better visibility between pedestrians and drivers.	May be more difficult for large trucks and buses to turn right.
Physical	None identified.	Drainage may be adversely affected.
Socioeconomic	Low to moderate costs.	None identified.
Enforcement, Education, and Maintenance	None identified.	None identified.

Exhibit 9-4. Summary of issues for curb extensions.

9.1.3 Modify Stop Line Location

Description

Visibility is a key consideration for determining the location of stop lines. The FHWA *Pedestrian Facilities Users Guide—Providing Safety and Mobility* suggests advance stop lines as a possible countermeasure.[38] At signalized pedestrian crossing locations, the vehicle stop line can be moved 15 to 30 ft further back from the pedestrian crossing than the standard 4 ft distance to improve visibility of through bicyclists and crossing pedestrians for motorists (and particularly truck drivers) who are turning right. Advanced stop lines benefit pedestrians, as the pedestrians and drivers have a clearer view and more time to assess each other's intentions when the signal phase changes, as shown in Exhibit 9-5.

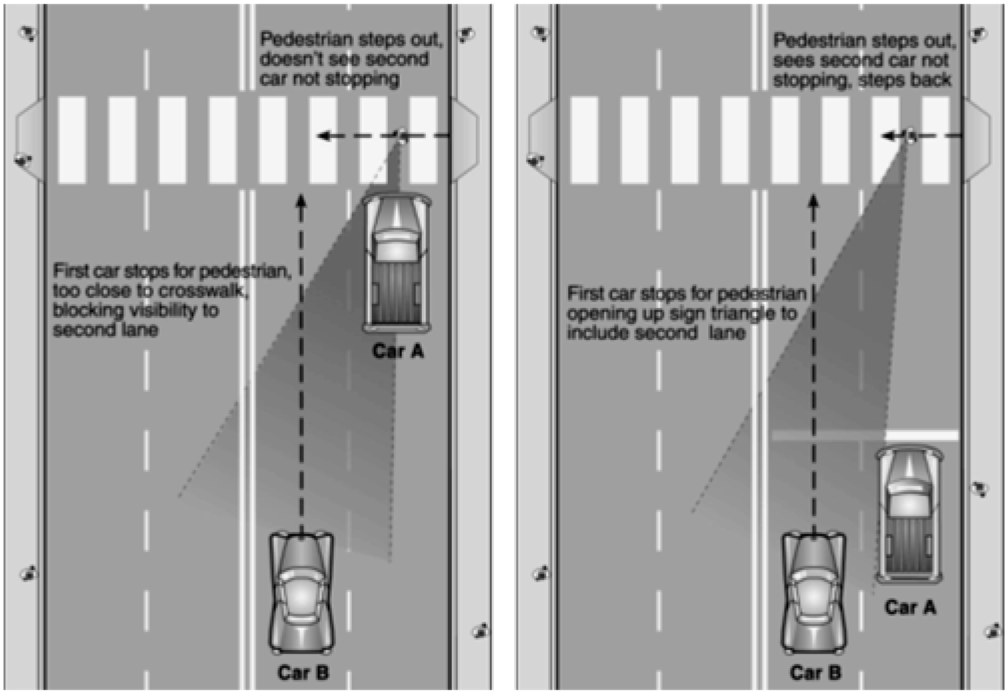


Exhibit 9-5. Benefits of Modifying Stop Line Location
Source: *Crossing Enhancements*, Pedestrian and Bicycle Information Center, www.walkinfo.org.

Applicability

Relocated stop lines may apply to intersections with frequent conflicts between pedestrians and adjacent right-turning vehicles, or a history of right-turn-on-red vehicle/pedestrian collisions.

Safety Performance

One evaluation study found that advance stop lines resulted in reduced right-turn-on-red conflicts with cross traffic; more right-turn-on-red vehicles also made complete stops behind the stop line. Another study determined that stop line relocation resulted in better driver compliance with the new location and increased elapsed time for lead vehicles entering the intersection. This may decrease the risk of pedestrian collisions involving left-turning vehicles.[(104),(108),(109)] However, placing the crosswalk at least 10 ft or more from the cross-street flow line or curb also provides more time for drivers to react for the presence of pedestrian crossing on the street they are about to enter.[(110)]

Operational Performance

Advance stop lines increase the clearance time for vehicles passing through the intersection. As a result, there may be an increase in lost time. If in-pavement stop line vehicle detectors are already installed at this signalized intersection, they may need to be replaced or modified.

Multimodal Impacts

Advance stop lines can better allow trucks entering the intersection from the side street to turn wide, thereby allowing smaller curb radii that are more pedestrian friendly.

Physical Impacts

No physical needs have been identified.

Socioeconomic Impacts

Minimal costs associated with stop line alterations.

Enforcement, Education, and Maintenance

Supplemental signing (e.g., STOP HERE with appropriately oriented downward pointing arrow) and enforcement of the relocated stop lines may be necessary.

Summary

Exhibit 9-6 summarizes the issues associated with stop line alterations.

Characteristic	Potential Benefits	Potential Concerns
Safety	Decreased risk of pedestrian collisions.	None identified.
Operations	None identified.	Increase in vehicular clearance time and lost time.
Multimodal	Facilitates turning movements of heavy trucks.	None identified.
Physical	No physical needs identified.	None identified.
Socioeconomic	None identified.	None identified.
Enforcement, Education, and Maintenance	Improved compliance.	None identified.

Exhibit 9-6. Summary of issues for stop line alterations.

9.1.4 Improve Pedestrian Signal Displays

Traffic signals should allow adequate crossing time for pedestrians and an adequate change and clearance interval based on walking speed. Pedestrian signal enhancements include:

- Separate pedestrian signals (WALK/DON'T WALK)
- Accessible pedestrian signals.
- Countdown displays.
- Animated eyes display.

Application

Chapter 5 provided guidance on the use of pedestrian signals and accessible pedestrian signals. Current thinking suggests that redundancy in information benefits all pedestrians. For example, sighted pedestrians may react more quickly to the WALK indication when provided an audible cue in addition to the pedestrian signal display. Therefore, accessible pedestrian signals may enhance the usability of the intersection for all pedestrians, not just those with visual impairments.

Countdown signals, shown in Exhibit 9-7(a), display the number of seconds remaining before the end of the flashing DON'T WALK interval. The WALKING PERSON symbol and flashing and steady UPRAISED HAND symbol still appear at the appropriate intervals. The countdown signals do not change the way a signal operates; they only provide additional information to the pedestrian. All pedestrian signal heads used at crosswalks where the pedestrian change interval is more than 7 seconds shall include a pedestrian change interval countdown display in order to inform pedestrians of the number of seconds remaining in the pedestrian change interval.[1]

Another innovative pedestrian signal treatment is an animated eyes display, shown in Exhibit 9-7(b). The animated, LED signal head is used to prompt pedestrians to look for turning vehicles at the start of the WALK indication. The signal head includes two eyes that scan from left to right.

Animated eyes are included in the MUTCD for optional use with the pedestrian signal WALK indication.[1]

(a) Countdown display.[111]

(b) Animated eyes display.

Exhibit 9-7. Examples of countdown and animated eyes pedestrian signal displays.

Safety Performance

The available research does not provide a clear indication of the safety effects of installing pedestrian signals. One report suggests that installing pedestrian signals is associated with a 15 to 17 percent reduction in pedestrian collisions.[112] However, a number of older studies found that pedestrian signalization does not improve safety.[113],[114] Larger pedestrian signal heads were described in the literature as a treatment to enhance conspicuity, though no research on the effect on pedestrian safety was found.

Accessible pedestrian signals assist visually impaired pedestrians. Different devices generating audible messages (audible at pedestrian head or audible at push button), vibration at push button, and transmitted messages are in use.[115] A recent study found a 75 percent reduction in the percentage of pedestrians not looking for threats and a similar reduction in conflicts at an intersection equipped with speakers providing messages prompting pedestrians to look for turning vehicles during the walk interval.[116]

Countdown displays may reduce vehicle-pedestrian conflicts resulting from pedestrians attempting to cross the intersection at inappropriate times. Some studies of these pedestrian countdown signals found no statistically significant reductions in pedestrian crash rates. The countdowns did result in a higher percentage of successful crossings by pedestrians (completed their crossing before conflicting traffic received the right-of-way).[110],[117],[118] A 2005 study in San Francisco, California, indicated a reduction of up to 52 percent by converting to countdown signals.[119]

Results from studies of the use of animated-eye displays show increased pedestrian observation of traffic behavior and reductions in pedestrian/vehicle conflicts at a variety of intersection configurations.[116],[120] The 2009 MUTCD allows for and provides a standard for its design (Section 4E.04).

Exhibit 9-8 presents the results of selected references involving the addition of pedestrian signals.

Treatment	Implication
Convert WALK / DON'T WALK pedestrian signals to countdown signals	52% reduction in pedestrian-related crashes.

Exhibit 9-8. Safety effects associated with addition of pedestrian signals: selected findings.[147]

Operational Performance

These treatments should have a negligible effect on vehicle operations. Redundant visual and audible displays may reduce the delay pedestrians experience in initiating their crossing, which may reduce the delay for right-turning vehicles.

Multimodal Impacts

Some treatments described above are of specific benefit to people with visual disabilities, although all pedestrians are likely to benefit from redundancy. They should be considered when modifying intersections.

Apart from pedestrians, there are no specific impacts to other transportation modes.

Physical Impacts

No particular specific physical needs have been identified.

Socioeconomic Impacts

Pedestrian signals and the pedestrian signal enhancements described above have moderate costs.

Enforcement, Education, and Maintenance

As some of the treatments described above have not seen widespread use (e.g., the animated eyes display), some education on the meaning of the devices should be considered upon their introduction to the public.

Summary

Exhibit 9-9 summarizes the issues associated with pedestrian signal display improvements.

Characteristic	Potential Benefits	Potential Concerns
Safety	Give pedestrians improved awareness of traffic.	None identified.
Operations	None identified.	None identified.
Multimodal	All pedestrians, but especially visually impaired pedestrians, are likely to benefit.	None identified.
Physical	None identified.	None identified.
Socioeconomic	None identified.	Some enhancements are expensive.
Enforcement, Education, and Maintenance	None identified.	Education may be necessary.

Exhibit 9-9. Summary of issues for pedestrian signal display improvements.

9.1.5 Modify Pedestrian Signal Phasing

Description

In general, shorter cycle lengths and longer WALK intervals provide better service to pedestrians and encourage greater signal compliance. Pedestrian walking speeds generally range between 2.5 to 6.0 ft/s.[3] The MUTCD uses a walk speed of 3.5 ft/s for determining crossing times (Page 497, Sect. 4E.06-07).[1] However, FHWA pedestrian design guidance recommends a lower speed to accommodate users who require additional time to cross the roadway, and in particular a lower speed in areas where there are concentrations of children and or elderly persons.[37],[38] The *HCM 2000* indicates that if elderly persons constitute more than 20 percent of the total pedestrians, the average walking speed should be decreased to 3.0 ft/s.[2]

Three options beyond standard pedestrian signal phasing are:

- The leading pedestrian interval.
- The lagging pedestrian interval.
- The exclusive pedestrian phase.

A leading pedestrian interval entails retiming the signal splits so that the pedestrian WALK signal begins a few seconds before the vehicular green. While the vehicle signals are in "All Red," this allows pedestrians to establish their presence in the crosswalk before the turning vehicles, thereby enhancing the pedestrian right-of-way.

A lagging pedestrian interval entails retiming the signal splits so that the pedestrian WALK signal begins a few seconds after the vehicular green for turning movement. The 2001 ITE guide, *Alternative Treatments for At-Grade Pedestrian Crossings*, indicates that this treatment is applicable at locations where there is a high one-way to one-way turning movement and works best where there is a dedicated right-turn lane.[110] This benefits right-turning vehicles over pedestrians by giving the right turners a head start before the parallel crosswalk becomes blocked by a heavy and continuous flow of pedestrians.

An exclusive pedestrian signal phase allows pedestrians to cross in all directions at an intersection at the same time, including diagonally. It is sometimes called a "Barnes dance" or "pedestrian scramble." Vehicle signals are red on all approaches of the intersection during the exclusive pedestrian signal phase. The objective of this treatment is to reduce vehicle turning conflicts, decrease walking distance, and make intersections more pedestrian-friendly. The 2001 ITE guide refers to research that indicates that leading intervals were more effective treatments than this scramble pattern.[110]

Application

Leading pedestrian phasing may be considered where:

- There is moderate to heavy pedestrian traffic.
- A high number of conflicts/collisions occur between turning vehicles and crossing pedestrians.

Lagging pedestrian phasing may be considered where:

- There is moderate to heavy pedestrian traffic.
- There is right-turn channelization that is heavily used by vehicles.
- A high number of conflicts/collisions occur between right-turning vehicles and crossing pedestrians.

Exclusive pedestrian phasing (scramble) may be considered where:

- There is heavy pedestrian traffic.
- Delay for vehicular turning traffic is excessive due to the heavy pedestrian traffic.
- There are a large number of vehicle-pedestrian conflicts involving all movements.

Note that for any of the three treatments, practitioners should use accessible pedestrian signals to give people with visual disabilities information regarding the walk phase in the absence of predictable surging traffic.

Safety Performance

Several studies have demonstrated that imposing leading pedestrian intervals significantly reduces conflicts for pedestrians.[(106),(110),(121)] Crash analysis conducted at 26 locations with leading pedestrian intervals in New York City (based on up to 10 years of data) showed that leading pedestrian intervals have a positive effect on pedestrian safety, especially where there is a heavy concentration of turning vehicles. This evidently occurs regardless of pedestrian volume.

None of the studies of lagging pedestrian intervals considered the safety effect of this treatment.

Using exclusive pedestrian intervals that stop traffic in all directions has been shown to reduce pedestrian crashes by 50 percent in some locations (i.e., downtown locations with heavy pedestrian volumes and low vehicle speeds and volumes).[(104),(122)]

Operational Performance

The leading pedestrian phase will increase delay at the intersection due to a loss in green time. A solution for the issue of loss of green time for vehicles when using a leading pedestrian interval is based on trading the leading pedestrian interval seconds at the beginning of the cycle for seconds at the end of the cycle. This causes all movements to receive less green time, but optimizes that time. However, this timing was not investigated empirically.[(106)]

A main operational disadvantage of lagging pedestrian intervals is additional delays to pedestrians.

With concurrent signals, as described above, pedestrians usually have more crossing opportunities and shorter waits. Unless a system more heavily penalizes motorists, pedestrians will often have to wait a long time for an exclusive pedestrian phase. As a result, many pedestrians will simply choose to ignore the signal and cross if and when a gap in traffic occurs.[(104),(122)] In addition, an exclusive pedestrian phase may increase the overall cycle length of the intersection, thus increasing delay for all users. On the other hand, an exclusive pedestrian phase removes pedestrians from the vehicular phases, thus increasing vehicular capacity during those phases.

Multimodal Impacts

Pedestrians may become impatient or ignore a lagging pedestrian interval or exclusive pedestrian phase and begin crossing the road during the DON'T WALK phase.

Physical Impacts

No specific physical needs were identified.

Socioeconomic Impacts

Minimal costs are associated with the retiming of the pedestrian signals. The exclusive pedestrian phase, if implemented, may require additional signing and pavement markings to indicate that diagonal crossings may be made (2009 MUTCD, Section 3B.18).[(1)]

Enforcement, Education, and Maintenance

Leading or lagging pedestrian phases should be accompanied by police enforcement to ensure that vehicles and pedestrians obey traffic signals.

Summary

Exhibit 9-10 summarizes the issues associated with pedestrian signal phasing modifications.

Characteristic	Potential Benefits	Potential Concerns
Safety	Reduce pedestrian/vehicle collisions.	None identified.
Operations	Exclusive phase: increased capacity for vehicular turning movements.	Lead phase: increased vehicular delay. Exclusive phase: increased vehicular delay due to potentially longer cycle length.
Multimodal	Lead phase: reduced pedestrian delay.	Lag phase: increased pedestrian delay. Exclusive phase: increased pedestrian delay due to potentially longer cycle length.
Physical	None identified.	None identified.
Socioeconomic	Lead or lag phases: little or no cost.	Exclusive phase: low cost to implement; moderate costs associated with vehicle delays.
Enforcement, Education, and Maintenance	None identified.	Enforcement may be necessary.

Exhibit 9-10. Summary of issues for pedestrian signal phasing modifications.

9.1.6 Grade-Separated Pedestrian Treatment

Description

In some situations, it may be feasible to separate pedestrian movements from an intersection. Pedestrian overpasses and underpasses allow for the uninterrupted flow of pedestrian movement separate from the vehicle traffic. However, it increases out-of-direction travel, both horizontally and vertically, for the pedestrian in the process.

Applicability

Pedestrian grade separation may be appropriate in situations where:

- An extremely high number of pedestrian/vehicle conflicts or collisions are occurring at the existing crossing location.
- School crossings exist or high volumes of children cross.
- A crossing has been evaluated as a high-risk location for pedestrians.
- Turning vehicles operate with high speeds.
- Sight distance is inadequate.

Usually, a warrant for a grade pedestrian separation is based on pedestrian and vehicle volume, vehicle speed, and area type. Warrants usually differ for new construction projects and existing highways. The first case provides greater opportunities for grade separation. In some cases, safety can be a major factor; for example, New Jersey Department of Transportation guidelines consider pedestrian overpasses and/or underpasses warranted if a safety evaluation indicates that erection of a fence to prohibit pedestrian crossing.[123]

Safety Performance

Ideally, pedestrian grade separations should completely remove any pedestrian/vehicle conflicts at the location in question. However, studies have shown that many pedestrians will not use overpasses or underpasses if they can cross at street level in about the same amount of time, or if the crossing takes them out of their way. Some pedestrians may avoid a pedestrian tunnel or overpass due to personal security concerns.

Operational Performance

Completely eliminating a pedestrian crossing area should improve traffic flow. However, a pedestrian overpass will not likely be used if it is too inconvenient. Use of a median pedestrian barrier or landscaping treatments should be considered to reduce midblock crossings and encourage pedestrians to use the grade-separated crossing.

Multimodal Impacts

Pedestrian access and convenience may be negatively affected by grade separation. Pedestrians with disabilities or low stamina may have difficulty with the out-of-direction travel and elevation changes associated with grade separation.

Physical Impacts

Construction of a bridge overpass or tunnel is required. Note that any new or modified pedestrian grade separation treatment must comply with ADA requirements. This may involve adding long ramps with landings at regular intervals or installing elevators.

Socioeconomic Impacts

Grade separation can be very expensive and difficult to implement. As a result, grade separation is usually only feasible where pedestrians must cross high-speed, high-volume arterials.(104) In most cases, other treatments are likely to be more cost effective.

Enforcement, Education, and Maintenance

Maintenance issues associated with litter and graffiti are significant with pedestrian overpasses and underpasses. Additional police enforcement may be needed because of the fear of crime in these facilities.

Summary

Exhibit 9-11 summarizes the issues associated with pedestrian grade separation.

Characteristic	Potential Benefits	Potential Concerns
Safety	Reduced pedestrian-vehicle collisions. Converting at-grade intersections to grade-separated interchanges is associated with a 57 percent reduction in injury crashes, although this finding is for all road users.[124]	Pedestrians may cross in unexpected locations due to inconvenience of grade separation.
Operations	Improved vehicular capacity.	None identified.
Multimodal	Fewer conflicts between pedestrians and vehicles.	Increased walking distance, delay, and difficulty for pedestrians.
Physical	None identified.	Grade separation structure required, as well as ramps or elevators to meet ADA requirements.
Socioeconomic	None identified.	Significant costs (grade separation).
Enforcement, Education, and Maintenance	None identified.	Graffiti removal and enforcement for personal security may be necessary.

Exhibit 9-11. Summary of issues for pedestrian grade separation.

9.1.7 High Visibility Crosswalks

Description

In some situations, increasing the conspicuity of crosswalks can provide a safety benefit to pedestrians at signalized intersections. Designs and product application vary around the country based on State and local needs. The crosswalk should include retroreflective pavement markings (versus only using a different material like brick for the crosswalk).

Applicability

The addition of high visibility crosswalks may apply to intersections with frequent conflicts between pedestrians and vehicles. Due to the low cost of this treatment, it could also serve as a systemic treatment on a series of intersections or jurisdiction-wide as a policy.

Safety Performance

Anecdotal evidence has shown a safety benefit to the installation of high visibility crosswalks. A case study in New York City in 1995 indicated reductions at a small number of installations at locations with a high number of pedestrian-vehicle crashes.

Additionally, a ladder-style, also referred to as a continental style, crosswalk (longitudinal versus lateral) was shown to be effective for keeping vehicles out of the crosswalk area.[125]

Operational Performance

None identified. The high visibility crosswalks typically have the same footprint as existing crosswalks.

Multimodal Impacts

High visibility crosswalks provide an enhanced space for pedestrian and bicycles to cross the intersection safely.

Physical Impacts

None identified. High visibility crosswalks typically have the same footprint as existing crosswalks.

Socioeconomic Impacts

Minimal costs are associated with high visibility pavement markings.

Enforcement, Education, and Maintenance

Because the high visibility pavement marking is installed in the travel lane, it will be necessary to maintain the markings. In some cases the markings (e.g., "ladder style" markings) can be designed so there is little or no pavement marking in the typical motor vehicle wheel paths.

Summary

Exhibit 9-12 summarizes the issues associated with high visibility crosswalks.

Characteristic	Potential Benefits	Potential Concerns
Safety	Decreased risk of pedestrian collisions.	None identified.
Operations	None identified.	None identified.
Multimodal	Enhanced space for pedestrian and bicyclists to cross.	None identified.
Physical	Installation can occur in the same footprint as standard crosswalks.	None identified.
Socioeconomic	None identified.	None identified.
Enforcement, Education, and Maintenance	Improved compliance.	Enhanced crosswalks may require additional effort to maintain pavement markings.

Exhibit 9-12. Summary of issues for high visibility crosswalks.

9.2 BICYCLE TREATMENTS

9.2.1 Provide Bicycle Box

Description

A bicycle box uses advance stop lines placed on the approach to a signalized intersection, typically in the rightmost lane, at a location upstream from the normal stop line location. These create a dedicated space for bicyclists—a bicycle box—to occupy while waiting for a green indication. Advance stop lines are used in conjunction with bicycle lanes or other similar bicycle provisions.

Note that this treatment is considered experimental; it is not currently identified in the MUTCD.

Applicability

This treatment may apply in situations where vehicle-bicycle collisions have been observed in the past, or vehicle/bicycle conflicts are observed in field observations. The treatment may be considered if a bike lane exists on the approach.

In locations with a high volume of right-turning motor vehicle traffic, use of this treatment may be beneficial.

Safety Performance

Such a treatment was found to be effective in Europe, resulting in a 35 percent reduction in through-bicycle/right-turning-vehicle collisions.[126]

Operational Performance

This treatment is not expected to have a significant effect on traffic operations unless a high volume of right-turning traffic is present.

Multimodal Impacts

Bicycle boxes permit bicyclists to pass other queued traffic on the intersection approach leg, giving them preferential treatment in proceeding through the intersection.

Enforcement, Education, and Maintenance

Concerns with providing a bicycle box include motorist violation of existing stop line, a lack of uniformity with other intersections, and a need for right-turn-on-red prohibitions. Users are not yet familiar with this application, so heavy education may be required.

Summary

Exhibit 9-13 summarizes the issues associated with providing a bicycle box.

Characteristic	Potential Benefits	Potential Concerns
Safety	Potential reduction in collisions between through bicycles and right-turning vehicles.	None identified.
Operations	None identified.	None identified.
Multimodal	Bicyclists can bypass queued traffic, thus reducing delay.	None identified.
Physical	None identified.	None identified.
Socioeconomic	None identified.	None identified.
Enforcement, Education, and Maintenance	None identified.	Enforcement of the box may be necessary.

Exhibit 9-13. Summary of issues for providing a bicycle box.

9.2.2 Provide Bike Lanes

Description

While bicycle lanes are frequently used on street segments, AASHTO cautions against the use of bicycle lane markings through intersections.[26] Special lanes for bicyclists can cause problems to the extent that they encourage bicyclists and motorists to violate the rules of the road for drivers of vehicles. Specifically, a bike lane continued to an intersection encourages right-turning motorists to stay in the left lane, not the right (bike) lane, in violation of the rule requiring that right turns be made from the lane closest to the curb. Similarly, straight-through, or even left-turning, bicyclists are encouraged to stay right. Installation of bike lanes at signalized intersections is associated with a range of vehicle-bicycle crash effects – both increases and decreases.[127]

The bike lane shall be positioned between the through lane and the right-turn only lane. A right-turn-only lane encourages motorists to make right turns by moving close to the curb (as the traffic law requires). A bicyclist going straight can easily avoid a conflict with a right-turning car by staying to the left of the right-turn lane. A bike lane to the left of the turn lane encourages bicyclists to stay out of the right-turn lane when going straight. The MUTCD requires through bicycle lanes to be positioned only to the left of a right-turn-only lane and to the right of a left-turn-only lane.

Applicability

This treatment may be applicable in situations where there are a high number of bicyclists using the road or where bicycle use is being promoted or encouraged.

Safety Performance

Some European literature suggests that bicycle lane markings can increase motorist expectation of bicyclists; one Danish study found a 36 percent reduction in bicycle collisions when these were marked.(128) Other research concludes that bicycle paths along arterials typically increase bicyclists' vulnerability to a collision at signalized intersections; however, raised and brightly colored crossings reduce the number of bicycle/vehicle conflicts and should improve safety.(120) Installation of colored bike lanes at signalized intersections has been associated with a 39 percent reduction in vehicle/bicycle crashes.(127)

Multimodal Impacts

Bicycle lanes delineate roadway space between motor vehicles and bicycles and provide for more predictable movements by each.(26)

Physical Impacts

Bicycle lanes may require additional right-of-way unless width is taken from the existing travel and/or parking lanes, either by lane narrowing or the removal of a lane.

Summary

Exhibit 9-14 summarizes of the issues associated with providing bicycle lanes.

Characteristic	Potential Benefits	Potential Concerns
Safety	Potential reduction in vehicle/bicycle collisions.	Potential increase in vehicle/bicycle collisions.
Operations	None identified.	None identified.
Multimodal	Bicycle lanes delineate roadway space between motor vehicles and bicycles and provide for more predictable movements by each.	None identified.
Physical	None identified.	Bicycle lanes may require additional right-of-way unless width is taken from existing lanes.
Socioeconomic	None identified.	None identified.
Enforcement, Education, and Maintenance	None identified.	None identified.

Exhibit 9-14. Summary of issues for providing bicycle lanes.

9.3 TRANSIT TREATMENTS

9.3.1 Relocate Transit Stop

Placement of bus stops in the vicinity of intersections can significantly influence safety and operational performance. Approximately 2 percent of pedestrian accidents in urban areas and 3 percent in rural areas are related to bus stops.(129) Proper placement and provisions at bus stops can reduce several safety and mobility problems. Traffic engineers often have two choices with regard to bus stop placement in the vicinity of an intersection: on the near side (upstream) or far side (downstream). The 1996 *Transit Cooperative Research Program (TCRP) Report 19: Guidelines for the Location and Design of Bus Stops* provides a comprehensive comparative analysis of far-side, near-side, and midblock placement of bus stops.(129)

Application

Relocation of a transit stop to a location upstream of the intersection (near side) should be considered in situations where there is congestion on the far side of the intersection during peak periods.

Relocation of a transit stop to a location downstream of the intersection (far side) should be considered in situations where one or more of the following exist:

- Heavy right-turn movement.
- Conflicts between vehicles trying to turn right, through vehicles, and stationary near-side buses, resulting in rear-end and sideswipe collisions.
- Pedestrian collisions because pedestrians cross in front of a stationary bus and are struck by a vehicle.

Safety Performance

One advantage of near-side placements is that the bus driver has the entire width of the intersection available to pull away from the curb. Near-side bus placements increase conflicts between right-turning vehicles, through traffic, and the bus itself. When the bus is stopped at the bus stop, traffic control devices, signing, and crossing pedestrians are blocked from view. Vehicles on the adjacent approach to the right may have difficulty seeing past a stopped bus while attempting a right turn on red.

Far-side bus stop placements minimize conflicts between right-turning vehicles and buses. Relocating the bus stop to the far side of the intersection can also improve safety by eliminating the sight distance restriction caused by the bus and encouraging pedestrians to cross the street from behind the bus instead of in front of it.(130) The presence of a far-side transit bus stop is associated with a 45 percent reduction in transit-related crashes.(131) The 1996 TCRP report recommends a minimum clearance distance of 5 ft between a pedestrian crosswalk and the front or rear of a bus stop.(129) Finally, the bus driver can take advantage of gaps in the traffic flow that are created at signalized intersections. However, far-side bus stops may cause rear-end collisions, as drivers often do not expect buses to stop immediately after the traffic signal.

Far-side bus stops appear to offer greater overall safety.

Operational Performance

Near-side bus stop placements minimize interference with through traffic in situations where the far side of the intersection is congested. This type of placement also allows the bus driver to look for oncoming traffic, including other buses with potential passengers for the stopped bus. However, if the bus stop services more than one bus, the right and through lanes may be temporarily blocked.

Far-side bus stop placements improve the right-turn capacity of the intersection. Yet they may block the intersection during peak periods by stopping buses or by a traffic queue extending back into the intersection. Also, if the light is red, it forces the bus to stop twice, decreasing the efficiency of bus operations.

Multimodal Impacts

Near-side bus stop placements allow pedestrians to access buses closest to the crosswalk, and allow pedestrians to board, pay the fare, and find a seat while the bus is at a red light. However, placing the bus stops on the near side of intersections or crosswalks may block pedestrians' view of approaching traffic and the approaching drivers' view of pedestrians.[104]

Physical Impacts

Near-side bus stops/bus shelter placements may interfere with the placement of a red-light camera.

Socioeconomic Impacts

Relocation of a bus stop is a relatively low-cost improvement, unless it involves the relocation of a bus bay and shelter.

Enforcement, Education, and Maintenance

Some jurisdictions have implemented or are considering a yield-to-bus law. If implemented, this would require all motorists to yield to buses pulling away from a bus stop and reduce transit/vehicle conflicts.

Far-side bus bays provide a location for police officers to conduct red-light running or speed enforcement, and can also facilitate U-turns.

From a driver education point of view, the traffic engineer and transit agency may consider consistently placing the bus stop either on the near side or the far side, so that motorists have an expectation of where the bus is going to stop at all signalized intersections in their jurisdiction.

Summary

Exhibit 9-15 summarizes of the issues associated with providing near-side or far-side transit stops.

Characteristic	Potential Benefits	Potential Concerns
Safety	Right-turning vehicle conflicts (far side). Sight distance issues for crossing pedestrians/vehicles on adjacent approach (far side). Rear-end conflicts (near side).	Right-turning vehicle conflicts (near side). Sight distance issues for crossing pedestrians/vehicles on adjacent approach (near side). Rear-end conflicts (far side).
Operations	Eliminates double stopping (near side).	Right-turn/through lanes may be blocked (near side). Intersection may be blocked (far side).
Multimodal	Passenger can board while light is red (near side). Less walking distance to crosswalk (near side).	None identified.
Physical	None identified.	May interfere with red-light camera placement (near side).
Socioeconomic	None identified.	Relocation (far or near) may be costly if it involves relocation of bus bay/bus shelter.
Enforcement, Education, and Maintenance	Far-side bus bays provide space for enforcement vehicles.	Enforcement of yielding to buses may be necessary.

Exhibit 9-15. Summary of issues for near-side/far-side transit stops.

9.4 TRAFFIC CONTROL TREATMENTS

Intersection-wide traffic control treatments can provide operational and/or safety benefits on all approaches and for all movements. Signal coordination improves traffic flow for through traffic and provides gaps for left-turn movements. Signal preemption and priority identifies and accommodates critical movements and users. Signal controller upgrades (from pre-timed to actuated) accommodate intersections where traffic flow is highly variable, reducing delays and driver frustration. Change and clearance interval adjustments can address a red-light running problem. Cycle length can also be adjusted based on the nature of the traffic flow through the intersection. Finally, the advisability of removal of a signalized intersection from late night/early morning flash mode should be evaluated.

9.4.1 Change Signal Control from Pre-timed to Actuated

Description

Traffic signal control at an intersection may be pre-timed, semi-actuated, actuated, adaptive or traffic responsive. A pre-timed mode of control could simply be a function of the capabilities of the controller (older controllers may not have actuated capabilities), or it could be a byproduct of the lack of detection at the intersection (for example, a modern controller with full actuated capabilities may be required to run pre-timed if no detection is in place). The mode of control used can have a profound effect on the operational efficiency and safety of the signalized intersection.

A pre-timed controller operates within a fixed cycle length using preset intervals and no detection. Pre-timed traffic control signals direct traffic to stop and permit it to proceed in accordance with a single predetermined time schedule or series of schedules.

Traffic engineers should consider upgrading intersections from pre-timed to more efficient types of control. Semi-actuated traffic signals have detectors located on the minor approaches and oftentimes in the left-turn lanes of the major approaches. Fully actuated traffic signals have detection on all approaches, have varying cycle lengths, and ensure acceptable servicing through basic controller timings.

Traffic responsive control uses system and presence detection to select one of a set of timing plans (pre-timed) based upon the traffic demand. This type of control further optimizes the operation by using the presence detection on the side streets and left turns to allocate unused green time to other phases as needed. Adaptive control dynamically assigns green time for each phase based upon system detection.

Selecting the best type of control for a location requires full knowledge of local conditions, but, in general, can be based on:

- Variations in peak and average hourly traffic volumes on the major approaches.
- Variations in morning and afternoon hourly volumes.
- Percentage of volumes on the minor approaches.
- Usage by large vehicles, pedestrians, and bicycles.
- Capabilities of existing traffic control equipment.
- Locations where main or side street traffic could benefit from progression or platooning.

Applicability

Converting a signal from pre-timed to a more efficient type of control may be considered in the following situations:

- Where fluctuations in traffic cannot be anticipated and thus cannot be programmed with pre-timed control.
- At complex intersections where one or more movements are sporadic or subject to variations in volume.
- At intersections that are poorly placed within a traffic corridor of intersections with pre-timed traffic signals.
- To minimize delay in periods of light traffic.

Safety Performance

Actuated traffic signals and traffic signal systems control (intelligent signal systems) provide better service to all movements at an intersection, reducing driver frustration and the likelihood of red-light running. However, they can also make it more difficult for pedestrians with visual impairments to predict when changes in signal phasing will occur. There is little research on the safety effects of changing signal control from pre-timed to actuated, but the possibility of reduced rear-end and red-light running crashes due to fewer stops makes actuation a potential safety measure.

Operational Performance

Intelligent signal systems, used in appropriate situations, can reduce delays to vehicles, particularly in light traffic situations and for movements from minor approaches.

Benefits of intelligent signal systems may be less significant in situations where traffic patterns and volumes are predictable and do not vary significantly. Actuated control only may not be the best choice where there is a need for a consistent starting time and ending time for each phase to facilitate signal coordination with traffic signals along a corridor. Actuated signals are dependent on the proper operation of detectors; therefore, they are affected by a stalled vehicle, vehicles involved in a collision, or construction work. To a lesser degree, other types of intelligent signal control operation could be impacted by malfunction or loss of system detectors. Most intelligent signal systems rely upon fail-safe timing plans when one or more groups of detectors fail.

Multimodal Impacts

Pre-timed traffic signals may be more acceptable to the unfamiliar pedestrian than traffic-actuated signals in areas where there is large and fairly consistent pedestrian traffic crossing the road. Intelligent signal systems may cause confusion to the pedestrian with the operation of pedestrian push buttons where long cycle lengths or adaptive control is present. Actuated pedestrian push buttons must be located in appropriate locations and be accessible to be ADA compliant.

Physical Impacts

Approaches needing actuation require detectors. Depending on the type of detector, this may create physical impacts (see Chapter 5 for further discussion of detector types).

Socioeconomic Impacts

Generally speaking, intelligent signal system equipment costs more to purchase and install than pre-timed traffic controllers, although almost all traffic controllers purchased today are capable of actuated operation. Depending on the geometry, number of lanes, and traffic characteristics, detection can be a significant percentage of the cost of a signalized intersection, but many of the more advanced, newer types of detection can cover an entire approach (lefts and throughs) per unit.

Enforcement, Education, and Maintenance

Pre-timed traffic signals may lead to driver frustration in low-volume situations, as in the late evening/early morning hours, as the driver waits for the signal to change green while no other vehicles are present on the other approaches. This may lead to red-light running.

Intelligent signal systems require more equipment and components, and can be more costly to maintain. Detector and/or signal indication (bulb, lens, LED) failure are the most common public complaints.

Summary

Exhibit 9-16 summarizes the issues associated with providing signal actuation.

Characteristic	Potential Benefits	Potential Concerns
Safety	Improves safety. Reduces driver frustration, red-light running.	None identified.
Operations	Provides better service to minor approaches. Accommodates widely fluctuating volumes.	Can sometimes reduce smooth platooning in coordinated systems. Requires proper operation of detectors.
Multimodal	None identified.	May be problematic for unfamiliar pedestrians due to variations to cycle lengths or longer cycle lengths.
Physical	None identified.	Detectors required.
Socioeconomic	None identified.	Can be costly.
Enforcement, Education, and Maintenance	Enforcement needs may decrease.	Maintenance costs will likely increase to maintain detection.

Exhibit 9-16. Summary of issues for providing signal actuation.

9.4.2 Modify Change and Clearance Intervals (Yellow and All-Red)

Description

The yellow change interval warns approaching traffic of the change in assignment of right-of-way. Yellow change intervals, a primary safety measure used at traffic signals, are the subject of much debate. The yellow change interval is normally between 3 and 6 seconds. Since long yellow change intervals may encourage drivers to use it as a part of the green interval, a maximum of 5 seconds is commonly employed. Longer yellow intervals are generally associated with higher approach speeds. Local practice dictates the length of the change interval.

The ITE standard formula for change intervals is a follows:

$$CP = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V} \quad \text{(U.S. Customary)}$$

where:
CP = change period (s)
t = perception-reaction time of the motorist (s); typically 1
V = speed of the approaching vehicle (ft/s)
a = comfortable deceleration rate of the vehicle (ft/s^2); typically 10 ft/s^2
W = width of the intersection, curb to curb (ft)
L = length of vehicle (ft); typically 20 ft
g = grade of the intersection approach (%); positive for upgrade, negative for downgrade

Intersections where the existing yellow change interval time is less than the time needed for a motorist traveling at the prevailing speed of traffic to reach the intersection or stop comfortably before the signal turns red will require a longer yellow change interval. The minimum length of yellow should be determined using the kinematics formula in the 1985 ITE proposed practice assuming an average deceleration of 10 ft/s or less, a reaction time of 1 second or more, and an 85th percentile approach speed. An additional 0.5 seconds of yellow time should be considered for locations with significant truck traffic, significant population of older drivers, or more than 3 percent of the traffic entering on red.(133)

The red clearance interval is an optional interval that follows the yellow change interval and precedes the next conflicting green interval. The red clearance interval provides additional time following the yellow change interval before releasing conflicting traffic. The decision to use a red clearance interval is determined based on engineering judgment and assessment of any of the following criteria:

- Intersection geometrics.
- Collision experience.
- Pedestrian activity.
- Approach speeds.
- Local practices.

The red clearance interval is typically either set by local policy or calculated using an equation that determines the time needed for a vehicle to pass through the intersection. The equation most commonly used is described in various documents (134) (and Chapter 5). As intersections are widened to accommodate additional capacity, the length of the calculated clearance interval increases. This increase may contribute to additional lost time at the intersection, which negates some of the expected gain in capacity due to widening.

Applicability

Modifying the yellow or red clearance interval may be considered where:

- A high number of angle/left-turn collisions occur due to through/left-turning drivers failing to clear the intersection or stop before entering the intersection at onset of the red.
- A high number of rear-end collisions occur because drivers brake sharply to avoid entering the intersection at the onset of the red.
- A high number of red-light violations are recorded.

Safety Performance

At intersection approaches where yellow signal timing duration is set below values associated with ITE guidelines or similar kinematic-based formulae, increasing yellow change interval duration to achieve ITE guidelines can significantly reduce red-light running. Increasing yellow change and/or red clearance interval timing to achieve values associated with ITE guidelines or similar kinematic formulae can significantly reduce motorists entering the intersection at the end of the yellow phase.

The best estimate of the crash effects associated with implement improved change interval timing, based on before-after studies, is about 8 to 14 percent reduction in total crashes, and about a 12 percent decrease in injury crashes.[135]

Research shows that yellow interval duration is a significant factor affecting the frequency of red-light running and that increasing yellow time to meet the needs of traffic can dramatically reduce red-light running. Bonneson and Son (2003) and Zador et al. (1985) found that longer yellow interval durations consistent with the ITE Proposed Recommended Practice (1985) of using 85th percentile approach speeds are associated with fewer red-light violations, all other factors being equal. Bonneson and Zimmerman (2004) found that increasing yellow time in accordance with the ITE guideline or longer reduced red light violations more than 50 percent. Van Der Host found that red light violations were reduced by 50 percent one year after yellow intervals were increased by 1 seconds.[140] Retting et al (2007) found increasing yellow time in accordance with the guideline reduced red-light violations by 36 percent on average. Retting, Chapline & Williams (2002) found that adjusting the yellow change interval in accordance with the ITE guidelines reduced total crashes by 8 percent, right-angle crashes by 4 percent, and pedestrian and bicycle crashes by 37 percent.[78]

One study conducted by Souleyrette et al. (2004), suggests modest short-term crash reductions, but no longer-term effects associated with installing red clearance intervals.[136]

Exhibit 9-17 presents selected findings associated with signal clearance modifications.

Treatment	Finding
Retiming to ITE standards. [137]	Reduced red-light violations by 50 percent.
Add all-red clearance interval.[136]	Modest short-term crash reductions, but no longer-term effects.
Retiming signal change intervals to ITE standards.[138]	8 percent estimated reduction in all collisions. 12 percent estimated **increase** in rear-end collisions. 39 percent estimated reduction in vehicle-bicycle and vehicle-pedestrian collisions.
Retiming signal change intervals to ITE standards.[139]	5 percent estimated reduction in all collisions. 9 percent estimate reduction in fatal and injury collisions.

Exhibit 9-17. Safety effects associated with modifying change and clearance intervals: selected findings.

Operational Performance

Extending the yellow and red interval will increase the amount of lost time, decreasing the overall efficiency of the intersection.

Multimodal Impacts

Either extending the yellow and/or red clearance interval or providing a red clearance interval will benefit pedestrians, giving them additional time to clear the intersection. The elderly or people with mobility disabilities may benefit substantially.

Physical Impacts

No physical impacts are associated with this treatment.

Socioeconomic Impacts

The treatment has been shown to reduce red-light running at a wide variety of signalized intersections.

Enforcement, Education, and Maintenance

Local practice varies as to legal movements during the yellow phase. Police, traffic engineering staff, and the public need to be clear and in agreement about what is permissible in their jurisdiction.

Summary

Exhibit 9-18 summarizes the issues associated with modifying yellow and/or red clearance intervals at signalized intersections.

Characteristic	Potential Benefits	Potential Concerns
Safety	Angle collisions are reduced. Left-turn collisions are reduced. Rear-end collisions are reduced.	None identified.
Operations	None identified.	Increased lost time.
Multimodal	The elderly and people with mobility disabilities have more time to cross.	None identified.
Physical	No physical requirements.	None identified.
Socioeconomic	Low-cost alternative to police and automated enforcement.	None identified.
Enforcement, Education, and Maintenance	Red-light enforcement may become less necessary.	None identified.

Exhibit 9-18. Summary of issues for modifying yellow/red clearance intervals.

9.4.3 Modify Cycle Length

Description

Calculating and selecting cycle length requires judgment on the part of the traffic engineer or analyst. General practice suggests a cycle length between 50 and 120 seconds. For low-speed urban roads, a shorter cycle length is preferable (50 to 70 seconds). For wider roadways (greater than 50 ft) with longer pedestrian crossing times (greater than 20 s seconds), or in situations where heavier traffic is present and left-turning vehicles are not effectively accommodated, a cycle length of 60 to 90 seconds may be preferable. At high-volume intersections, multiple phases to accommodate heavy turning movements may necessitate a cycle length of 90 to 120 seconds.[(140)] In addition, cycle lengths longer than 120 seconds may be needed at large intersections to accommodate multiple long pedestrian crossings in combination with heavy turning movements, especially during peak periods. Typically, system cycle lengths are governed by the higher volume intersections within the system and limit the flexibility of the traffic engineer in choosing a cycle length that may otherwise work better for a specific location.

Safety Performance

Longer cycle lengths may lead to driver frustration and red-light running, as it may take several cycles for a motorist to get through the intersection, particularly when attempting a left turn against opposing traffic. However, because an increase in cycle length reduces driver exposure to the yellow indication (e.g., a cycle length change from 60 to 120 seconds reduces the number of times that the yellow is presented by 50 percent), there is an inverse relationship between a change in cycle length and the frequency of red-light-running. That is, an increase in cycle length corresponds to a decrease in the frequency of red-light-running.[(141)]

No known research or specific collision modification factors exist for modifying cycle length.

Operational Performance

A cycle length of 90 seconds is often considered optimum, since lost time is approaching a maximum, capacity is approaching a minimum, and delay is not too great.[(140)] Longer cycle lengths may lead to excessive queuing on the approach and will interfere with turning movements (left- and right-turn channelization) if through traffic is severely backed up.

Conversely, intersection capacity drops substantially when cycle lengths fall below 60 seconds, as a greater percentage of available time is used up in the yellow and red clearance intervals.

Multimodal Impacts

A shorter cycle length may not provide pedestrians with sufficient time to safely cross the intersection, particularly if it has turning lanes. Conversely, a longer cycle length may encourage impatient pedestrians to cross illegally during the red phase.

Physical Impacts

No physical impacts are associated with the modification of cycle length.

Enforcement, Education, and Maintenance

As part of regular traffic signal observations (recommended every 3 to 5 years, or as needed), consider modifying cycle lengths and splits (and offsets in coordinated systems) to accommodate emerging operational needs.

Socioeconomic Impacts

No significant costs are associated with this treatment, apart from labor.

Summary

Exhibit 9-19 summarizes the issues associated with cycle length modification.

Characteristics	Potential Benefits	Potential Concerns
Safety	Increase in cycle length corresponds to a decrease in the frequency of red-light running.	Longer cycle lengths could induce some drivers to run red lights.
Operations	Reduction in delay optimized at 90 seconds.	Excessive queuing (with longer cycle lengths). Inadequate capacity (with cycle lengths that are too short).
Multimodal	None identified.	Inadequate crossing time for pedestrians (with cycle lengths that are too short).
Physical	None identified.	None identified.
Socioeconomic	None identified.	None identified.
Enforcement, Education, and Maintenance	None identified.	Increased maintenance cost of regular signal observations and retiming.

Exhibit 9-19. Summary of issues for cycle length modifications.

9.4.4 Late Night/Early Morning Flash Removal

Description

Some jurisdictions operate traffic signals in flashing mode during various periods of the night, the week, or for special events. Flashing operation can benefit traffic flow, particularly with pre-timed signals, when traffic is very light (late evening/early morning hours, or on a Sunday or holiday in an industrial area).

Two modes of flashing operation are typically used: red-red and red-yellow. Red-red (all approaches receive a flashing red indication) is used where traffic on all approaches is roughly the same. In this instance, the intersection operates as an all-way stop. Red-yellow (the minor street receives a flashing red indication and the major street receives a flashing yellow indication) is used in situations where traffic is very light on the minor street. In this instance, the intersection operates as a two-way stop.

Safety Performance

One study examined safety impacts associated with converting 12 intersections from nighttime flashing operation to steady operation in Winston-Salem, NC. The analysis indicated that flashing operation reduced nighttime angle crashes (the ones most likely to be positively affected) by approximately 34 percent. Total nighttime crashes also saw a significant reduction of approximately 35 percent.[(142)]

A separate study evaluated safety impacts associated with a change in statewide late night flash policy by the North Carolina DOT making it standard practice to operate signals in steady mode at all times. Before this policy, it was standard practice to allow traffic signals to operate in late night flash mode unless directed otherwise by the division traffic engineer. The policy also changed the standard operating times for late night flash operations. As a result of this policy, many signals were either removed from late night flash operations or had their late night flash operating times modified to conform to the new policy. Replacing nighttime flash with steady operation was associated with an estimated 48 percent reduction in nighttime frontal and opposing direction sideswipe collisions and head-on collisions, and an estimated 27 percent reduction in all nighttime collisions.

Selected study findings associated with the removal of a traffic signal from a flashing mode operation (such as during the late-night/early morning time period) are shown in Exhibit 9-20.

Treatment	Finding
Remove signal from late night/early morning flash mode.[142],[143]	34 percent estimated reduction in nighttime angle collisions. 35 percent estimated reduction in all nighttime collisions. 48 percent estimated reduction in nighttime frontal and opposing direction sideswipe collisions and head-on collisions 27 percent estimated reduction in all nighttime collisions

Exhibit 9-20. Safety effects associated with removal of signal from late night/early morning flash mode: selected findings.

Operational Performance

If the signalized intersection removed from flashing operation is not fully actuated and responsive to traffic demand, increased red-light violations and/or complaints about unnecessary long waits on red signals may occur.

Multimodal Impacts

Removing a traffic signal from a flash mode will require vehicles to come to a complete stop during the red phase. This treatment should give vehicles more time to see, respond, and yield to any pedestrians.

Physical Impacts

No physical impacts are associated with this treatment.

Socioeconomic Impacts

No costs are associated with this treatment.

Enforcement, Education, and Maintenance

When a traffic signal is taken out of flash mode, police enforcement could be undertaken at the location to ensure habituated drivers do not proceed through the intersection as if the signal were still operating in flashing mode. The traffic engineer may consider temporary signing/publicity to inform motorists of the change in operations and to explain the safety benefits.

Summary

Exhibit 9-21 summarizes the issues associated with flash mode removal.

Characteristic	Potential Benefits	Potential Concerns
Safety	Angle collisions are reduced.	Could induce red-light running on minor legs if controller is not sufficiently sensitive to minor road demand.
Operations	None identified.	Increased delay for through traffic.
Multimodal	Motorists forced to yield to pedestrians.	None identified.
Physical	None identified.	None identified.
Socioeconomic	None identified.	None identified.
Enforcement, Education, and Maintenance	None identified.	Enforcement and temporary signing may be needed for a period after conversion.

Exhibit 9-21. Summary of issues for flash mode removal.

9.5 STREET LIGHTING AND ILLUMINATION

9.5.1 Provide or Upgrade Illumination

Description

The purpose of roadway lighting is to enhance visibility and conspicuity for drivers, bicyclists, and pedestrians, thereby improving their ability to see each other and the physical infrastructure of the intersection. This allows them to react more quickly and accurately to each other when natural light drops below a certain level, either at night or during bad weather.

Applicability

Consider intersection lighting at all signalized intersections. More nighttime collisions than expected may justify upgrades, particularly if the nighttime collisions involve pedestrians, bicyclists, and/or fixed objects.

Design Features

The illumination design at an intersection should meet lighting criteria established by the Illuminating Engineering Society of North America (IESNA) in IESNA RP-8-00, *American National Standard Practice for Roadway Lighting.*(70) The basic principles and design values for intersections have been presented previously (Chapter 5) and include overall light level and uniformity of lighting.

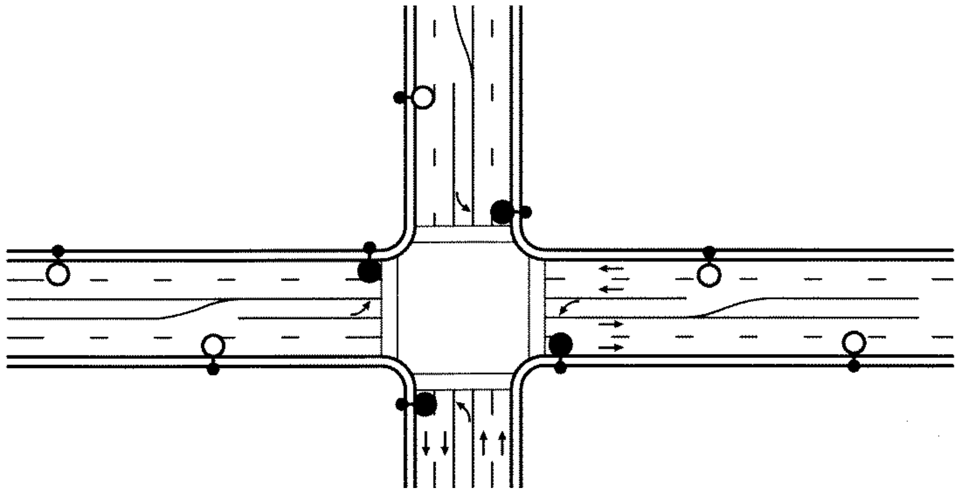
Some of the factors that affect the light level and uniformity results include:

- Luminaire wattage, type, and distribution.
- Luminaire mounting height.
- Pole placement and spacing.

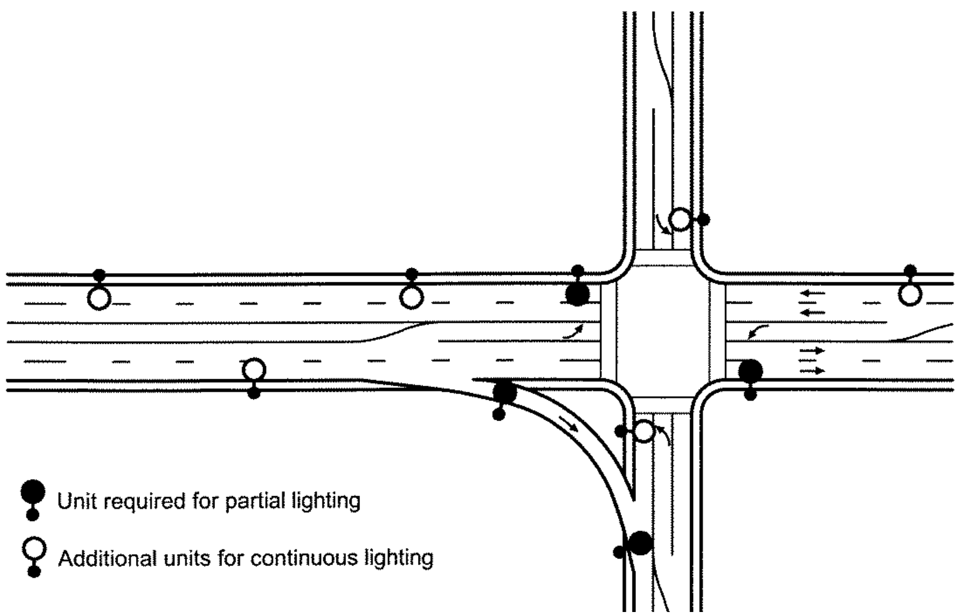
These factors are interrelated. For example, higher mounting heights improve uniformity by spreading the light over a larger area; however, the overall light level decreases unless larger wattages are used or poles are placed closer together. Good illumination design balances these various factors against an overall desire to minimize the number of poles and fixtures (both for cost savings and for minimizing the number of fixed objects in the right-of-way).

Pole Placement and Spacing

Besides the types of poles and fixtures, the placement is also an important aspect of a good roadway design. Several factors need to be considered in pole placement. The first is safety. Most important is to place the pole at an offset distance that can assist in preventing crashes (vehicles and pedestrians). Second, determine the pole spacing most efficacious for initial and long-term maintenance costs, yet still meeting the lighting requirement. At intersections, shared use of poles for signal equipment and illumination is recommended. Exhibit 9-22 shows examples from RP-8-00 of illumination pole layouts typical at signalized intersections with and without channelized right-turn lanes. However, recent research to improve lighting at midblock pedestrian crosswalks suggests it may be desirable to locate poles approximately one third to one half the luminaire mounting height back from the crosswalk to improve lighting for pedestrians. This may require separate poles for signal equipment and luminaires.(144) For intersections providing separate pedestrian pedestals at the crosswalk, the mast arm poles for vehicle signal heads should be located for optimal illumination as well. Intersection lighting, when crosswalks are present, should account for the presence of pedestrians and attempt to achieve positive contrast.



(a) Typical lighting layout for intersection without right-turn bypass lane.



(b) Typical lighting layout for intersection with right-turn bypass lane.

Exhibit 9-22. Typical lighting layouts.[70, figure D3]

Safety Performance

Optimal illumination and visibility reduces the chance of nighttime accidents and enhances traffic flow. Roadway lighting also increases sight distance, security, and the use of surrounding facilities. Installation of lighting at intersections is associated with a 38 percent reduction in all dark condition collisions and a 42 to 59 percent reduction in vehicle/pedestrian collisions in dark conditions.[145]

Operational Performance

No documented relationship exists between illumination and operational intersection performance. The authors believe that illumination likely has little effect on traffic flow, delay, and queuing.

Multimodal Impacts

As noted above, illumination demonstrably reduces pedestrian crashes and provides a more secure nighttime environment for all intersection users.

Physical Impacts

Illumination typically has little effect on the overall footprint of an intersection. Commonly, combination poles support both signal heads and luminaires, so additional poles are rarely needed in the immediate vicinity of the intersection. However, the recent research cited previously suggests the possibility of improved pedestrian visibility using additional poles upstream from the crosswalk.

Socioeconomic Impacts

Illumination also reduces the fear of crime at night, and it promotes business and the use of public streets at night.[70]

In addition to the initial capital cost and maintenance of illumination fixtures, illumination requires energy consumption. The Roadway Lighting Committee of IESNA believes that lighting of streets and highways is generally economically practical and that such preventive measures can cost a community less than the crashes caused by inadequate visibility.[70] Judicious design of luminaire types, wattages, mounting height, and pole spacing may increase visibility at the intersection without significantly increasing energy costs.

Summary

Exhibit 9-23 summarizes the issues associated with providing illumination.

Characteristic	Potential Benefits	Potential Disbenefits
Safety	Reported reductions in nighttime collisions.	None identified.
Operations	None identified.	None identified.
Multimodal	May reduce pedestrian crashes.	None identified.
Physical	Little impact.	None identified.
Socioeconomic	May reduce fear of nighttime crime.	Additional energy consumption.
Enforcement, Education, and Maintenance	None identified.	Maintenance of illumination will be necessary.

Exhibit 9-23. Summary of issues for providing illumination.

9.6 REMOVE TRAFFIC SIGNAL

As indicated in Section 4B.03 of the MUTCD, improper or unjustified traffic control signals can result in one or more of the following disadvantages:

- Excessive delay.
- Excessive disobedience of the signal indications.
- Increased use of less adequate routes as road users attempt to avoid the traffic control signals.
- Significant increases in the frequency of collisions (especially rear-end collisions).

Converting traffic signals to roundabouts or multi-way stop controls at appropriate settings and under appropriate traffic conditions can provide a range of safety, operational, environmental, and economic benefits.

9.6.1 Convert Signalized Intersection to a Roundabout

Description

The modern roundabout is a circular intersection with design features promoting safe and efficient traffic flow. At roundabouts in the United States, vehicles travel counterclockwise around a raised center island, with entering traffic yielding the right-of-way to circulating traffic. In urban settings, entering vehicles negotiate a curve sharp enough to slow speeds to about 15 to 20 mph; in rural and suburban settings, entering vehicles may be held to somewhat higher speeds (30 to 35 mph). Within the roundabout and as vehicles exit, slow speeds are maintained by the deflection of traffic around the center island and the relatively tight radius of the roundabout and exit lanes. Roundabouts have replaced many formerly signalized intersections.

Applicability

Converting a signalized intersection to a roundabout requires sufficient right-of-way to accommodate the circumference of the roundabout, which may include one, two, or three circulating lanes, depending on the volume of traffic. Mini roundabouts can be installed with less right-of-way, including some cases where no additional right-of-way is needed.

Safety Performance

Conversion of signalized intersections to roundabouts is associated with substantial safety benefits. Before-after analysis conducted for nine such conversions as part of NCHRP Report 672 estimated a 48 percent reduction in all crashes, and a 78 percent reduction in injury crashes.[146]

Treatment	Finding
Convert signalized intersection to roundabout.[146]	48 percent estimated reduction in all collisions. 78 percent estimated reduction in injury collisions.

Exhibit 9-24. Safety effects associated with converting traffic signals to roundabouts: selected findings.

Operational Performance

In addition to providing safety effects, converting signalized intersections to roundabouts is associated with substantial reductions in vehicle delay. Several studies have reported significant improvements in traffic flow following conversion of traditional intersections to roundabouts. A study of three locations in New Hampshire, New York, and Washington, where roundabouts replaced traffic signals or stop signs, found an 89 percent average reduction in vehicle delays and a 56 percent average reduction in vehicle stops.[148] A study of 11 intersections in Kansas found a 65 percent average reduction in delays and a 52 percent average reduction in vehicle stops after roundabouts were installed.[149]

Multimodal Impacts

Conversion of signalized intersections to roundabouts can benefit pedestrians. Roundabouts generally are safer for pedestrians than traditional intersections. In a roundabout, pedestrians walk on sidewalks around the perimeter of the circular roadway. If they need to cross the roadway, they cross only one direction of traffic at a time. In addition, crossing distances are relatively short, and traffic speeds are lower than at traditional intersections. Studies in Europe indicate that, on average, converting conventional intersections to roundabouts can reduce pedestrian crashes by about 75 percent.[150],[151] Single-lane roundabouts in particular have been reported to involve substantially lower pedestrian crash rates than comparable intersections with traffic signals. Safety studies on bicyclists at roundabouts have mixed findings, with some European studies showing higher crash rates for bicycles at roundabouts compared with traffic signals.[146]

Physical Impacts

Converting a signalized intersection to a roundabout requires sufficient right-of-way to accommodate the circumference of the roundabout. In many cases, construction of a roundabout in place of a traffic signal will require the acquisition of small amounts of right-of-way at the intersection. However, because roundabouts generally require fewer approach lanes than signalized intersections, in some cases existing travel lanes approaching the intersection can be converted to parking, bike lanes, or other uses. Roundabouts can also improve the esthetics of existing signalized intersections, including the addition of landscaping.

Socioeconomic Impacts

Converting a signalized intersection to a roundabout requires significant capital investment. However, roundabouts offer lower lifecycle costs compared with traffic signals, which require electrical power and maintenance of signal hardware (including detectors). Reduced vehicle delays and other operational benefits associated with roundabouts can lower vehicle operating costs (including fuel consumption) for motorists and transit agencies.

Summary

Exhibit 9-25 summarizes the issues associated with converting traffic signals to roundabouts.

Characteristic	Potential Benefits	Potential Disbenefits
Safety	Substantial reductions in all collisions and injury collisions.	None identified.
Operations	Substantial reductions in traffic delays and vehicle stops.	None identified.
Multimodal	Roundabouts generally are safer for pedestrians than traditional intersections.	Multi-lane roundabouts can be challenging for visually impaired pedestrians. Safety studies on bicyclists at roundabouts have mixed findings.
Physical	Esthetic improvement, including landscaping.	May require additional right-of-way.
Socioeconomic	Lower life cycle costs, vehicle operating costs (including fuel consumption) for motorists.	Requires significant capital investment.
Enforcement, Education, and Maintenance	Roundabouts require less maintenance than traffic signals.	Public information may be needed.

Exhibit 9-25. Summary of issues for converting traffic signals to roundabouts.

9.6.2 Convert Signalized Intersection to All-Way Stop Control

Description

All-way stop control requires vehicles approaching the intersection from all directions to stop prior to entering the intersection. Because of the large number of vehicle stops and delays associated with this form of control, its use is generally limited to residential areas and low-speed settings.

Applicability

Converting a signal to all-way stop control requires thoughtful analysis and consideration, as it is not a common practice. Before converting a signal to all-way stop control, the engineer should review the guidance in the MUTCD Part 2B.07.

Safety Performance

Researchers identified the effect on intersection crashes of converting nearly 200 one-way street intersections in Philadelphia from signal to all-way stop sign control.[152] Using crash and traffic volume data for a comparison group, regression models were computed to represent the normal crash experience of signal controlled intersections of one-way streets, by impact type, as a function of traffic volume. Estimates were obtained for different classes of crashes categorized by impact type, day/night condition, and impact severity. Aggregate results indicate that replacing signals by all-way stop signs on one-way streets is associated with a reduction in crashes of approximately 24 percent, combining all severities, light conditions, and impact types.

Treatment	Finding
Convert signalized intersection to multi-way stop.[152]	24 percent estimated reduction in all collisions. 25 percent estimated reduction in right-angle collisions. 17 percent estimated reduction in pedestrian collisions (46 percent reduction at night)

Exhibit 9-26. Safety effects associated with converting traffic signals to multi-way stop.

Operational Performance

By design, all-way-stop control generates considerable vehicle delay compared with traffic signal operation because all vehicles are required to stop before entering the intersection.

Multimodal Impacts

Conversion of signalized intersections to all-way stop control benefits pedestrians and bicyclists because of the low traffic speeds of motor vehicles in the vicinity of the intersection.

Physical Impacts

Conversion of signalized intersections to all-way stop control eliminates traffic signal poles, but introduces sign supports. Intersection sight distance differs depending on the type of intersection and maneuver involved. Signalized intersections require that drivers be provide with an unobstructed view of both the approach triangle and the departure triangle, whereas intersections controlled by all-way stop signs have no such requirements.[153]

Socioeconomic Impacts

Conversion of signalized intersections to all-way stop control reduces costs required to electrify and maintain traffic signals. The cost of installing and maintaining multi-way stop signs is relatively low.

Summary

Exhibit 9-27 summarizes the issues associated with converting traffic signals to all-way stop control.

Characteristic	Potential Benefits	Potential Disbenefits
Safety	Reduced crashes.	None identified.
Operations	None identified.	Increased vehicle delay.
Multimodal	Benefits pedestrians and bicyclists because of the low traffic speeds of motor vehicles in the vicinity of the intersection.	None identified.
Physical	Eliminates traffic signal poles.	Requires installation of sign poles.
Socioeconomic	Reduces costs required to electrify and maintain traffic signals.	None identified.
Enforcement, Education, and Maintenance	Eliminates traffic signal maintenance.	Significant education will be required to share the signal removal decision with the public and public officials. The location may require periodic police enforcement of stop signs.

Exhibit 9-27. Summary of issues for converting traffic signals to all-way stop control.