Transportation Advisory Board Work Session

Agenda

February 19, 2024 @ 4:00 PM

City Hall Commission Chambers
401 S. Park Avenue

welcome

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1. **Meeting Called to Order**

2. **Discussion Item (s)**

   a. City Truck Routes Discussion 90 minutes

3. **Adjournment**

Transportation Advisory Board

agenda item

item type
Discussion Item (s)

meeting date
February 19, 2024

prepared by
Hongmyung Lim, Engineer II

approved by

subject
City Truck Routes Discussion

motion | recommendation

background
City Commission has approved and adopted the Transportation Master Plan in 2023. An element in the Master Plan was City-wide Truck Routes. While the routes have been depicted on a map, further discussion and actions must be done to fully establish the truck routes.

strategic objectives

alternatives | other considerations

fiscal impact

attachments
1. Truck Routes Management

Design and Access Management Guidelines for Truck Routes: Planning and Design Guide (2020)

DETAILS

102 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-48179-3 | DOI 10.17226/25950

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SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine. 2020. *Design and Access Management Guidelines for Truck Routes: Planning and Design Guide*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25950.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 943

Design and Access Management Guidelines for Truck Routes: Planning and Design Guide

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Subscriber Categories
Design • Motor Carriers • Operations and Traffic Management

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

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TRB
TRANSPORTATION RESEARCH BOARD

2020

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state departments of transportation (DOTs) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration (FHWA), United States Department of Transportation, under Agreement No. 693JJ31950003.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the National Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments, by committees of AASHTO, and by the FHWA. Topics of the highest merit are selected by the AASHTO Special Committee on Research and Innovation (R&I), and each year R&I's recommendations are proposed to the AASHTO Board of Directors and the National Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

NCHRP RESEARCH REPORT 943

Project 15-62
ISSN 2572-3766 (Print)
ISSN 2572-3774 (Online)
ISBN 978-0-309-48179-3
Library of Congress Control Number 2020942661

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Washington, DC 20001

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FOREWORD

By William C. Rogers
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NCHRP Research Report 943: Design and Access Management Guidelines for Truck Routes: Planning and Design Guide (referred to herein as the Guide) provides access management and geometric design approaches for truck routes, whether formally designated by a transportation agency to serve trucks or for any other routes that carry a substantial volume of trucks, while improving traffic operations and safety for all road users.

Trucks are an important consideration in the design and access management of roadways. Trucks are substantially larger than passenger cars and have very different operating characteristics. Trucks take longer to accelerate, make much wider turns at intersections, and often require oversize/overweight (OSOW) permits. For the most part, trucks are only a limited portion of the motor vehicle traffic stream. As a result, except for industrial and port locations, most roadways and intersections are not designed for trucks; rather they accommodate trucks, while also serving other travel modes.

Under NCHRP Project 15-62, MRIGlobal was asked to develop guidelines for transportation practitioners on access management and design for truck routes and site layout to facilitate truck movement for direct incorporation into planning processes, and to design specifications for local governments and state transportation agencies to improve truck safety and operations. The guidelines address a broad range of issues related to access management and design for truck routes and site layout, such as (1) land use and zoning impacts on truck movement; (2) strategies for efficient movement and delivery of goods; (3) strategies for assessing benefit-cost differentials in providing truck accommodations; (4) model access management guidelines, policies, and strategies for designating and developing truck routes and networks; (5) geometric design and operations policies and practices to accommodate trucks at access points and along corridors, including innovative intersections and interchanges; (6) balancing truck needs with other modes; (7) recommendations for revisions or supplements to the TRB *Access Management Manual*; and (8) model language for incorporating findings into local land use decisionmaking processes.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Design and Access Management Guidelines for Truck Routes: Planning and Design Guide

The purpose of this Guide is to provide transportation agencies with guidance in dealing with practical issues of selecting and managing access along truck routes, while improving traffic operations and safety.

In this Guide, the term *truck route* applies both to routes that are formally designated by a transportation agency to serve trucks and to any other routes that carry a substantial volume of trucks. The formal designation of truck routes is a key operational and planning activity that should consider the truck demand volumes, the origins and destinations of truck shipments, and the suitability of particular roads and corridors to accommodate trucks of specific sizes. Planning for truck routes includes consideration of land use, roadway functional classification, strategic freight corridors, interagency collaboration, truck delivery needs, and site layout and internal circulation. A key aspect of planning is the position of each roadway in the transportation network, including the hierarchy of roadways and the freight function of each roadway. For example, Interstate highways and strategic corridors serve state-to-state and regional commerce; other roads serve as connections between freight activity centers and strategic corridors; while still other roads serve as distribution routes to deliver goods to markets.

Trucks are an important consideration in the design and access management of roadways. Trucks are substantially larger than passenger cars, and their size needs to be a factor when designing geometric elements of the roadway and selecting access management treatments for the roadway. The length of trucks is a key consideration when selecting an appropriate storage length for turn lanes and intersection spacing. The height of trucks is an important factor in designing (and signing for) bridge clearances, particularly when accommodating oversize/overweight (OSOW) vehicles. Where trucks are expected to use a driveway, particular consideration should be given to truck needs when designing various elements of the driveway, such as throat length and width, driveway profile, curb termination treatment, curb return radius, and driveway operation (e.g., one-way versus two-way, right-in/right-out).

Trucks also have quite different operating characteristics than passenger cars. They take longer to accelerate from a stopped position and decelerate to a stopped position. Turning maneuvers are also a key challenge faced by trucks, particularly on urban and suburban arterials. Where trucks make right turns at intersections, it is desirable to provide a curb return radius sufficiently large that a truck can make a right turn without encroaching on the curbline or on an adjacent or opposing lane.

The movement of OSOW trucks generally requires operators to obtain a permit from the state department of transportation (DOT). Each state has its own rules about how permits are applied for and issued, how routes for OSOW trucks are determined, and what time-of-day or other restrictions may apply to OSOW truck movements. Routing considerations

generally include physical conditions, such as overhead structures, structural capacity of bridges, cross section widths, overhead traffic signals, and roundabouts.

With the exception of some industrial and port locations, where the traffic stream may consist almost exclusively of trucks, very few roadway segments and intersections are designed solely to serve trucks. At most locations, trucks constitute only a limited portion of the motor vehicle traffic stream, and other travel modes—including automobiles, bicyclists, pedestrians, and transit—must also be served. There are inherent conflicts between the needs of these various modes, such that designing solely for trucks might make travel inefficient or inconvenient for other modes. Thus, for the most part, roadways and intersections are not designed *for* trucks, but are designed to accommodate trucks, while also serving other travel modes. This Guide will help designers seeking an appropriate balance among travel modes that may vary substantially from corridor to corridor and from project to project. Included in the Guide are five case studies, which highlight truck-related challenges or concerns faced by transportation agencies, and the innovative strategies used by these agencies to mitigate the challenges or concerns.

CHAPTER 1

Introduction

This Guide addresses geometric design and access management for truck routes. In this Guide, the term *truck route* applies both to routes that are formally designated by a transportation agency to serve trucks and to any other routes that carry a substantial volume of trucks. Trucks are the largest and heaviest vehicles that regularly use the road and street network, and trucks have different operational characteristics than other vehicles, so accommodation of trucks on roads and streets presents challenges to designers. Designers have found that careful management of access to and from the road network and application of innovative access management techniques can increase traffic operational efficiency and reduce traffic crashes. Such access management techniques include driveway design and control, median treatments and auxiliary lanes, innovative methods for handling intersection turning movements, and novel designs for the crossroad area at freeway interchanges. Each of these design approaches must be adapted to effectively serve the truck traffic that may be present.

Decisions concerning access management design have often focused on serving passenger vehicle traffic; however, on a truck route, this can also benefit truck travel by increasing the efficiency and safety of particular roads and streets. It is important for designers to recognize that trucks, as well as passenger vehicles, require safe and efficient access. Trucks must make turning maneuvers where truck routes turn or intersect, where trucks enter or leave the truck route to follow other streets from or to their origin or destination, and where the origin or destination for a truck is a property adjacent to the truck route. Thus, curb return radii where trucks make turning maneuvers, turning designs that utilize right-in/right-out access restrictions, median U-turn roadways, J-turns, continuous flow intersections, turn lanes at intersections or at individual driveways, and driveways that themselves serve truck origins and destinations should each be designed to appropriately serve trucks.

Transportation agencies and communities establish truck routes so that through trucks will travel along roads and streets that are suitable for large and heavy vehicles rather than along roads that are not designed to accommodate them. Most laws, ordinances, and rules concerning truck routes indicate that truck routes are established for through trucks, but that trucks with local origins or destinations may use other roads and streets to travel to and from the established truck routes. Transportation agencies must establish appropriate methods of choosing truck routes to ensure that the selected roads and streets are suitable for truck travel but do not decrease efficiency by taking trucks too far out of their way or increase crash risk by increasing travel distance (and, therefore, vehicle-miles of travel) too much.

Roadway design considerations have become increasingly multimodal in nature. Some locations in industrial or port areas primarily serve truck traffic and can be designed almost exclusively with truck operations in mind. In other cases, more generous design to accommodate trucks will also benefit other travel modes. Often, however, roadway and intersection design must consider a balance among the often conflicting needs of several travel modes including automobiles, bicycles, pedestrians, transit, and trucks. This Guide will help designers seeking an appropriate balance among travel modes that may vary substantially from corridor to corridor and from project to project.

Much attention has recently focused on the concept of *complete streets*, emphasizing the need for roads and streets designed to serve all types of users by achieving an appropriate (and site-specific) balance between the needs of specific user types. Most examples cited for application of the complete streets concept emphasize the need to accommodate pedestrians and bicycles. Insufficient attention has been paid to design of streets designated as truck routes, where the needs of trucks should be a priority, while also considering the needs of other user types.

Transportation agencies need guidance to assist them in dealing with the practical issues of selecting and managing access along truck routes, while also improving traffic operations and safety. This includes consideration of truck movements that follow the truck route, that enter and leave the truck route at intersections, and that enter and leave the truck route at individual driveways. Key goals in managing the interface between truck routing and access management considerations include the following:

- Selecting appropriate truck routes that either already have appropriate access management techniques in place to serve passenger vehicles and trucks or that can be improved to provide appropriate access management.
- Establishing appropriate access management guidelines for selecting and designing access management techniques along new or established truck routes, without limiting the maneuverability of trucks.
- Improving access management design on truck routes where truck access needs are not being met.
- Designing access management techniques on truck routes with appropriate consideration of all user types so that the needs of trucks and passenger vehicles are met, and the needs of pedestrians, bicycles, and transit are also addressed in an appropriate site-specific balance based on their volumes and the position of the road in the transportation network.

This Guide is intended to meet these needs. The target audience for the Guide includes planners and engineers in federal, state, and local transportation agencies and in consulting firms that work for these agencies. The target audience includes any organization responsible for planning or designing roads that will be used by trucks. Organizations to whom this Guide may be useful include state DOTs; metropolitan planning organizations (MPOs); regional planning organizations (RPOs); city, county, and municipal transportation agencies; and independent toll road, turnpike, toll bridge, and tunnel authorities.

The remainder of this Guide is organized as follows. Chapter 2 presents an overview of truck operational challenges and needs. Chapter 3 presents planning for truck routes and other related considerations that affect design and access management for trucks. Chapter 4 addresses geometric design and access management to accommodate trucks. Chapter 5 discusses balancing truck considerations with other travel modes.

CHAPTER 2

Overview of Truck Operational Challenges and Needs

2.1 Introduction

Trucks are an important consideration in the design and access management of roadways. The size, weight, height, and operational characteristics of trucks are uniquely different from that of passenger cars and need to be a factor when designing geometric elements of the roadway and selecting access management treatments for the roadway. Physical characteristics of trucks (e.g., length, width) and operational characteristics and needs of trucks (e.g., turning path, acceleration and deceleration, parking needs) are crucial to assessing the traffic operational and safety performance of a roadway, particularly when trucks constitute a significant portion of the vehicle mix.

2.2 Trucks as a Design Vehicle

Trucks are wider and longer than buses and passenger cars, and therefore the geometric design requirements for trucks are greater than for other design vehicles. In selecting an appropriate design vehicle for any roadway, the designer should consider the largest design vehicle that is likely to use that roadway with considerable frequency, or a design vehicle with special characteristics appropriate to a particular location (AASHTO 2018). The design vehicle is used in the design of critical features such as curb return radii, turning radii at intersections, and driveway width, which are typically designed to accommodate the turning radius and swept path width of a specific design vehicle. The design vehicle is also used in such roadway features as storage length of turn lanes and driveway throat length, which are typically designed to accommodate the length of a specific design vehicle. Section 4.2 presents a detailed discussion of design vehicles and considerations for selecting an appropriate design vehicle.

2.3 Turning Characteristics of Trucks

Turning maneuvers are one of the key challenges faced by trucks on urban and suburban arterials. Because of their larger width and length, trucks require a larger turning path than other vehicles for making a turning maneuver. Specifically, trucks exhibit offtracking, which is a function of the spacing between the truck's tire axles. A turning template for a specific design vehicle, or an automated version of a turning template in computer-aided design and drafting (CADD) software, can be used to assess whether truck encroachment on the curbline or another lane will occur.

Some transportation agencies have indicated that right turns at intersections are the most problematic for trucks. Where trucks make right turns at intersections, it is desirable to provide a sufficiently large curb return radius so that a truck can make a right turn without encroaching on the curbline or on an adjacent or opposing lane. However, when balancing the needs of trucks with other user modes, a transportation agency may (if the applicable state vehicle code allows) find it desirable to accept occasional encroachment on adjacent or opposite lanes. Left-turn maneuvers at intersections may be less critical for trucks than right-turn maneuvers, but left turns can still present challenges for trucks. Double left-turn lanes are implemented by some transportation agencies to accommodate trucks because the outer (rightmost) left-turn lane can provide a larger turning radius. Section 4.3 discusses truck-turning considerations in the design of intersections.

The turning characteristics of trucks are also an important consideration in the design of interchange ramp terminals. It is important to provide sufficient turning radii for trucks turning from the ramp to the crossroad and for trucks turning from the crossroad to the ramp. Section 4.4 presents a discussion of the following five types of interchange designs, and how trucks can be considered in each design:

- Conventional diamond interchanges and closely related interchange configurations.
- Single-point diamond interchanges.
- Full cloverleaf interchanges.
- Diverging diamond interchanges.
- Roundabout interchanges.

Where trucks are expected to use a driveway, particular consideration should be given to the turning capabilities of the design vehicle when designing the driveway. In the selection of curb return radius and throat width, and in the decision whether or not to include a median in the driveway, designers should consider the larger turning radii that trucks need when making turns into and out of a driveway (see Section 4.5).

In higher-speed environments, particularly in rural areas, large trucks may experience off-tracking when negotiating horizontal curves. To address this issue, the traveled way may need to be widened at some horizontal curves to fully accommodate trucks (see Section 4.6.2).

2.4 Storage Length for Trucks

The length of trucks is a key consideration when selecting an appropriate storage length for turn lanes, intersection spacing within an interchange, and the throat length of a driveway. A common design vehicle on truck routes and freight corridors is the WB-67, which is 73.5 ft in length. In comparison, a single-unit truck is approximately 30 ft in length and a passenger car is approximately 20 ft in length. If left- or right-turn lanes are not designed with sufficient storage length, the queue of vehicles waiting to turn may extend into the adjacent lane and block through-moving vehicles. Section 4.3.3 presents queue storage length adjustments for trucks, which can be considered in determining an appropriate length for a left-turn lane to accommodate trucks.

Storage length is also an important consideration in interchange design. Sufficient spacing between the crossroad ramp terminals is desirable to provide sufficient storage space for large vehicles within the interchange on the arterial crossroad. Storage space at interchanges is discussed further in Section 4.4.

Where trucks are expected to use a driveway, particular consideration should be given to the length of the design vehicle when designing the driveway. The determination of an appropriate driveway throat length should be based on the length of the design vehicle. The driveway throat needs to be long enough for trucks to enter or exit the site without interfering with onsite traffic or with through traffic on the roadway. Section 4.5 presents a discussion of the consideration of trucks in driveway design.

2.5 Truck Acceleration and Deceleration

Trucks have quite different operating characteristics than passenger cars when accelerating from a stopped position or decelerating to a stopped position. This is an important distinction when considering the benefits of installing a left- or right-turn lane. A truck decelerates and accelerates more slowly than a passenger car; therefore, when a truck has to stop behind a turning vehicle, it causes additional delay to the vehicles following the truck. A turn lane removes the turning vehicles from the through lane and minimizes the deceleration and acceleration of all traffic, including trucks. For example, because of the slower acceleration of trucks, drivers of trucks may be more selective in choosing a gap when making a left-turn maneuver. A left-turn lane provides a sheltered location for drivers to wait for a gap in opposing traffic. Sections 4.3.3 and 4.3.4 present a more detailed discussion of the consideration of trucks in the need for and design of left- and right-turn lanes, respectively.

2.6 Truck Deliveries and Parking

Businesses typically generate demand for pickups and deliveries whether loading zones are provided are not. Furthermore, in recent years the demand for truck deliveries has increased substantially with the increased popularity of e-commerce. Given the desire by transportation agencies to serve all travel modes effectively, there are increasing demands for space in the roadway cross section, which may limit the space available for trucks to stop and make pickups and deliveries. Trucks must often stop along roads and streets to make pickups and deliveries at locations where off-road loading and unloading areas are not available, and where no curbside loading zones are provided. This is an ongoing challenge for trucking companies, who risk a citation for parking in a center two-way left-turn lane, through lane, or bike lane to complete their delivery or pickup. Section 3.1.5 presents a further discussion of challenges related to truck deliveries.

There is a nationwide shortage of truck parking places, either to accommodate a driver's need for rest or for drivers to wait for their scheduled delivery time (due to early arrival). The shortage of parking areas has existed for a long time, but the lack of parking areas has recently become a more critical issue with the new federal mandate for on-vehicle electronic data loggers and the increased freight demand due to the increase in e-commerce. Many more drivers are now choosing to park their trucks illegally, in exposed positions on highway shoulders or on ramps. Section 3.7 presents a more detailed discussion of challenges related to truck parking.

2.7 Balancing Truck Needs with Other Modes

While truck routes should be designed to accommodate the types of trucks that use the route with considerable frequency, the needs of other modes present on the truck route—such as pedestrians, bicyclists, and transit—should be considered as well. This does not necessarily mean that facilities for every mode are provided, but rather the appropriate balance among the needs of each mode be sought throughout the truck route. Chapter 5 summarizes the key issues in balancing truck considerations with the needs of pedestrians, bicyclists, and transit.

CHAPTER 3

Planning for Truck Routes and Other Related Considerations

Chapter 3 presents current practices for planning, truck routing, enforcement, roadway maintenance, driveway permits, OSOW permits, and truck parking to accommodate truck operations on the roadway system.

3.1 Planning

Planning for truck routes includes consideration of land use, roadway functional classification, strategic freight corridors, interagency collaboration, truck delivery needs, site layout, and internal circulation. A key aspect of planning is the position of each roadway in the transportation network, including the hierarchy of roadways and the freight function of each roadway. For example, Interstate highways and strategic corridors serve state-to-state and regional commerce, other roads serve as connections between freight activity centers and strategic corridors, while still other roads serve as distribution routes to deliver goods to markets.

3.1.1 Land-Use Considerations

Land use influences the volume and types of trucks that use a roadway and, therefore, plays an important role in the way that freight is served, and other user modes are considered on the roadway. Land-use controls are the tools used by municipalities to manage the type and intensity of activity on a property and influence the conditions in which trucks operate. Land-use controls may be enacted to encourage or discourage specific types of development. As a result, land use and vehicular usage are critically connected, with land-use controls dictating how vehicles operate, park, deliver, and load goods.

The most common form of land-use control and regulation is zoning. Zoning regulations are used by municipalities to control and direct the development of property within their borders. Zoning regulations may be used to provide more details regarding land-use control or provide more broad terms of use. Specific zoning regulations may vary by jurisdiction, in terms of how they are applied and what can be regulated.

On roadways with high truck volumes or adjacent to land uses that generate truck trips, the roadway and other surrounding land uses should be able to accommodate efficient and manageable truck operations. Conversely, some areas may impose strict usage regulations aimed at limiting or prohibiting truck operations.

In each of the following area types and land uses, the extent to which trucks are accommodated and the types of trucks that are accommodated vary:

- **Industrial Areas**—Roadways within industrial areas and other freight-oriented areas typically experience relatively high volumes of truck traffic. They should be designed to provide for truck mobility, access, and circulation. Design considerations include lane width, turning radii, median island radii, vertical clearance, and location of fixed objects (e.g., signs, utility and signal poles, street trees, other roadside features) (City of Portland 2008). Industrial areas may not experience as many pedestrians, bicyclists, or transit users as urban areas; however, even industrial roadways need to safely accommodate and balance the needs of pedestrians, bicyclists, and transit. Each roadway's user mix and resulting needs should be assessed on a case-by-case basis.

- **Urban Core Areas**—Roadways within urban cores and other diverse activity areas typically experience a mix of user modes, including motor vehicles and trucks, pedestrians, bicyclists, and transit users. Designing to accommodate trucks should not conflict with the needs of motor vehicles, pedestrians, bicyclists, and transit users in urban areas. Achieving an appropriate balance of the various user modes in design will require careful consideration of the specific mix of user modes for a particular site. In other words, it may be important to accommodate freight on one urban corridor but focus on pedestrian needs on a nearby corridor. Designers need to "apply sound design principles within different urban environments to address a variety of multimodal transportation needs" (City of Portland 2008).

  When designating a truck route that is not already an arterial, it is important that such routes not split neighborhoods in urban areas.
- **Residential Areas**—Residential areas and other community-oriented areas typically experience low volumes of truck traffic and are primarily designed for automobile, pedestrian, and bicycle movements. With the exception of fire trucks, garbage trucks, and the occasional moving truck, most trucks entering residential areas are smaller-sized delivery trucks (e.g., FedEx, UPS).

  Some agencies allow designated truck routes through residential areas where needed for continuity of the truck route network, but the density of such residential areas is often limited.

3.1.2 Roadway Functional Classification

Land use should be considered in conjunction with roadway functional classification in establishing truck routes. Arterials often serve as truck routes through land uses of all types, although arterials with residential development are less desirable as truck routes than arterials through other land-use types. Collectors are most suitable as truck routes when they serve commercial or industrial development. Local roads and streets are seldom suitable as truck routes, except when they serve a specific facility for which there is no alternative truck route.

3.1.3 Identification of Strategic Freight Corridors

A number of transportation agencies have directed their statewide planning process toward establishing strategic freight corridors to recognize the routes that are used most extensively for truck movements. The strategic corridors provide a focus for review of geometrics to accommodate trucks; review of congestion levels; review of regional freight flows; review of access connections to freight centers, including services, terminals, and high-volume shippers/receivers; and prioritization of roadway improvements. Where freight advisory committees have been established, the committee also has a key role in identifying the strategic corridors. As with the National Highway Freight Network (see Section 3.2.4) established at the federal level, state strategic freight corridors have no legal or regulatory status, but simply provide a management tool for prioritization and decisionmaking.

3.1.4 Interagency Collaboration

Collaboration between various stakeholders, including transportation agencies, trucking companies/associations, residents, property owners, and developers, during the planning process is likely to result in a better design for trucks as well as other roadway users. Several transportation agencies have established statewide or local freight advisory groups that meet regularly (e.g., bi-monthly, quarterly) to discuss safety, operational, and design issues for accommodating trucks on the roadway system.

The collaborative approach may help to align access issues with context classification and improve site plans in terms of freight loading zones and alternative access locations. Wherever a new development is proposed that would generate high truck volumes, traffic impact studies should be reviewed to consider the effects of the proposed development on the roadway system. Coordinated discussion with the trucking industry is encouraged to make sure the following design issues are considered:

- Turning radii.
- Intersection dimensions.
- Storage length.
- Driveway dimensions.
- Parking.

3.1.5 Truck Delivery Considerations

In recent years, the demand for truck deliveries has increased substantially with the increased popularity of e-commerce. To minimize the impact of truck deliveries on motor vehicle traffic, pedestrians, and bicyclists, and to reduce traffic delays and the potential for crashes, many trucking companies and businesses have strategized new approaches to managing deliveries, including making deliveries during off-peak or nighttime hours. Challenges associated with this type of operation may include (1) the possible need for receivers of these deliveries to staff up during what are often nonbusiness hours, (2) availability of parking needed for staging of trucks just outside the city, so that trucks can wait for the time during which deliveries are allowed, and (3) possible increased costs for truck operators and/or shipment receivers due to added staff and equipment waiting time prior to deliveries.

An important consideration in the planning of bicycle lanes is the location of frequent truck deliveries. If possible, placing a bicycle lane on a route where frequent truck deliveries occur should be avoided because the presence of parked trucks in a bicycle lane would be problematic for bicyclists. In some cases, for example, if a one-way street is involved, placing the bicycle lane on the other side of the street from frequent delivery locations may be preferable.

3.1.6 Site Layout and Internal Circulation

Trucks require more space to maneuver and have different operational characteristics than cars, with additional needs related to roadway geometry. Trucks also involve different supporting facilities for which access and location are of primary importance. In addition, interactions between trucks and multimodal users must be considered, particularly in high-volume usage areas. This section identifies site layout needs to adequately provide for site circulation where a significant number of trucks are anticipated. The location of gates providing access to the site should be considered as part of the site layout, as discussed in Section 4.5.11.

Special Characteristics of Trucks

Trucks have specific site layout needs, especially at locations expected to accommodate a substantial volume of trucks. Trucks have greater turning radii than other vehicles and require more space for turning maneuvers. Wider lanes and a greater corner radius may be necessary to accommodate larger tractor trailers and other wide-bodied vehicles. Auxiliary lanes or additional storage length for these lanes may be necessary to safely facilitate turns on and off the property. In addition, storage areas to allow trucks to queue without obstructing through traffic or other roadway users may be needed. Interactions between trucks and other roadway users should be organized to minimize traffic conflicts where possible. The selection of a design vehicle as well as a design speed will play a major role in site layout.

Consideration of Site Type

There are different types of sites that illustrate the varying conditions in which trucks need to be accommodated. This section examines three distinct settings—a shopping center, an industrial or freight-oriented area, and an urban core or diverse activity area—as examples of different site characteristics and how they impact truck operations and usage. Each site is designed with different goals and development patterns that have implications for street design and roadway engineering. However, the site layout must support the various types of traffic that will be needed to serve the site so that it can function effectively and efficiently.

Shopping areas, as illustrated in Figure 1, are examples of sites where trucks and other vehicles require access and have different needs. Trucks require access to the loading docks, shipping bays, and delivery facilities to complete their trips. This differs from private vehicles, which require general parking and pedestrian access to entries and sidewalks. The site circulation facilities for trucks should be planned separately from, yet concurrently with, facilities for other vehicles. Access from the street to the shopping center may be from different entrances. Whereas most

a. Aerial view of suburban shopping area. (Photo source: Google Earth.)

b. Non-standard sign used at shopping center to guide truck drivers to loading docks and customers to parking areas. (Photo source: AECOM.)

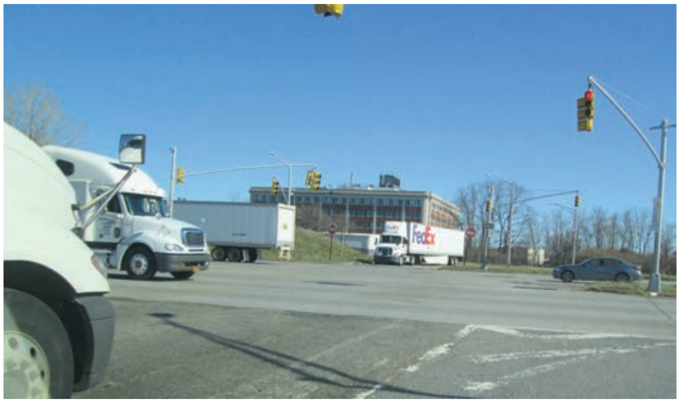
Figure 1. Shopping areas.

shopping centers' frontages face the street for easy access to shoppers, delivery trucks mainly access the backs of stores for deliveries. The separate access facilities for trucks should avoid pedestrian and vehicle conflicts. For trucks, getting to the site is as important as staying there; an easy access route leading to an adequate space for short- and long-term loading and unloading of goods is desirable. This dedicated space is more than a parking space; it needs to have sufficient clearance for the quick loading and turning around of trucks. This should be a restricted area to ensure safety of users and efficiency of the delivery. Egress from the delivery area should be as protected as ingress. Lanes to be used by trucks should be wider than travel lanes used predominantly by cars.

Industrial areas, or freight-oriented areas, as illustrated in Figure 2, exemplify sites where trucks are not as likely to interact with other users, but still require site planning for efficient and safe usage by trucks. Industrial parks tend to be located in wide, expansive areas, so narrow access roads that may be located in an urban core are not generally an issue. The access roads from other main thoroughfares and highways need to provide direct access to the industrial park without circuitous routing. It is thus advantageous for the industrial park to be located adjacent to the highway, such as on a dedicated truck exit that has restricted entry. With a dedicated access road, it could be specifically tailored for heavy truck traffic. This could include greater turning radii and geometry, such as wider lanes and asphalt engineered for heavy loads.

One of the most challenging settings for truck site planning is a dense urban environment, often referred to as an urban core, as illustrated in Figure 3. In downtown development areas, pedestrian usage and walkability are often prioritized. Passenger cars face spatial challenges in the urban

a. Aerial view of industrial area. (Photo source: Google Earth.)



b. Truck activity near access to industrial area. (Photo source: AECOM.)

Figure 2. Industrial areas.

a. Aerial view of urban core area. (Photo source: Google Earth.)

b. Truck turning across pedestrian crossing. (Photo source: AECOM.)

Figure 3. Urban core areas.

environment, but such challenges are even more significant for trucks. These include parking maneuvers, loading, circulation, capacity, and queuing. Truck circulation in these areas should be planned concurrently with the rest of the site plan to ensure that trucks are properly integrated to reduce impacts on the area and effectively serve the area. Route or time-of-day restrictions may be options to minimize potential conflicts (Anderson 2017; Holguin-Veras et al. 2015).

3.2 Truck Routing

Truck routes, as defined in this Guide, include roads formally designated as truck routes as well as any road that carries a substantial volume of trucks. Truck routes should be designed to accommodate the types of trucks that use the route with considerable frequency. The formal designation of truck routes is a key operational and planning activity that should consider the truck demand volumes, the origins and destinations of truck shipments, and the suitability of particular roads and corridors to accommodate trucks of specific sizes. When designating a truck route that is not already an arterial, it is also important that such routes not split neighborhoods in urban areas.

3.2.1 National Network

Establishment of a National Network (NN) of truck routes was mandated in the 1982 Surface Transportation Assistance Act (STAA). The NN includes the entire Interstate Highway System (with minor exceptions) and other roads designated by the U.S. Secretary of Transportation based on recommendations by the states. The NN includes approximately 200,000 mi of roads and has been very stable in extent of 25 years. Changes in the NN may occur when a state petitions the Secretary of Transportation to add or delete roads from the NN.

The NN was designated by the U.S. Secretary of Transportation based on the following criteria (23 CFR 658.9):

- For those states with detailed lists of individual routes, the routes on the NN have been designated on the basis of the following criteria:
  - The route is a geometrically typical component of the Federal-Aid Primary[1] (FAP) system, serving to link principal cities and densely developed portions of the states.
  - The route is a high-volume route utilized extensively by large vehicles for Interstate commerce.
  - The route does not have any restrictions precluding use of conventional combination vehicles.
  - The route has adequate geometrics to support safe operations, considering sight distance, severity and length of grades, pavement width, horizontal curvature, shoulder width, bridge clearances and load limits, traffic volumes and vehicle mix, and intersection geometry.
  - The route consists of lanes designed to be 12 ft or more in width or is otherwise consistent with highway safety.
  - The route does not have any unusual characteristics causing current or anticipated safety problems.
- For those states where state law provides that STAA authorized vehicles use all or most of the FAP system, the NN is no more restrictive than such law.

3.2.2 Truck Size and Weight on the National Network

Federal regulations for the NN concerning the length of conventional tractor-trailer trucks require that (23 CFR 658.13)

- No state shall impose a length limitation of less than 48 ft on a semitrailer operating in a tractor-semitrailer combination. [Note: In 25 states, trucks with 53-ft semitrailers are permitted to operate on the NN under grandfather provisions; in three additional states, trucks with 53-ft semitrailers and specific limitations on kingpin-to-rear-axle (KPRA) distance are permitted to operate on the NN under grandfather provisions.]
- No state shall impose a length limitation of less than 28 ft on a semitrailer or trailer operating in a tractor-semitrailer-trailer combination.
- No state shall impose an overall length limitation on commercial vehicles operating in tractor-semitrailer or tractor-semitrailer-trailer combinations.

[1] Since the establishment of the NN, the FAP system has been discontinued and replaced by the National Highway System (NHS)—see Section 3.2.5.

- No state shall prohibit tractor-semitrailer-trailer combinations.
- No state shall prohibit the operation of semitrailers or trailers that are 28.5 ft long when operating in a tractor-semitrailer-trailer combination if such trailer or semitrailer was in actual and lawful operation on December 1, 1982, and such combination had an overall length not exceeding 65 ft.
- No state shall prohibit the use of trailers or semitrailers that were in actual or lawful use in such state on December 1, 1982.
- If, on December 1, 1982, state length limitations on a semitrailer were described in terms of the distance from the kingpin to rearmost axle, or end of semitrailer, the operation of any semitrailer that complies with that limitation must be allowed.

Federal regulations for the NN concerning the length of conventional tractor-trailer trucks are as follows (23 CFR 658.15):

- No state, with the exception of Hawaii, shall impose a width limitation of more or less than 102 in. on vehicles operating on the NN.

These length and width limits presented do not include the following (23 CFR 658.16):

- Rearview mirrors, turn signal lamps, handholds for cab entry/egress, splash and spray suppressant devices, and load-induced tire bulge.
- All non-property-carrying devices or components thereof:
  - At the front of the semitrailer or trailer.
  - That do not extend more than 3 in. beyond each side or the rear of the vehicle.
  - That do not extend more than 24 in. beyond the rear of the vehicle and are needed for loading and unloading.
  - Are listed explicitly in Appendix D to 23 CFR 658.

Federal regulations for the Interstate Highway System concerning the weight of conventional tractor-trailer trucks require, except for certain grandfathered vehicle weight limits or where an overweight permit is issued, the following (23 CFR 658.17):

- The maximum gross vehicle weight shall be 80,000 lb except where a lower gross vehicle weight is dictated by the bridge formula (see below).
- The maximum gross weight upon any one axle, including any one axle of an axle group, is 20,000 lb.
- The maximum gross weight on tandem axles is 34,000 lb.
- The gross weight on two or more consecutive axles exceeds the following bridge formula, except that two consecutive sets of tandem axles may carry a gross load of 34,000 lb each if the overall distance between the first and last axle is 36 ft or more and the total gross weight of the vehicle does not exceed 80,000 lb.

$$W = \left(\frac{LN}{N-1} + 12N + 36\right) \tag{1}$$

where:

W = maximum weight carried on any group of two or more axles (lb).
L = distance between the outer axles in any group of two or more axles (ft).
N = number of axles in the axle group.

- States may not limit tire loads to less than 500 lb per inch of tire or tread width, except that such limits may not be applied to tires on the steering axle.
- States may not limit steering axle weights to less than 20,000 lb or the axle rating established by the manufacturer, whichever is lower.

3.2.3 Access Routes to the National Network

Federal regulations indicate that states (or local jurisdictions) may not enact or enforce any law denying reasonable access to vehicles with dimensions authorized by the STAA between the NN and terminals; and facilities for food, fuel, repairs, and rest; or denying reasonable access to points for loading and unloading. States may not enact or enforce any law denying access within 1 road-mile from the NN along the most reasonable and practicable route available except for specific safety reasons on individual routes. Distinctions between vehicle types shall be based only on significant, substantial differences in their operating characteristics. Blanket restrictions on 102-in.-wide vehicles shall not be imposed. Vehicle dimension limits shall not be more restrictive than federal requirements. Truck operators may request access from the NN by specific truck types along specific routes to points of loading and unloading, and states shall have procedures for review of such access routes within 90 days.

3.2.4 National Highway Freight Network

The Fixing America's Surface Transportation (FAST) Act of 2015 mandated creation of a National Highway Freight Network (NHFN) to strategically direct federal resources toward improved performance of the highway portions of the U.S. freight transportation system. The NHFN is primarily a device for prioritizing federal funding; there are no truck size and weight regulations applicable specifically to the NHFN. The NHFN consists of four components:

- Primary Highway Freight System (PHFS)—consisting of most of the Interstate Highway System and a few additional roads.
- Other Interstate Highways not on the PHFS.
- Critical Rural Freight Corridors (CRFCs).
- Critical Urban Freight Corridors (CUFCs).

The NHFN is a subset (including about 25%) of the NN, not including the CRFCs and CUFCs, which have not been completely selected yet.

3.2.5 National Highway System

The NHS includes the Interstate Highway System as well as other roads important to the U.S. economy, defense, and mobility. NHS roads receive special consideration in planning and funding road improvements because the design of improvement projects on NHS roads involve a greater level of federal agency review than on other roads. The NHS differs from the NN in that the NHS includes roads of importance to all travel modes, not just trucks. Both the NHS and the NN include approximately 200,000 mi of road, and there is substantial overlap between the two systems. However, the NN includes approximately 65,000 mi of roads not on the NHS, and the NHS includes approximately 50,000 mi of road not on the NN.

The subsystems of the NHS include the following:

- Interstate highways.
- Other principal arterials.
- Strategic Highway Network (STRAHNET).
- Major strategic highway network connectors.
- Intermodal connectors.

Many Interstate highways and other principal arterials are important truck routes. STRAHNET highways are a network of roads that has been designated as important to U.S. strategic defense, including transportation to and from defense facilities, continuity, and emergency capabilities for defense purposes. Major strategic highway network connectors provide access routes between STRAHNET roads and major military installations. Intermodal connectors provide access between NHS roads and major intermodal facilities, such as airports, ports, and rail yards. STRAHNET roads, major strategic highway connectors, and intermodal connectors are typically designed to accommodate large trucks and carry substantial volumes of truck traffic.

3.2.6 Truck Route Designation by Individual State and Local Agencies

State and local agencies are free to designate truck routes or to prohibit all trucks, or trucks of particular sizes or weights, from using roads that are not part of the NN. Such designations and prohibitions can generally be made without reference to federal regulations or criteria. However, if a particular road is requested as part of an access route to the NN, any decision to deny that request must be based on rational, safety-related criteria. Specific considerations in identifying and designating truck routes are discussed in Section 3.2.7.

Individual agencies communicate truck route designations and prohibitions to the trucking industry in a variety of manners. For example, California focuses on mapping approved service access and terminal access to the NN and signing of service access and terminal routes that truck drivers can follow.

Michigan publishes maps for truckers showing “gold routes,” which constitute the NN, and “green routes,” which are other routes where large trucks can operate without restriction. The gold and green routes together constitute most of the state highway system. (Note: in the printed version, the gold routes are light gray and the green routes are darker gray. The electronic version—posted on the web at www.trb.org—retains the color version.) The maps also identify a limited number of state highways where trucks are prohibited, or truck size or weight is restricted. A sample of Michigan’s truck route map is shown in Figure 4.

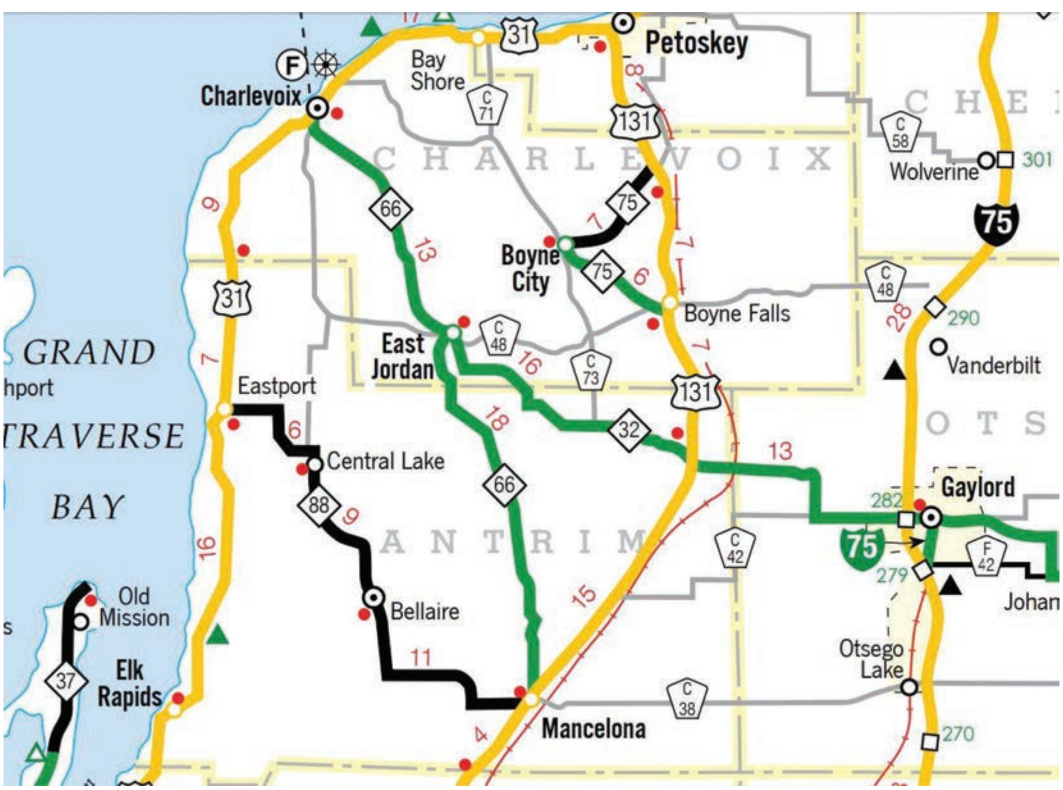


Figure 4. Sample of Michigan truck route map **(Source: Michigan DOT).**

Colorado publishes maps showing designated routes that must be used by trucks hauling nuclear or other hazardous materials. Trucks loaded with hazardous materials subject to the Colorado routing regulations must use the designated routes. For local pickups and deliveries, hazardous materials trucks must avoid populated and residential areas, if possible, while utilizing the shortest and most direct route to minimize distance traveled off the designated route system.

The Federal Motor Carrier Safety Administration (FMCSA) maintains a website known as the National Hazardous Materials Route Registry (www.fmcsa.dot.gov/regulations/hazardous-materials/national-hazardous-materials-route-registry-state/) that identifies all roads in the United States that are designated for travel by trucks carrying hazardous materials. It also identifies roads on which trucks carrying hazardous materials are restricted or prohibited.

3.2.7 Factors to Consider in Identifying and Designating Truck Routes

The following factors should be considered in identifying and designating truck routes:

- Truck characteristics
  - Design vehicle dimensions and turning performance
  - Existing and anticipated usage by OSOW vehicles
- Roadway network characteristics
  - Functional classification
  - Position of roadway in transportation network and connectivity needs
  - Network constraints
  - Available alternative routes
- Roadway facility characteristics (including access management provisions)
  - Lane width
  - Shoulder width
  - Traffic-signal spacing
  - Driveway density and design
  - Median treatment and related features
  - Auxiliary lanes
  - Presence of bicycle facility
  - Height restrictions
  - Weight restrictions
- Land-use and environmental characteristics
  - Land use immediately adjacent to the roadway and in nearby areas
  - Location relative to land uses that generate truck movements
  - Location relative to environmentally sensitive areas
- Operational and safety characteristics
  - Traffic volume and congestion levels
  - Existing truck volume
  - Existing percentage of trucks in traffic stream
  - Pedestrian volumes
  - Bicycle volumes
  - Traffic speed
  - Split between through traffic versus local traffic

Among these parameters are considerations associated with roadway access management strategies, including the following:

- Median treatment and related features, such as installation of medians to reduce head-on conflicts and selection of median width to accommodate U-turns.

- Traffic-signal spacing that allows for progression commensurate with the posted speed.
- Design and operation of driveways, such as design of driveway width and profile to accommodate trucks as well as other users and provision of corner clearance near intersections.
- Conventional intersection designs, such as construction of auxiliary lanes and needed turning geometry.
- Alternative intersection designs, such as provisions for indirect left turns and construction of roundabouts.

Although truck routes, whether formally designated or not, may represent most of the mileage that a truck needs to travel between its trip origin and destination, consideration must also be given to the "first mile" and the "last mile" in truck route planning. The first mile is the connection needed to get from the trip origin to the truck network; while the last mile is the connection needed to get from the truck network to the trip destination. Routing options for these connections may require special consideration, because the roadways involved are often not part of any truck network, may not be frequently used by trucks, and may be located in built-up areas. As a result, these connections may represent significant challenges to finding a route that can accommodate the truck movement without adversely affecting the roadway facility, while being sensitive to the needs of adjacent communities. In truck route planning, agencies and truck operators need to recognize that achieving this balance may require further investigation to select the route to use. Access management provisions along the routing options (e.g., signal spacing, median cross section, auxiliary lanes) should be considerations in the route selection. (See Section 3.2.1 for information on the NN and Section 3.2.3 for information concerning federal regulations that pertain to access routes to the NN.)

3.2.8 Truck Prohibitions

State and local transportation agencies have the authority to prohibit all trucks, or trucks that exceed particular size or weight limits, on roads where this makes engineering sense, except for roads on the NN. However, truck prohibitions or restrictions are only practical where there are suitable alternative routes for trucks. Federal law in 49 USC 5112 allows states, local jurisdictions, and Indian tribes to designate routes for or prohibit transportation of hazardous materials shipments requiring placarding on particular routes, but such decisions must enhance public safety and cannot be made arbitrarily. Routing regulations for hazardous materials trucks must be made in consideration with other affected jurisdictions and must maintain reasonable routes for hazardous materials trucks to research terminals; facilities for food, fuel, repairs, and rest; and places where hazardous materials are loaded and unloaded.

3.3 Enforcement

3.3.1 Types of Enforcement Activities

Law enforcement agencies in each state undertake truck-oriented enforcement activities including the following:

- Routine enforcement of state and local traffic laws that apply to all vehicles.
- Enforcement of truck size and weight regulations.
- Inspections for enforcement of the Federal Motor Carrier Safety Regulations and the U.S. DOT hazardous materials regulations for Interstate commerce.
- Inspections for enforcement of state motor carrier safety regulations and hazardous materials regulations for intrastate commerce.

Many states have adopted all or part of the Federal Motor Carrier Safety Regulations and the U.S. DOT hazardous materials regulations that apply to Interstate commerce for application to intrastate commerce as well. In many states, federal agencies have delegated their enforcement of federal regulations within that state to a state law enforcement agency, such as the state police or highway patrol. Many state law enforcement agencies have a motor carrier enforcement unit specifically responsible for enforcement of motor carrier safety and hazardous materials regulations.

Law enforcement agencies typically conduct truck enforcement activities in three ways:

- Routine stopping of trucks when a patrol officer observes a violation.
- Random stopping of trucks for inspection at locations where a need for enforcement has been identified.
- Systematic stopping of all or most trucks at established weigh stations.

The relationship of highway design to each of these three types of enforcement activities is discussed in the next three sections.

3.3.2 Routine Stopping of Trucks for Observed Violations

Law enforcement officers routinely stop trucks when a violation is observed. Observed violations could include violations of state or local traffic laws (e.g., speeding, improper lane changing) or violations of motor carrier safety or hazardous materials regulations (e.g., equipment violation, improper placarding). Such violations may occur anywhere on the highway system. Law enforcement officers prefer to stop trucks at locations with full paved shoulders or that otherwise provide a good place for both the truck and the officer's vehicle to stop. If a truck is stopped on an unpaved, soft shoulder, the truck may become mired and require a tow truck to extricate it, which consumes time for both the officer and the truck driver. If the shoulder is not wide enough, the truck may encroach on the traveled way when stopped.

Trucks on the NN are permitted to be up to 8.5 ft in width, so a truck stopping on an 8-ft shoulder may still encroach on the traveled way. Therefore, on truck routes where paved shoulders are not wider than 8.5 ft, transportation agencies may want to provide paved turnouts at intervals or other appropriate stopping areas large enough for a truck and at least one other vehicle. The space should be sufficient enough for an officer to perform an inspection. A typical turnout size might be 200 ft by 20 ft. Provision of turnouts at intervals also provides operational flexibility to the roadway, such as a stopping area for vehicle breakdowns or an off-road site for crash investigations.

3.3.3 Enforcement Sites for Random Stopping of Trucks

Law enforcement agencies often target specific roads for random inspection of trucks. Such roads may include truck routes with large volumes of trucks or roads that appear to be used frequently by truckers avoiding a fixed enforcement site, such as a weigh station. Transportation agencies can assist law enforcement agencies by providing off-road areas specifically for enforcement activities on roads where random enforcement is needed. Random enforcement activities could include vehicle inspections, review of driver logs, review of OSOW permits, and weighing the truck with a portable scale.

An ideal site for random enforcement would include the following:

- A level, paved roadside area sufficiently large for enforcement activities.
- A hard, stable surface suitable for use of a portable scale.
- A traffic barrier between the enforcement area and the roadway to protect the officers, the truck driver, and their vehicles.

Figure 5. Typical roadside area used for random truck enforcement. **(Photo source: Google Earth.)**

- Sufficient space for trucks completing inspections to pull around trucks in ongoing inspections and for trucks placed out of service to remain parked.

Figure 5 shows a photograph of a typical site for random enforcement.

3.3.4 Weigh Stations

Fixed weigh stations also play a key role in truck enforcement activities. Weigh stations are typically provided on the highway right of way at state ports-of-entry and at other strategic locations on intercity truck routes. Weigh stations not only provide a facility for quickly determining truck gross weights and axle loads, but they can also provide space for vehicle inspections, review of driver logs, review of OSOW permits, and parking for vehicles placed out of service. Some state design manuals include information on weigh station design.

Advanced technology can enhance the effectiveness and efficiency of weigh station operations. A state-of-the-art weigh station may include the following:

- Weigh-in-motion sensors on the roadway in advance of the weigh station to detect potentially overweight vehicles.
- Transponders to communicate signals to the truck driver (e.g., bypass/enter) in advance of the weigh station.
- Sensors at the weigh station entrance to detect overheated brakes.
- Cameras to automatically read the truck's license plate.
- Cameras to automatically read the truck's inspection sticker to determine whether it has been inspected recently.

Technology of this type allows law enforcement officers to quickly assess which trucks should be stopped for weighing and inspection and which should be waved through.

3.4 Roadway Maintenance

The presence of trucks on roadways generates unique maintenance issues as a result of heavy loads and wide turning paths. Access management treatments may also present maintenance challenges.

Figure 6. Rutting resulting from truck encroachment at a roundabout approach and rutting resulting from truck encroachment at a loon. **(Photo source: MRIGlobal.)**

3.4.1 Encroachment on Shoulders or Roadside Areas

Damage to areas outside the traveled way as a result of encroachment by turning trucks is a key maintenance concern for transportation agencies. Some access management techniques require turning maneuvers. Common elements that are damaged due to truck encroachment include shoulders, curbs, drainage features, areas behind the curb, pedestrian button pedestals, and median barrier attenuators. Figure 6 shows rutting behind curbs at a roundabout approach and outside a loon at a median U-turn roadway. Damage to curbing on a roundabout center island is shown in Figure 7.

Designers need to utilize turning templates in CADD software in areas where trucks are prevalent. Providing a traversable path for trucks will help mitigate damage resulting from

Figure 7. Curb damage on center island of a roundabout. **(Photo source: MRIGlobal.)**

encroachment. In situations where a large curb return radius is not practical, adding reinforced pavement behind a mountable curb will prevent rutting behind the curb and damage to the curb. This strategy should only be done in situations where pedestrians are not anticipated to be using the pavement behind the curb.

3.4.2 Snow Removal

In areas where snow is expected annually, designers should consider snow storage in the vicinity of intersections and other design elements used by trucks. Snow removal and roadway treatment operators should be trained on how to safely remove snow and treat innovative intersection and interchange designs. Clear Roads Pooled Fund Project 14-03 is developing a training video and manual for the best practices and techniques in clearing different interchange configurations and other geometric layouts (Qi 2018).

3.4.3 Additional Considerations

Innovative access management treatments, such as indirect left-turn movements discussed in Section 4.3.6, and innovative interchange designs, discussed in Section 4.4, often need extensive signing. Transportation agencies should train maintenance personnel on placement of these signs and should plan for the additional maintenance needed to maintain the signs.

Where flexible delineator posts are used to separate traffic lanes, maintenance crews should be prepared to replace the posts more often if large truck volumes are present. Pavement markings tend to wear more quickly where there are large truck volumes, so more frequent restriping may be needed. Rutting of pavement and development of pot holes are more common on roadways with heavy truck use. It is recommended to use reinforced pavement for turn lanes because of added stresses caused by deceleration of heavy loads and lateral forces resulting from turning trucks.

3.5 Driveway Permits

A driveway permit is "a legal document that grants approval to construct and operate a driveway or other access of a certain design at a specific location on a given roadway for specific purposes" (Koepke and Levinson 1992). Driveway permits "are typically required when any new access point is to be constructed or when an existing access point needs to be modified within the right-of-way" (Williams 2002).

The objectives of regulating access points through driveway permitting include the following (Williams 2002):

- Maintaining the functional integrity of the state highway system.
- Encouraging uniformity of standards and practices.
- Maintaining smooth and efficient traffic flow.
- Enforcing minimum distances between driveways.
- Minimizing conflict points.
- Maintaining appropriate sight distances on the state highway system.
- Monitoring driveway design.
- Providing for motorist and pedestrian safety.
- Maintaining highway right-of-way drainage.
- Facilitating public access to state rights of way.
- Promoting close cooperation with local governments in site planning.
- Preserving transportation corridors.
- Protecting the public investment in the state highway system.

The driveway permitting process not only establishes the number of driveways a property may have, but it also influences driveway locations. Driveway permits often include conditions, such as provision of turn lanes, wide turning radii, and so forth.

For sites where truck access is needed—such as retail and wholesale businesses and manufacturing facilities that need truck pickups and deliveries—consideration of internal site circulation for trucks must be taken to ensure the internal site operation will not result in truck spillback onto the public street or highway. Most transportation agencies request an internal site circulation plan as part of a driveway permit request for commercial or industrial facilities. The internal site circulation plan typically includes the following:

- Number, location, and width of driveways.
- Type of driveway operation (one-way/two-way, right-in/right-out versus all movements, including left turns).
- Location of loading docks or delivery doors.
- Internal site circulation routes between driveways and loading docks or delivery doors, in relation to buildings and parking areas.

For many sites, transportation agencies typically allow only one driveway but may make an exception to this policy based on internal site circulation needs. Transportation agencies have indicated that gas stations can be challenging sites for internal circulation because they are relatively small sites, and they need to accommodate truck-turning maneuvers and customer circulation when trucks are parked during deliveries. For this reason, two driveways may be permitted for gas stations. In some cases where two driveways are provided, however, transportation agencies may require that one driveway operate as an entrance-only driveway and the other as an exit-only driveway. Another option is to locate one of the driveways on a side street if feasible.

NCHRP Synthesis 304: Driveway Regulation Practices suggests that, during the driveway permit application process, it is important to review what design is required to accommodate the demand for the development (Williams 2002). The access provided should meet the design criteria of the roadway, especially on truck routes. The Access Management Application Guidelines (AMAG) recommend that, when evaluating access permits, agencies assess the type, size, and number of trucks that would use a driveway to ensure, where practical, that these vehicles do not have an undue impact on the traffic stream (Dixon et al. 2016).

The AMAG state that "the safety and operational impacts on pedestrians, cyclists, and transit should be explicitly considered when an application for a driveway is reviewed." At locations where pedestrian volumes are high, the number and width of driveways should be minimized. Also, at locations where existing or anticipated pedestrian volumes are high and large trucks will be making deliveries, the AMAG suggest that agency staff work with the developer to establish time periods for deliveries to minimize interactions between pedestrians and trucks.

3.6 Oversize/Overweight Permits

The movement of OSOW trucks generally requires operators to obtain a permit from the state DOT. Permits are issued for trucks transporting indivisible loads. If a load is divisible, that load is expected to be transported within the normal truck size and weight limitations. FHWA (2015) has published a compilation of truck size and weight limit laws showing the maximum sizes and weights of trucks that can operate without permits in each state.

Each state has its own rules about how permits are applied for and issued, how routes for OSOW trucks are determined, and what time-of-day or other restrictions may apply to OSOW truck movements. State DOTs are generally moving toward online permitting systems. Some online systems provide online interactive tools that assist truck operators in determining a route based on OSOW truck dimensions.

The OSOW permit may include time restrictions to when the load can move within the jurisdiction. Some states restrict movement in urban areas during designated peak hours. Some states prohibit movement of certain OSOW loads during nighttime hours. However, the opposite also occurs; in one particular metropolitan area, OSOW loads may only move during nighttime hours.

One state reports that their biggest problem with oversize permit trucks is bridge hits from overheight trucks. However, another state reports that they get very few bridge hits from permit trucks and that most bridge hits result from nonpermit trucks (Potts et al. 2019).

3.6.1 Routing Considerations

Routing considerations for overweight trucks focus primarily on the structural capacity of bridges. Routes for overweight trucks should not include bridges that cannot carry the trucks' weight.

Most access management treatments are not an issue for oversize trucks traveling straight through the treatment. Where trucks must turn at an intersection, the pavement width and curb return radius should be assessed. Indirect left-turn treatments may present challenges for oversize trucks making left turns (see the following and Section 4.3.6). Some intersection and interchange features are easier for oversize trucks to traverse than others.

Routing considerations include physical conditions, such as overhead structures, cross section widths, overhead traffic signals, and roundabouts. Particular attention should be paid to horizontal clearance and vehicle undercarriage clearance at roundabouts. Routing considerations may also include whether there are locations that may not be compatible with the truck movement, such as environmentally sensitive areas. Special events, such as marathons and road races, may create the need for imposing temporary restrictions on oversize truck movements because of competing demands for the road space.

Any type of overhead structure should be examined in planning an oversize truck route to make sure the clearance height is adequate. The number of lanes, lane widths, and widths of bridge structures should also be considered. Locations where the normal 1.5-ft lateral offset outside the edges of the traveled way is not provided should be considered. Traffic-signal span wires present a unique challenge for overheight trucks. Some agencies have reported the need to raise span wires on hot days in order to get an overheight load to clear an overly sagged span wire. Roundabouts should be examined carefully during the route planning to make sure the oversize truck can traverse the roundabout. Roundabouts should be designed to handle oversize trucks up to a certain maximum size on routes that experience OSOW loads on a regular basis; this can be accomplished with horizontal clearances and truck aprons surrounding the central island without affecting the operation of the roundabout for smaller vehicles.

The online permitting systems of some states include automated routing tools that can be utilized for OSOW trucks up to a specific maximum size and weight. Larger and heavier OSOW trucks require manual assessment of routes. Other states prefer to retain OSOW routing as an entirely manual process to ensure that no key factors in the routing decision are overlooked.

Routes for OSOW trucks should be planned in consultation with local municipalities and MPOs.

3.6.2 Route Continuity

Infrastructure improvement projects should be planned to maintain route continuity for OSOW permit trucks. Part of the project planning process should be to investigate past OSOW permit operations and ensure that new projects do not introduce new restrictions that create discontinuities in routes likely to be used by future OSOW permit operations. As part of the planning process, route continuity and available alternative routes should be analyzed, and routes likely to be used by future OSOW permit operations should be preserved with respect to the following:

- Vertical and horizontal clearance limitations at structures.
- Bridges with limited structural capacity.
- Roundabout geometrics.
- Conventional intersection geometrics.
- Horizontal and vertical roadway alignments.

3.6.3 Consideration of Intersection and Interchange Design Features

Any type of indirect left-turn treatment that requires a truck to make a U-turn may not be functional for an oversize truck. Agencies should avoid routing an oversize load through the U-turn roadways of Restricted Crossing U-Turn (RCUT) and Median U-Turn (MUT) intersection types (see Section 4.3.6). Even where these U-turns are designed with loons to accommodate trucks, many oversize trucks may not be able to complete the U-turn maneuver.

Roundabouts (see Section 4.3.7) are often designed to accommodate oversize trucks up to a certain maximum size determined by the designer. Steerable rear axles can assist an oversize truck in traversing a roundabout. In unusual situations, roundabouts may be temporarily closed to other traffic to allow an oversize truck to traverse the roundabout very slowly. Roundabouts may also be designed with a traversable center island in situations where OSOW trucks are common. One state has provided a roadway traversing the center island of a roundabout with lockable gates to ensure that the roadway is only used for oversize truck movements of which the state DOT is aware.

Certain interchange configurations (see Section 4.4) are more accommodating to oversize trucks than others. Single-Point Diamond Interchanges (SPDIs) provide large turning radii for left-turning vehicles, which should easily be traversed by oversize vehicles. Diamond interchanges in rural areas are generally designed with turning radii large enough to handle most oversize trucks. It should be noted though that encroachment into adjacent or opposing lanes of traffic is often required for oversize trucks to complete turning maneuvers and, in some cases, law enforcement assistance may be needed to temporarily stop other traffic and provide a clear turning path for an oversize truck. Diverging Diamond Interchanges (DDIs) with multilane approaches generally work well for oversize trucks. Oversize trucks will most likely need to utilize all lanes of the approaches to complete turning maneuvers.

While some intersection and interchange design features are more difficult for oversize trucks to traverse than others, this should not discourage agencies from implementing such treatments where they provide traffic operational and safety benefits for traffic as a whole. However, agencies should consider the availability of alternative routes for oversize trucks as part of the design process.

3.7 Truck Parking

3.7.1 On-Street Loading and Unloading Zones

Trucks must often stop along roads and streets to make pickups and deliveries at locations where off-road loading and unloading areas are not provided. Where there is a continuing need, transportation agencies can sign curbside loading zones in accordance with the FHWA *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) Section 2B.46, Parking

Standing and Stopping Signs, and mark loading zones on the pavement in accordance with MUTCD Section 3B.19, Parking Space Markings (FHWA 2009).

There are many locations where curbside pickups and deliveries need to be made, but no curbside loading zones are provided. Reasons why curbside loading zones may not be provided include the following:

- The agency does not mark loading zones as a matter of policy.
- Traffic demand is sufficiently high that no curbside parking of any kind is permitted.
- Pickups and deliveries at that location are perceived to be infrequent.

Businesses typically generate demand for pickups and deliveries whether loading zones are provided or not. Residences also generate pickup and delivery demand and, especially in this age of online shopping, deliveries to multifamily residential buildings have become substantial. Transportation agencies should consider how these demands can and should be met in the absence of loading zones. Should illegal curb parking for pickups and deliveries be accepted as undesirable but necessary? Should trucks making pickups and deliveries park in center two-way left-turn lanes and other median areas? Should pickup and delivery times be regulated by local ordinances?

Planning for curbside loading and unloading needs should address the following:

- Typical delivery vehicle sizes.
- Typical duration of delivery stops.
- Compatibility with adjacent pedestrian, bicycle, and transit facilities.

Consultation with truck operators and local businesses is needed to reach satisfactory plans for loading and unloading facilities where off-street facilities are not available. Designated bicycle and transit facilities should be located to avoid roadways with curbside loading and unloading activities to help minimize conflicts that may occur with truck activities.

Freight and Service Activity Generation software (Holguin-Veras et al. 2016) is available to assist in planning for on-street loading and unloading zones and off-street loading and unloading facilities. The software can make estimates of freight and service activities at the Zip Code and establishment levels for the entire United States.

3.7.2 Off-Street Loading and Unloading Facilities

Off-street loading and unloading facilities should be encouraged in land development projects through zoning ordinances and review of development impact studies. In dense urban areas, alleys are often provided to allow off-street loading and unloading. Section 3.5 indicates that internal site circulation plans and loading and unloading facilities should be addressed in the driveway permit review process.

Many off-street loading and unloading facilities either have gates that can be closed at the discretion of the site owner to restrict trucks from entering or have established entry/exit time schedules. Off-street parking/waiting areas should be provided so that trucks waiting to enter the facility do not need to queue on a public highway. This should be considered in driveway design and in the review of site circulation plans (see Sections 3.5 and 4.5).

Planning for off-street loading and unloading should consider the following:

- Truck routing and circulation to access loading and unloading facilities.
- Location of loading and unloading facilities so that trucks entering the facility (including trucks backing into the facility) do not impede traffic on a traveled way.
- Location of loading and unloading facilities so that trucks do not block pedestrian or bicycle facilities, including sidewalks, during loading and unloading operations.

3.7.3 Truck Parking Places for Driver Rest

There is a nationwide shortage of truck parking places for driver rest. Over-the-road truck drivers are required to take 10 hours off duty following no more than 14 consecutive hours on duty or a cumulative total of 11 hours of driving time during that 14-hour period (49 CFR 395). When approaching the 11- or 14-hour limit, or sooner, truck drivers must find a place to park their vehicle and go off duty. The shortage of parking areas has existed for a long time, but the lack of parking areas has recently become a more critical issue with the new federal mandate for on-vehicle electronic data loggers (EDLs) into which drivers make entries when they come on and go off duty and when they begin and end driving. Before EDLs, when necessary, a driver might take some time to find a safe place to park after the 11th hour of driving or the 14th hour on duty; extending the search for a safe parking place beyond the 11th or 14th hour was illegal, but drivers were unlikely to be cited for this violation. Now, any search for a safe parking place after the 11th or 14th hour is electronically documented as a driver violation. Thus, if a driver enters a truck stop just before the 11th hour of driving or the 14th hour on duty, expecting to remain there for 10 hours off duty, but finds that all parking spaces are taken, any continued search for a safe parking place to spend the off-duty period will constitute a violation of the hours-of-service rules for that driver.

Many more drivers are now choosing to park their trucks illegally, in exposed positions on highway shoulders or on ramps, risking a parking citation (a nonmoving violation), rather than an hours-of-service violation. The rest areas provided by transportation agencies typically have limits on the maximum time trucks can remain that are shorter than the required 10-hour off-duty period.

The challenge created by the lack of truck parking places is not necessarily the responsibility of transportation agencies to resolve, because most parking spaces for trucks are provided at commercial facilities, such as truck stops. Nevertheless, the lack of truck parking spaces is having undesirable effects on the highway system, so it is certainly desirable that a combination of action by transportation agencies and commercial operators address this issue.

CHAPTER 4

Geometric Design and Access Management to Accommodate Trucks

4.1 Introduction

Chapter 4 addresses geometric design and access management to accommodate trucks. With the exception of some industrial and port locations, where the traffic stream may consist almost exclusively of trucks, very few roadway segments and intersections are designed solely to serve trucks. At most locations, trucks constitute only a limited portion of the motor vehicle traffic stream, and other travel modes—including automobiles, bicyclists, pedestrians, and transit—must also be served. There are inherent conflicts between the needs of these various modes such that designing solely for trucks might make travel inefficient or inconvenient for other modes. Thus, for the most part, roadways and intersections are not designed *for* trucks, but are designed to accommodate trucks, while also serving other travel modes.

This chapter presents the design vehicles that are used to represent the maneuverability and turning paths of trucks in the design of intersections, interchanges, driveways, roadways, and work zones to accommodate trucks. Designs developed by each transportation agency should be reasonably consistent, with particular issues addressed in a consistent manner, to enhance driver expectancy for both motorists and truck drivers.

4.2 Design Vehicles

One or more design vehicles is selected to guide the design of each road improvement project. The design vehicle for any given street or highway is not necessarily the largest vehicle that ever uses that street or highway but rather a vehicle that uses the street or highway with sufficient frequency to be chosen as a basis for design. In selecting appropriate design vehicle(s), roadway designers consider the vehicle mix likely to use the road and the character of the development served by the road.

The primary purposes for which design vehicles are selected are as follows:

- To minimize encroachment by larger vehicles on curbs, shoulders, adjacent lanes, and opposing lanes as those vehicles traverse roadways and intersections.
- To estimate the storage space needed for larger vehicles in median opening areas and auxiliary lanes.

4.2.1 AASHTO Design Vehicles

The AASHTO A Policy on Geometric Design of Highways and Streets, commonly known as the *Green Book*, presents dimensions and performance criteria for nine types of trucks that may be used as design vehicles for particular projects (AASHTO 2018). Table 1 contains a

Table 1. Design vehicle dimensions (adapted from the *Green Book*).

Design Vehicle Type	Symbol	Dimensions (ft)											
		Overall			Overhang		WB_1	WB_2	S	T	WB_3	WB_4	Typical Kingpin to Center of Rear Tandem Axle
		Height	Width	Length	Front	Rear							
Single-Unit Trucks													
Single-Unit Truck	SU-30	11.0–13.5	8.0	30.0	4.0	6.0	20.0	—	—	—	—	—	—
Single-Unit Truck (three axle)	SU-40	11.0–13.5	8.0	39.5	4.0	10.5	25.0	—	—	—	—	—	—
Combination Trucks													
Intermediate Semitrailer	WB-40	13.5	8.0	45.5	3.0	4.5[a]	12.5	25.5	—	—	—	—	25.5
Interstate Semitrailer	WB-62*	13.5	8.5	69.0	4.0	4.5[a]	19.5	41.0	—	—	—	—	41.0
Interstate Semitrailer	WB-67**	13.5	8.5	73.5	4.0	4.5[a]	19.5	45.5	—	—	—	—	45.5
"Double-Bottom" Semitrailer/Trailer	WB-67D	13.5	8.5	72.3	2.3	3.0	11.0	23.0	3.0[b]	7.0[b]	22.5	—	23.0
Rocky Mountain Double Semitrailer/Trailer	WB-92D	13.5	8.5	97.3	2.3	3.0	17.5	40.0	4.5	7.0	22.5	—	40.5
Triple-Semitrailer/Trailer	WB-100T	13.5	8.5	104.8	2.3	3.0	11.0	22.5	3.0[c]	7.0[c]	22.5	22.5	23.0
Turnpike Double Semitrailer/Trailer	WB-109D*	13.5	8.5	114.0	2.3	4.5[a]	12.2	40.0	4.5[d]	10.0[d]	40.0	—	40.5

*Design vehicle with 48.0-ft trailer as adopted in 1982 STAA.
**Design vehicle with 53.0-ft trailer as grandfathered in with 1982 STAA.
[a] This is the length of the overhang from the back axle of the tandem axle assembly.
[b] Combined dimension is typically 10.0 ft.
[c] Combined dimension is typically 10.0 ft.
[d] Combined dimension is typically 12.5 ft.

- WB_1, WB_2, WB_3, and WB_4 are the effective vehicle wheelbases, or distances between axle groups, starting at the front, and working toward the back of each unit.
- S is the distance from the rear effective axle to the hitch point or point of articulation.
- T is the distance from the hitch point or point of articulation measured back to the center of the next axle or the center of the tandem axle assembly.

summary of the characteristics of these truck design vehicles. The overall length of a truck is the distance from the front to the rear of the vehicle not including appurtenances, such as loading/unloading devices, resilient bumpers, or aerodynamic devices.

Table 1 includes the following design vehicles:

- Two single-unit truck design vehicles: the two-axle SU-30, with an overall length of 30 ft; and the three-axle SU-40, with an overall length of nearly 40 ft.
- Three tractor-semitrailer trucks: the four-axle WB-40 with a trailer length of 33 ft; the five-axle WB-62, with a trailer length of 48 ft; and the five-axle WB-67 with a trailer length of 53 ft.
- One twin "double-bottom" tractor-semitrailer-trailer truck: the five-axle WB-67D with two 28.5-ft trailers.
- Three longer combination vehicles (LCVs): the seven-axle tractor-semitrailer-trailer WB-92D with one 48-ft and one 28.5-ft trailer, known as a "Rocky Mountain Double"; the seven-axle tractor-semitrailer-trailer WB-100T triple-trailer truck; and the nine-axle tractor-semitrailer-trailer WB-109D with two 48-ft trailers, known as a "Turnpike Double."

The sizes of the WB-62, WB-67, and WB-67D design vehicles are largely set by the 1982 STAA. Although the STAA does not control the overall length of trucks, it does require states to permit maximum trailer lengths of at least 48 ft for tractor-semitrailer trucks on the NN of truck routes (designated by the U.S. Secretary of Transportation in consultation with the states), and access routes to and from the NN. The majority of states permit tractor-semitrailer trucks with 53-ft trailers to operate on the NN. Some states allow tractor-semitrailer trucks with 53-ft trailers but limit the KPRA to 41 ft or less, which limits the space the truck needs to make a turning maneuver. Many tractor-semitrailer trucks have the capability to move their rear axles forward and back to accommodate such regulations.

The STAA set a maximum trailer length of 28.5 ft for tractor-semitrailer-trailer trucks. Trucks with two or more trailers that exceed the STAA trailer length limits, including all triple-trailer trucks, are classified as LCVs, and are generally allowed to operate only where they operated prior to enactment of the STAA. Only limited exceptions to the STAA restrictions on LCV operation have been made since 1982. For a more detailed discussion of the NN and its access routes, see Section 3.2 on truck routing.

The STAA also established a uniform nationwide maximum truck weight limit of 80,000 lb for the NN and its access routes, with maximum weights of 20,000 lb on any single axle and 34,000 lb on any double or tandem axle. With limited exceptions, these weight limits can only be exceeded where higher limits were in place when the STAA was enacted in 1982.

Up through the 1994 edition, the *Green Book* included a design vehicle known as the WB-50 that was intermediate in size between the WB-40 and the WB-62 design vehicles. Trucks like the WB-50 were once common on U.S. highways, but the WB-50 has been dropped from AASHTO policy because trucks of this size no longer exist, having been replaced by trucks like the WB-62 and WB-67. For this reason, the WB-50 is no longer appropriate for use in design.

4.2.2 Selection of Design Vehicles

The selection of an appropriate design vehicle is generally a project-level design decision. The *Green Book* states that, in selecting the design vehicle for any roadway, the designer should consider the largest design vehicle that is likely to use that facility with considerable frequency or a design vehicle with particular characteristics appropriate to a particular location (AASHTO 2018). Some state transportation agencies have a formal process for the selection of design vehicles.

Truck count data, gathered as part of the transportation planning process, can assist agencies in the selection of appropriate design vehicles for particular projects or corridors. The FHWA Traffic Monitoring Guide (FHWA 2016) requires vehicle classification counts to address 13 specific vehicle classes (see Figure 8). While the 13 vehicle classes do not correspond directly to the AASHTO design vehicles, classification count data can provide information on what types of vehicles can be expected for a specific project or corridor.

Truck routes may justify the choice of a larger design vehicle than other routes. The WB-67 tractor-semitrailer truck with a 53-ft trailer may be the appropriate design vehicle for many truck routes. Given the STAA legislation, the WB-67 has become the most common size truck on many truck routes throughout the United States, not just on freeways but on arterial roads and streets in both rural and urban areas as well. For example, most grocery stores and other

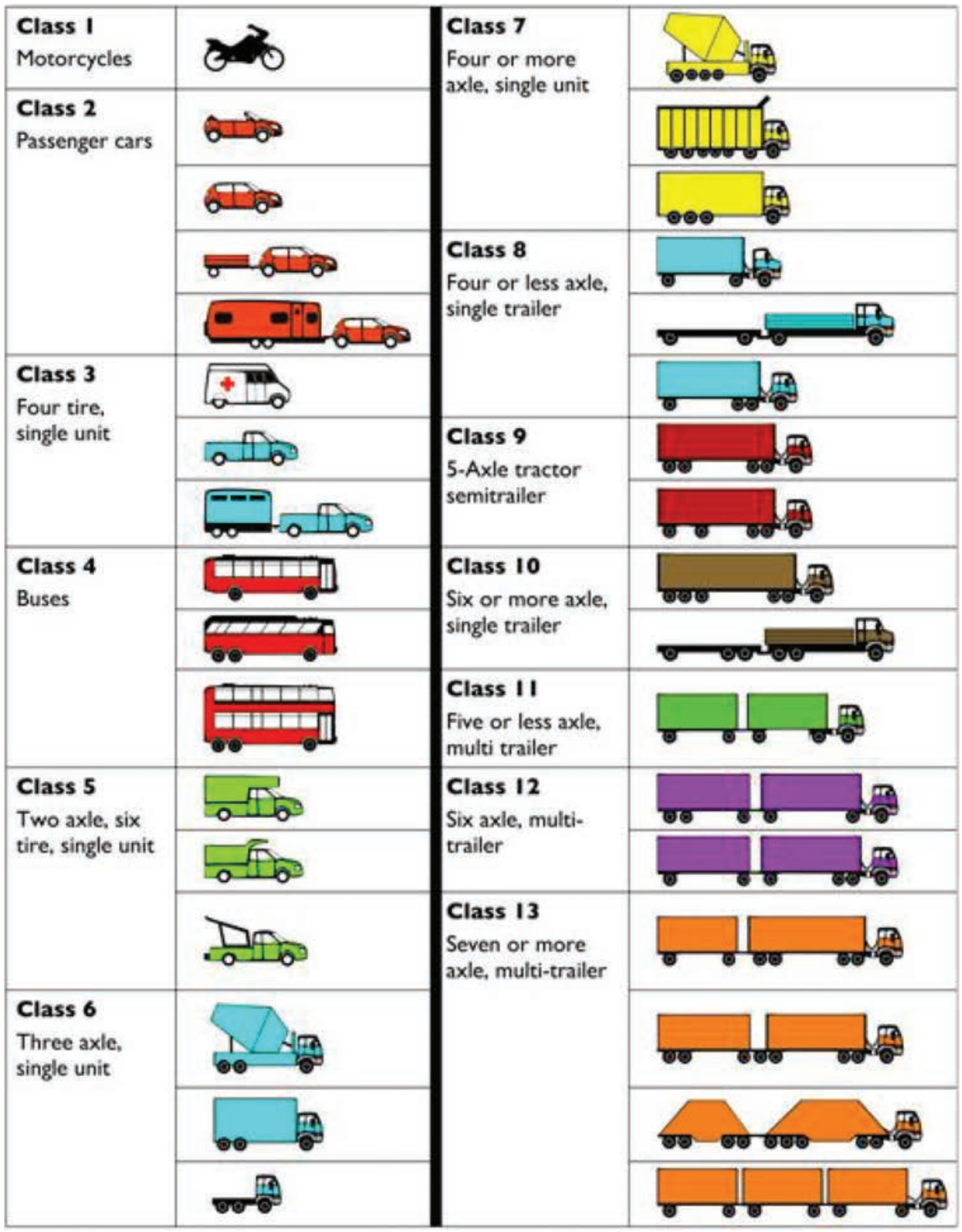


Figure 8. Thirteen vehicle categories required by FHWA for vehicle classification counts **(FHWA 2016)*****.***

retail businesses throughout the United States get their deliveries from WB-67 trucks, although WB-62 trucks or WB-67 trucks with the rear axles pulled forward for a 40- or 41-ft KPRA distance may be used in some states. As for the smaller semitrailer design vehicles, WB-40 trucks are specialized vehicles used in transporting some freight containers, while WB-62 trucks with 48-ft trailers have largely been replaced by WB-67 trucks. On the other hand, where agencies require WB-67 trucks to operate with a maximum 40-ft KPRA distance, the WB-67 truck will maneuver much like a WB-62.

Generally, a specific design vehicle is selected to guide the design of each project. However, if a project includes multiple roadways that vary in the types of truck traffic they serve, it may be appropriate to use a different design vehicle for each roadway. Furthermore, it is not necessary that every turning movement at every intersection be designed to accommodate the largest design vehicle considered in the design of the roadway, especially when that largest design vehicle is a WB-62, a WB-67, or an LCV. Every intersection of a truck route should be designed to accommodate through movements by the design vehicle; however, the largest design vehicles need to be considered in the design for turning movements at intersections only where large trucks are likely to make turning movements, such as at intersections with other truck routes. Where the minor road at an intersection on a truck route does not frequently serve larger trucks, a smaller design vehicle such as a SU-20, SU-30, or WB-40 may be appropriate. For example, if the minor road at an intersection on a truck route is a residential street, the appropriate design vehicle may be a single-unit truck of a size representative of garbage-collection and delivery trucks that use that street. While every residential street occasionally serves larger trucks, such as moving vans, there is no need to consider design vehicles that are not expected to use the street on a daily basis.

Every intersection should be designed to accommodate emergency vehicles, such as fire trucks, that may occasionally need to make turning maneuvers but, in designing for fire trucks, it is not necessary to minimize encroachment of the emergency vehicles on adjacent or opposing lanes. Similarly, projects on roadways that serve OSOW permit vehicles should be designed so that they do not eliminate the capability of the roadway to accommodate permit vehicles that currently use the roadway; since permit vehicle movements are generally occasional, rather than frequent, permit vehicles may need to encroach on adjacent or opposing lanes. The largest OSOW permit vehicle that uses a particular roadway should be used as a “check vehicle” to verify that any modified design can still accommodate OSOW vehicles that use the existing roadway.

4.2.3 Roadway Design for a Selected Design Vehicle

The design vehicle selected for a specific project or turning movement is used in the design of critical features, such as curb return radii at intersections, radii of turning roadways, and radii and width of driveways. These features are typically designed to accommodate the turning radius and swept path width of a specific design vehicle. The minimum turning radii of the *Green Book* design vehicles are shown in Table 2.

The minimum turning radius is the smallest radius through which the front axle of a truck can turn. Axles or axle sets farther to the rear of a truck do not follow the path of the front axle. This phenomenon is known as *offtracking*. At low speeds (which generally serve as the basis for intersection design), the rear axles of a truck follow a path inside of the path of the front axles.

The area between the path of the innermost edge of the vehicle body and the outermost edge of the vehicle body of the truck during a turn is known as the *swept path* of the truck. This is typically slightly wider than the area between the path of the inside front axle and the outside rear axle. The maximum width of the swept path at any point during a turn is

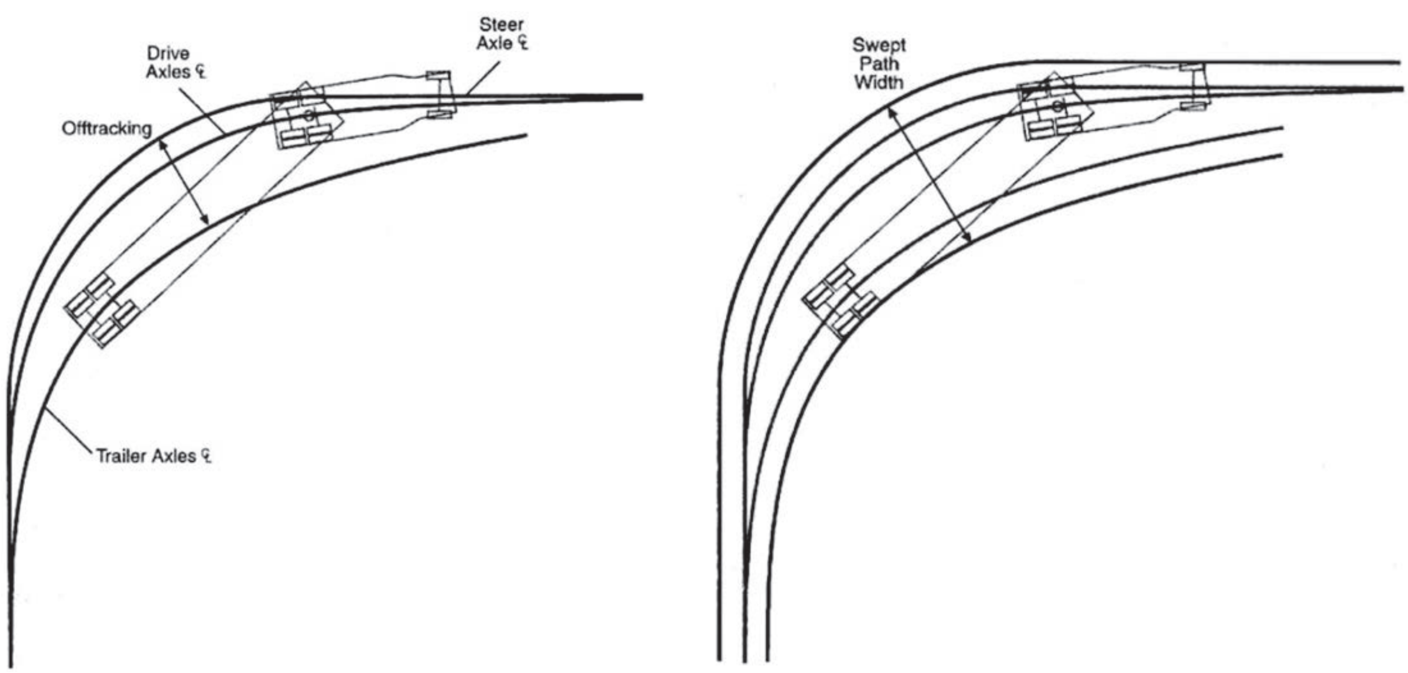
Table 2. Minimum turning radii of design vehicles (AASHTO 2018).

Design Vehicle Type	Single-Unit Truck		Single-Unit Truck (Three Axle)	Articulated Bus		Intermediate Semitrailer
Symbol	SU-30		SU-40	A-BUS		WB-40
Minimum Design Turning Radius (ft)	41.8		51.2	39.4		39.9
Centerline[a] Turning Radius (CTR) (ft)	38.0		47.4	35.5		36.0
Minimum Inside Radius (ft)	28.4		36.4	21.3		19.3
Design Vehicle Type	**Interstate Semitrailer**		**"Double-Bottom" Combination**	**Rocky Mtn Double**	**Triple-Semitrailer-trailers**	**Turnpike Double-Semitrailer-trailer**
Symbol	WB-62*	WB-67**	WB-67D	WB-92D	WB-100T	WB-109D*
Minimum Design Turning Radius (ft)	44.8	44.8	44.8	82.0	44.8	59.9
Centerline[a] Turning Radius (CTR) (ft)	41.0	41.0	40.9	78.0	40.9	55.9
Minimum Inside Radius (ft)	7.4	1.9	19.1	55.6	9.7	13.8

*Design vehicle with 48-ft trailer as adopted in 1982 STAA.
**Design vehicle with 53-ft trailer as grandfathered in with 1982 STAA.
[a]The turning radius assumed by a designer when investigating possible turning paths and set at the centerline of the front axle of a vehicle. If the minimum turning path is assumed, the CTR approximately equals the minimum design turning radius minus one-half the front width of the vehicle.

known as the *swept path width*. Figure 9 illustrates offtracking and swept path width. Both the minimum turning radius and the swept path width are considered in designing an intersection to determine whether a specific truck design vehicle can maneuver through an intersection without encroaching on a curbline or shoulder area, an adjacent lane, or the opposing direction of travel.

Turning templates are used to incorporate consideration of minimum turning radius and swept path width in design. Turning templates show the offtracking and swept path width that will occur for a specific truck making a turning maneuver at very low speeds; for this



(a) Offtracking (b) Swept Path Width

Figure 9. Illustration of truck offtracking and swept path width during a turning maneuver **(Harwood et al. 2003).**

reason, turning templates are said to illustrate *low-speed offtracking*. Turning templates are needed because offtracking and swept path width are not constant throughout a truck-turning maneuver. Offtracking and swept path width develop gradually as a truck enters a turn and may eventually reach a constant or steady-state value. An example of a turning template from the *Green Book* for the WB-67 design vehicle is shown in Figure 10. Turning templates like these, drawn to scale, were formerly used manually in the development of intersection plans. Today, commercially available software can be used in conjunction with CADD software to develop designs to accommodate specific trucks. The software user may specify the path of the front axles for a turning maneuver (or series of turning maneuvers) by any design vehicle, and the software will show the path of the rear axles, the inside and outside of the vehicle body, and other specified points on the vehicle.

Low-speed offtracking and swept path width increase with the distances between axles of a single-unit truck and between axles and hinge points of a combination or multi-unit truck. Hinge points include the kingpin that connects a tractor to a following semitrailer and the hitch point that connects a tractor or semitrailer to full trailers that follow.

Rear swingout is the phenomenon by which the rear outside corner of a truck follows a path outside the rear outside axle of a truck during a turn. Rear swingout increases as the distance from the rear axle to the rear of the truck, known as rear overhang, increases. However, turning plots show that, while the outside rear corner of the trailer of a combination truck follows a path outside the rear trailer wheels, it is inside the swept path of the truck. For this reason, rear swingout is rarely a concern to other vehicles unless they are making a parallel turn, which might be the case at double or triple turn lanes. None of the *Green Book* design vehicles have rear swingout that exceeds 0.69 ft for a turn with a radius of 50 ft, even with the rear axles pulled forward to maintain a KPRA distance of 41 ft (Harwood et al. 2003).

4.2.4 Accommodating Large Design Vehicles on the Roadway System

While the WB-67 design vehicle may be the appropriate design vehicle for most truck routes, not all arterial roads and streets, especially in urban areas, can fully accommodate turning maneuvers by such a large vehicle. Adjacent development may limit making the roadway wide enough and/or the turning radii large enough to accommodate a WB-62 or WB-67 truck. Thus, as much as designers would like to fully accommodate an appropriate design vehicle, there are locations where this is not possible without interfering with adjacent development. Therefore, in restrictive conditions, it may be desirable to consider (if the applicable state vehicle code allows) occasional encroachment on opposing lanes rather than incur the social costs of interfering with existing development or the economic costs of prohibiting trucks. Mitigation strategies could include rerouting trucks away from the intersection when acceptable alternative routes are available.

The curb return radius is the curved curb connecting the curblines along the outside of the two intersecting streets at each corner of an intersection. Figure 11 illustrates a typical curb return radius. Where trucks make right turns at intersections, it is desirable to provide a curb return radius sufficiently large that a truck can make a right turn without encroaching on the curbline or on an adjacent or opposing lane. A turning template for a specific design vehicle, or an automated version of a turning template in CADD software, can be used to assess whether truck encroachment on the curbline or another lane will occur. It should also be recognized that, where a pedestrian crosswalk is present, longer curb return radii can increase the crossing distance for pedestrians (see AASHTO 2004; AASHTO 2018). Longer curb return radii may also result in locating the stop line for vehicles approaching the intersection further from the curbline, which may reduce intersection sight distance. The tradeoffs between accommodating trucks and pedestrians are examined in Section 5.1.

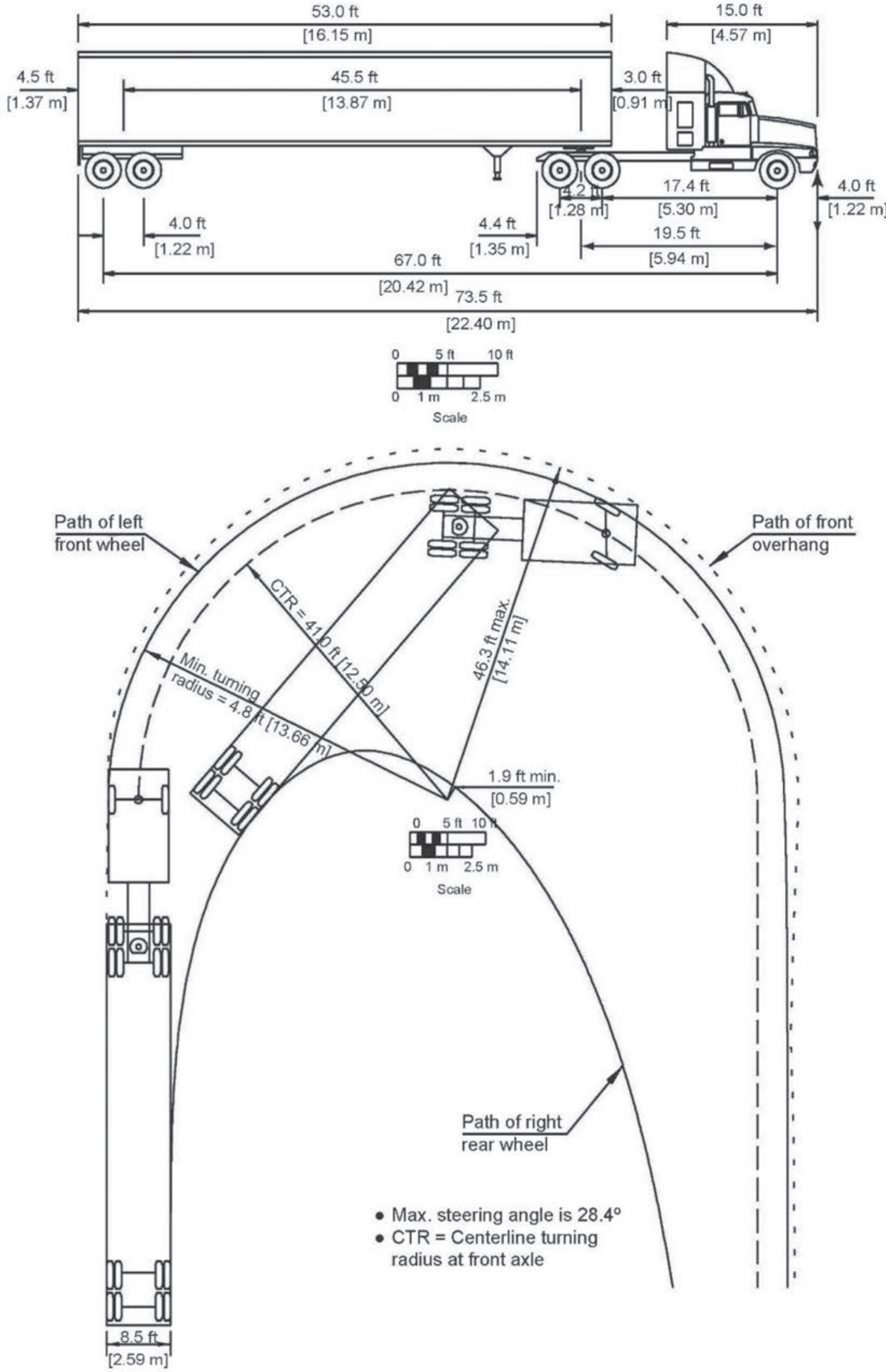


Figure 10. Dimensions and minimum turning path for the Interstate semitrailer (WB-67) design vehicle **(AASHTO 2018)*.***

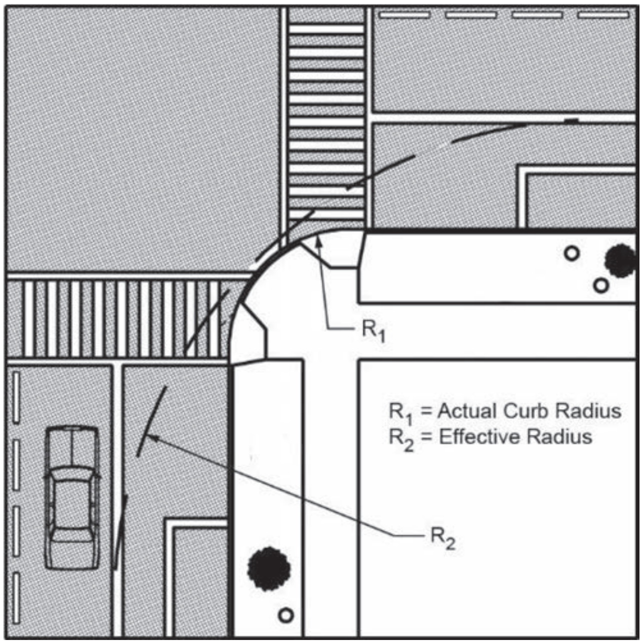


Figure 11. Typical intersection corner with actual curb return radius and effective radius **(adapted from the *Green Book*).**

Figure 11 shows that, where parking lanes or other features, such as curb extensions are present, there is an effective radius for right-turn maneuvers that is larger than the actual curb return radius.

Turning templates for specific design vehicles, or the software equivalent of such templates, are also used to assess median opening designs. These assessments can evaluate whether turning trucks will encroach on the median, whether left-turning trucks will encroach on adjacent turn lanes (for double and triple left-turn lanes), or whether the areas required for opposing left-turning trucks within the intersection overlap.

Indirect left-turn treatments, such as those discussed in Section 4.3.6, should accommodate the larger design vehicles if large trucks frequently make the left-turn maneuver in question.

There are many intersections on truck routes along urban arterials and in small towns where, even though it may be desirable to design the intersection based on a WB-62, WB-67, or LCV, it is infeasible to provide intersection geometrics that minimize encroachment on adjacent or opposing lanes without widening the roadway in a manner that would interfere with surrounding development. From a community impact standpoint, it is not generally desirable to acquire right of way and remove buildings or other development that are important to the community, solely to accommodate large trucks. Alternatives that may be considered in such situations include the following:

- Reconfigure the intersection to accommodate truck-turning maneuvers without encroachment on adjacent or opposing lanes. This alternative may involve right-of-way acquisition and have undesirable impacts on surrounding development.
- Keep the current geometrics and accept occasional encroachment by turning trucks on adjacent or opposing lanes. This alternative may limit the operational efficiency of the intersection, but other motorists can usually respond to occasional truck encroachments without creating safety concerns. This alternative is explicitly encouraged by some agencies (see Section 4.3.1) but may be unacceptable in jurisdictions that prohibit encroachment by vehicles on adjacent or opposing lanes by law.

- Where the volume of turning movements by large trucks is so high that interference with traffic operations would be more than occasional, rerouting truck traffic may be appropriate. Rerouting of trucks needs to be considered in consultation with the local community.

4.3 Intersections

Section 4.3 presents a range of intersection features and types that may be used in better accommodating trucks on the road network. Many of these intersection features and types have been used extensively for many years and are familiar to motorists and truck drivers. The discussion also includes some innovative intersection types that have come into general use only in recent years. Continuing public education may be desirable to familiarize motorists with these innovative intersection types and how trucks operate on them.

4.3.1 Curb Return Radius

The curb return radius is the curved curbline connecting the curblines along the outside of the two intersecting streets at each corner of an intersection. Figure 11 illustrates a typical curb return radius. Where trucks make right turns at intersections, it is desirable to provide a curb return radius sufficiently large that a truck can make a right turn without encroaching on the curbline or on an adjacent or opposing lane. A turning template for a specific design vehicle, or an automated version of a turning template in CADD software, can be used to assess whether truck encroachment on the curbline or another lane will occur. It should also be recognized that, where a pedestrian crosswalk is present, longer curb return radii can increase the crossing distance for pedestrians (AASHTO 2004; AASHTO 2018) and can result in a stop line location further from the curbline on the intersection approach, which may reduce intersection sight distance. Figure 12 illustrates the tradeoff between curb return radius and pedestrian crossing distance.

The curb return radius for a right turn at an at-grade intersection should be selected to accommodate the applicable design vehicle for a right-turn maneuver, which, as described in Section 4.2, might be anything from a single-unit truck to a WB-67 or larger, depending on the character of truck traffic on the minor road at the intersection. An SU-30 or SU-40 design vehicle might be used for right turns to minor residential streets, while a WB-62 or WB-67 design vehicle might be used for right turns to other truck routes or industrial areas.

As explained in Section 4.2, it is not always feasible to accommodate the desirable curb return radius because of the presence of adjacent development or the desire to reduce pedestrian crossing length. Some agencies are constrained by law to develop designs so that turning trucks will not encroach on adjacent or opposing lanes. Other agencies may find it desirable to accept occasional encroachment on adjacent or opposing lanes, especially where larger design vehicles turn right only occasionally. Figure 13 shows the turning paths of specific design vehicles for right turns at an intersection with a 30-ft curb return radius and a four-lane receiving roadway. The WB-40 will encroach slightly on an adjacent lane and the WB-62 and WB-67 will encroach on an opposing lane. If there were only two lanes on the receiving roadway, the truck might need to encroach on an adjacent or opposing lane on the approach roadway to avoid encroaching on the curbline. Other traffic at the intersection will likely adapt to such maneuvers if they occur only occasionally. Figure 14 illustrates the difference between "designing for" and "accommodating" large truck movements at intersections.

Some agencies have used mountable curb for smaller curb return radii, recognizing that some large trucks may encroach on the curbline. This practice is not desirable where pedestrians are present since pedestrians use the sidewalk adjacent to the curb return radius. Other agencies maintain a paved shoulder between the traveled way and the curb return radius at some

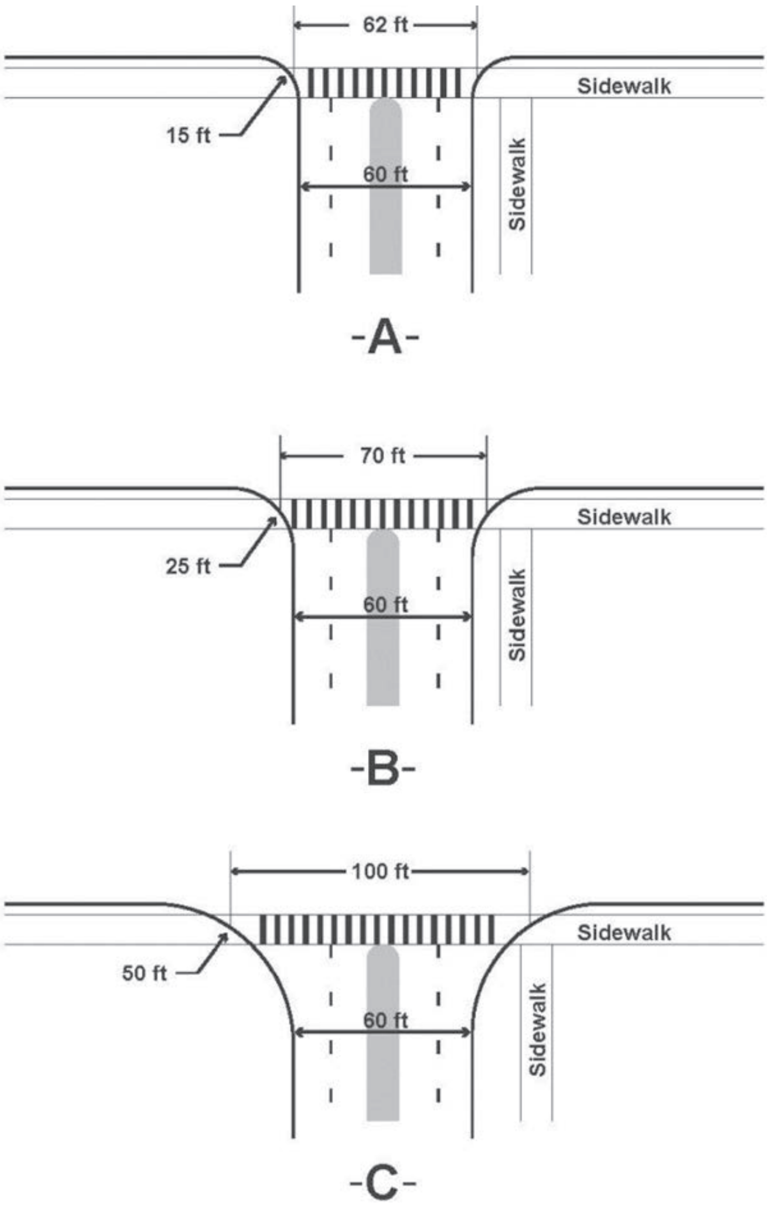


Figure 12. Variations in pedestrian crossing distance with different curb radius **(adapted from the *Green Book*).**

locations to minimize the potential for truck encroachment on the curbline. This may be effective in minimizing truck encroachment but, where pedestrians are present, it increases the pedestrian crossing distance by the width of the shoulder provided.

Where pedestrians cross the roadway in substantial numbers, it may not be desirable to provide the larger curb return radius, because this will increase the pedestrian crossing distance on the intersecting roadways. (See further discussion of resolving conflicts between pedestrians and trucks in Section 5.1.) In such cases, it may be desirable to use a smaller curb return radius that provides a shorter pedestrian crossing distance, as shown in Drawing A in Figure 12, or to keep the larger curb return radius but provide a channelized right-turn roadway (see Section 4.3.5). Provision of a channelized right-turn roadway can limit the pedestrian crossing distance, because a two-stage crossing is provided, but channelized right-turn roadways are undesirable for pedestrians with vision disabilities, who may not be able to detect approaching vehicles from unexpected angles when crossing the right-turn roadway (Potts et al. 2011).

40 Design and Access Management Guidelines for Truck Routes: Planning and Design Guide

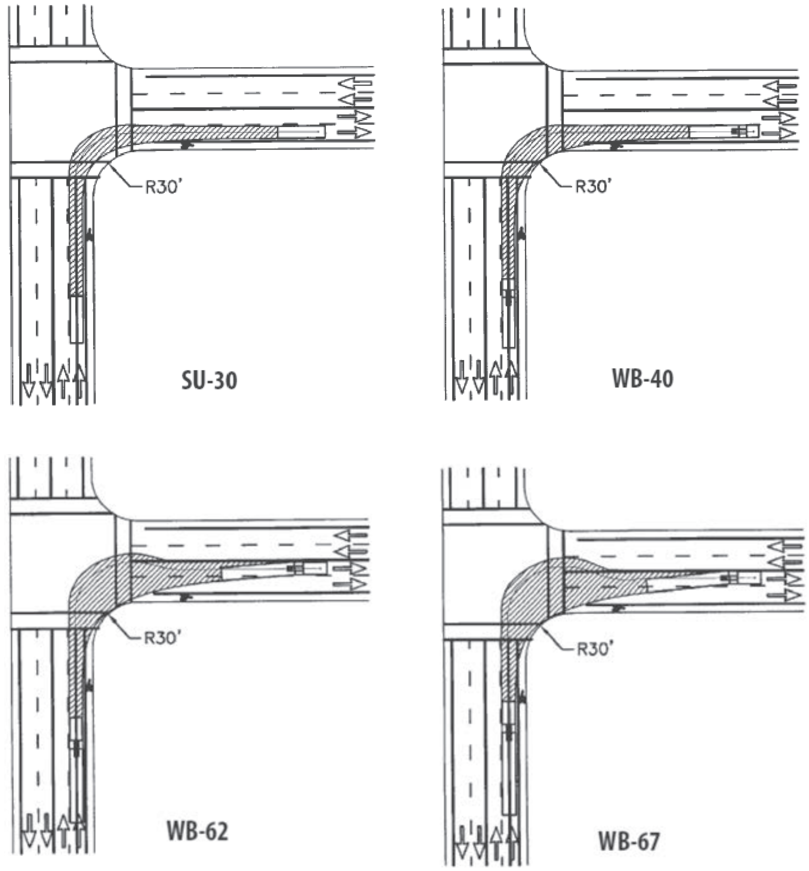


Figure 13. Turning requirements for specific design vehicles **(adapted from City of Portland, Oregon, 2008).**

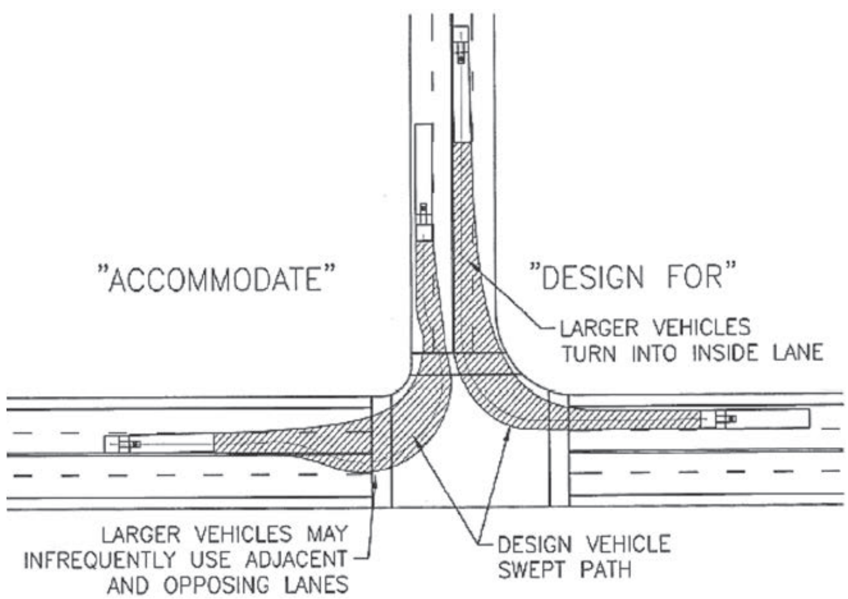


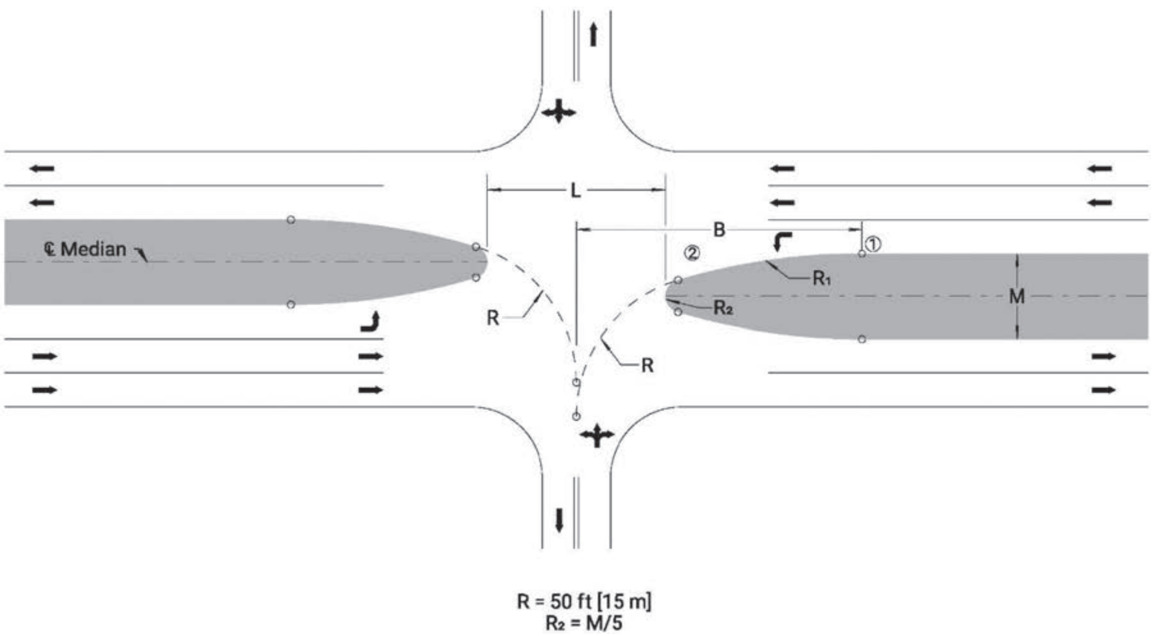
Figure 14. Comparison of "designing for" and "accommodating" large truck movements at an intersection **(City of Portland, Oregon, 2008).**

4.3.2 Median End Treatments

Median openings on divided highways at intersection and nonintersection locations are typically designed in accordance with guidance in Chapter 9 of the *Green Book*. The vehicle paths through the median opening for left-turning vehicles are typically laid out with turning template software, as discussed in Section 4.2.3 of this Guide. Median ends at median openings on roads with narrow medians are typically designed with a semicircular shape. However, where the median width exceeds 10 ft, the *Green Book* indicates that a median end with a bullet nose shape (shown in Figure 15) is preferred to more closely accommodate the turning path of truck design vehicles (AASHTO 2018). Turning radii of 40 ft can be used in design of median openings with minimum design low-speed turning maneuvers; where turning speeds exceed 15 mph, turning radii of 50 ft should be accommodated in above-minimum designs, and the median end treatments should be designed with dimensions shown in Figure 15.

4.3.3 Left-Turn Lanes

A left-turn lane is a separate, full-width lane provided exclusively for vehicles that are making a left turn from the roadway (Dixon et al. 2016), as illustrated in Figure 16. Left-turn lanes are used primarily at intersections and ramp terminals but may also be used at driveways



Width of Median, *M* (ft)	Dimensions In Feet When					
	R_1 = 90 ft		R_1 = 170 ft		R_1 = 230 ft	
	L	*B*	*L*	*B*	*L*	*B*
20	58	65	66	78	71	90
30	48	68	57	85	63	101
40	40	71	50	90	57	109
50	—	—	44	95	51	115
60	—	—	—	—	46	122
70	—	—	—	—	41	128

Figure 15. Above-minimum design of median openings with typical bullet nose ends (AASHTO 2018).

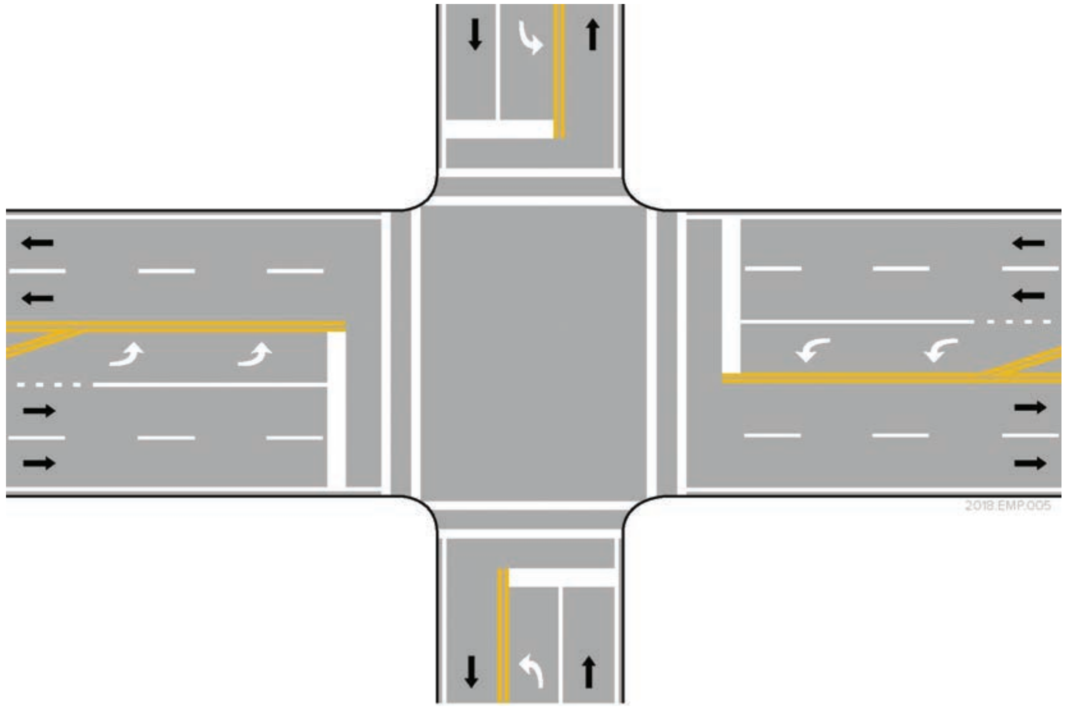


Figure 16. Four-leg intersection with left-turn lane on each approach.

and median openings. Left-turn lanes provide both traffic operational and safety benefits. Figures in this Guide, such as Figure 16, are presented to illustrate specific design features (in this case, left-turn lanes) and are not presented as complete guidance for every design feature that might be needed or provided at specific intersections.

Traffic Operational Benefits of Left-Turn Lanes

By removing left-turning vehicles from the through-traffic stream, left-turn lanes reduce delay to through vehicles (caused by stopping or slowing down behind the left-turning vehicle). Trucks benefit from this reduced delay as well. A truck accelerates more slowly than a passenger car; therefore, when a truck has to stop behind a left-turning vehicle, it causes additional delay to the vehicles following the truck. The traffic operational benefits of left-turn lanes can be quantified with *Highway Capacity Manual: A Guide for Multimodal Mobility Analysis* (2016) procedures and traffic simulation models.

Safety Benefits of Left-Turn Lanes

Removing left-turning vehicles from the through-traffic stream provides safety benefits as well by reducing the potential for rear-end collisions in which through vehicles strike the rear of left-turning vehicles. In addition, because left-turn lanes provide a sheltered location for drivers to wait for a gap in opposing traffic, left-turning drivers may be more selective in choosing a gap to complete their left-turn maneuver, which may reduce the potential for collisions between left-turn vehicles and opposing through vehicles. Drivers of trucks are likely even more selective than passenger-car drivers in choosing a gap in opposing traffic to complete a left-turn maneuver because trucks need a larger gap in opposing traffic than passenger cars. Therefore, provision of a left-turn lane is particularly important at locations where trucks frequently make left-turn maneuvers. Table 3 presents the estimated reduction in crashes after installation of a left-turn lane (AASHTO 2010).

Table 3. Estimated reduction in crashes after left-turn lane installation on major-road approaches to at-grade intersections (AASHTO 2010).

Intersection Characteristic	Reduction in Crashes (%)	
	Turn Lanes Added to One Approach	Turn Lanes Added to Both Approaches
Left-turn lane: rural		
Three-leg		
Stop signs	44	NA
Traffic signals	15	NA
Four-leg		
Stop signs	28	48
Traffic signals	18	33
Left-turn lane: urban		
Three-leg		
Stop signs	33	NA
Traffic signals	7	NA
Four-leg		
Stop signs	27	47
Traffic signals	10	19

NOTE: NA = Not Applicable.

Deciding Where to Install a Left-Turn Lane

The decision to install a left-turn lane at a particular location depends on a number of factors, including overall traffic volume, left-turn volume, and operating speed. Many transportation agencies have adopted their own left-turn lane recommendations and warrants based on one of the following references:

- Harmelink warrants (Harmelink 1967).
- *Green Book* guidance (AASHTO 2018).
- ITE guidelines for unsignalized left-turn lanes (Institute of Transportation Engineers 2011).
- Threshold traffic volumes for signalized and unsignalized left-turn lanes (Harwood et al. 2002).
- Warrants recommended in *NCHRP Report 279* (Neuman 1985).
- Warrants recommended in *NCHRP Report 745* (Fitzpatrick et al. 2013).

Chapter 21 of the AMAG presents an overview of each of these left-turn lane warrants and recommendations, and Chapter 16 of the TRB *Access Management Manual* (AMM) (Williams et al. 2014) presents examples of several transportation agencies' left-turn lane warrants.

Geometric Design Guidelines

The *Green Book* provides guidance on the geometric design of left-turn lanes. Left-turn lanes are typically 10 to 12 ft in width. Where substantial truck traffic turns left, a 12-ft width is preferable for left-turn lanes.

The *Green Book* also provides guidance on determining the length of left-turn lanes as the sum of a taper length, a deceleration length, and a storage length. The taper length and deceleration length are based on the assumption that a vehicle entering a left-turn lane should decelerate by no more than 10 mph in the through-traffic lanes before entering a left-turn lane. The storage length is based on consideration of peak-hour left-turn volumes to define the number of vehicles that typically need to be stored in the left-turn lane. Because of the extra length of trucks, longer left-turn lanes are a consideration to accommodate truck storage. The AMM and the AMAG identify the additional need to consider the volume (or percentage) of large vehicles and their extra vehicle length in estimating the storage length for left-turn lanes. The AMM presents an equation for estimating the left-turn storage length as follows:

$$L = \left(\frac{V}{N} \times k \times s\right) \tag{2}$$

where:

L = design length of left-turn storage (ft).
V = estimated left-turn volume (vph).
N = number of cycles per hour.
k = factor that is the length of the longest queue divided by the average queue length.
s = average length per vehicle, including the space between vehicles.

For k in the previous equation, a value of 2.0 is commonly used for major arterials, while a value of 1.5 to 1.8 might be considered for an approach on a minor street or on a collector. Also, s is generally assumed to be 25 ft. However, s can be adjusted based on the presence of trucks. Table 4 provides queue storage length adjustments for trucks that can be used for s based on the percentage of trucks in the left-turn lane.

The desirable storage length for left-turn lanes should also be a consideration on truck routes, even at locations where trucks are not likely to make left-turn maneuvers. Efficient through travel for trucks is important, and delay to trucks from the need to stop behind queues of left-turning vehicles spilling into the through lanes can hinder on-time deliveries.

Offset Left-Turn Lanes

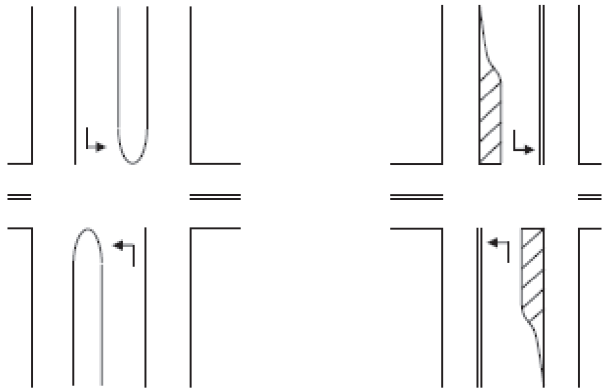
Vehicles in opposing left-turn lanes can each limit their driver's view of opposing traffic [see Figure 17(a)]. Truck drivers, with their increased eye height, may have an advantage over passenger-car drivers in this situation, because they may be able to see over an opposing passenger-car. However, in some situations, a truck driver's view of opposing traffic may be just as limited as a passenger-car driver's view. The presence of a large truck in a left-turn lane also decreases the ability of the driver of an opposing left-turn vehicle to judge gaps in oncoming traffic.

Offset left-turn lanes are implemented by moving each of the two opposing left-turn lanes to the left (creating space between the through lane and left-turn lane) so that the opposing left-turn lane is located to the right of the driver's field of view [see illustration in Figure 17(b)]. This design treatment, which opens up the view of opposing traffic to the left-turning driver, is particularly beneficial at wide medians. The restriction on the available sight distance for drivers of opposing left-turn vehicles is dependent on the amount and direction of the offset between the opposing left-turn lanes, as well as the sizes of the vehicles. *NCHRP Report 745*

Table 4. Queue storage length adjustments for trucks, used in Equation (2) for *s* (Williams et al. 2014).

Trucks (%)	Average Length per Vehicle for Determining Queue Storage[a] (ft)
≤ 2	25
5	28
10	32
15	35
20	38
25	41

[a]Based on a WB-67 truck.



(a) Opposing Left-Turn Lanes with Negative Offset

(b) Opposing Left-Turn Lanes with Positive Offset

Figure 17. Opposing left-turn lanes with and without positive offset **(AASHTO 2018).**

provides guidance concerning the appropriate offset distance for opposing left-turn lanes (Fitzpatrick et al. 2013).

Double and Triple Left-Turn Lanes

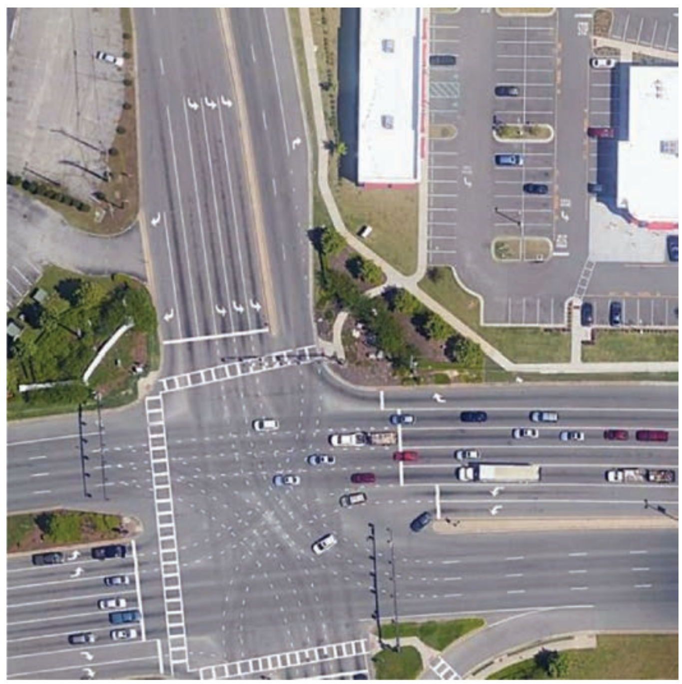
Double and triple left-turn lanes, as shown in Figure 18 are provided at intersections to increase the traffic operational efficiency of the intersection, limit the length of left-turn lanes, and limit the length of left-turn signal phases. Double and triple left-turn lanes are used almost exclusively at signalized intersections. Under certain conditions, double left-turn lanes accompanied by a separate left-turn signalization phase can accommodate up to approximately 180% of the volume that can be served by a single left-turn lane with the same available green time in the signal cycle. While double and triple left-turn lanes are often provided based on consideration of passenger cars alone, they can also enhance left-turn operations for trucks.

Turning maneuvers are one of the key challenges faced by trucks on urban and suburban arterials. Many of the transportation agencies surveyed in NCHRP Project 15-62 (Potts et al. 2019) indicated they have provided double or triple left-turn lanes specifically to facilitate left turns by trucks. Trucks seldom turn side by side in double or triple left-turn lanes. Instead, trucks tend to use the outside left-turn lane (i.e., the left-turn lane farthest to the right), which has the largest turning radius, or to stagger themselves such that trucks use all available lanes, but do not turn side by side. In some cases, WB-62 or WB-67 trucks turning left in the outside left-turn lane may encroach on the inside left-turn lane. The avoidance of side-by-side turning maneuvers limits the possibility of collisions between adjacent trucks but results in a reduction in the operational efficiency of the double or triple left-turn lanes. Nevertheless, even with some reduction in traffic operational efficiency due to avoidance of side-by-side turning maneuvers by trucks, the traffic operational efficiency of the intersection is still better than it would be if only a single left-turn lane were provided. Figure 19 shows a photograph of a double left-turn lane in which trucks are in staggered position in the two left-turn lanes preparing to make a left-turn maneuver. Computerized swept path width software can be used to mark turning paths through the intersection appropriate for vehicles turning side by side.

4.3.4 Right-Turn Lanes

A right-turn lane is a separate, full-width lane provided exclusively for vehicles that are making a right turn from the roadway (Dixon et al. 2016) (see Figure 20). Right-turn lanes are used primarily at intersections and ramp terminals but may also be used at driveways. Right-turn lanes provide both traffic operational and safety benefits.

(a) Double Left-Turn Lanes



(b) Triple Left-Turn Lanes

Figure 18. Typical double and triple left-turn lanes.
(Photo source: Google Maps.)

Traffic Operational Benefits of Right-Turn Lanes

By removing right-turning vehicles from the through-traffic stream, right-turn lanes reduce delay to through vehicles resulting from the need for the through vehicles to stop or slow behind the right-turning vehicle. Trucks benefit from the reduced delay provided by right-turn lanes as well. Trucks accelerate more slowly than passenger cars; therefore, when a truck has to stop behind a right-turning vehicle, it causes additional delay to the truck and to the vehicles following the truck. Some transportation agencies have indicated that right-turn lanes are often needed at entrances into developments generating truck traffic, particularly to accommodate truck deceleration. The traffic operational benefits of right-turn lanes can be quantified with *Highway Capacity Manual* procedures and traffic simulation models.

Figure 19. Trucks in staggered position preparing to turn left in a double left-turn lane. **(Photo source: MRIGlobal.)**

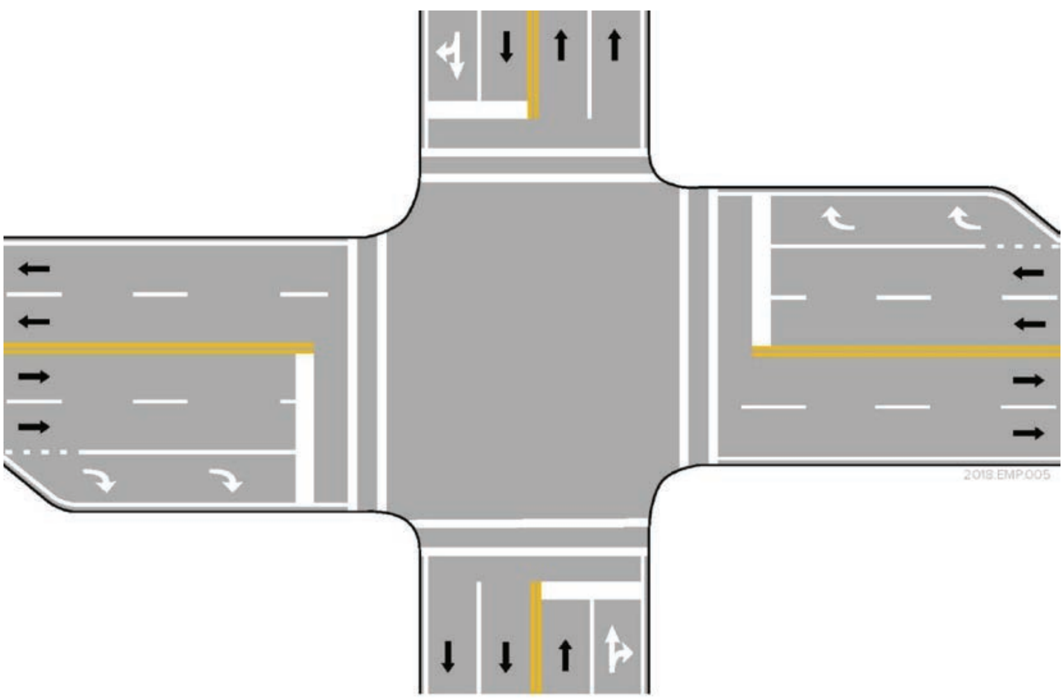


Figure 20. Four-leg intersection with right-turn lane on two approaches.

Safety Benefits of Right-Turn Lanes

Removing right-turning vehicles from the through-traffic stream provides safety benefits as well, by reducing the potential for rear-end collisions in which through vehicles strike the rear of right-turning vehicles. Table 5 provides crash modification factors for right-turn lanes, as presented in the AASHTO Highway Safety Manual (HSM).

Deciding Where to Install a Right-Turn Lane

The decision to install a right-turn lane at a particular location depends on a number of factors including the following:

- Through- and right-turn traffic volumes.
- Right-turn truck volumes.
- Posted and/or operating speed.
- Available sight distance.
- Crash history.
- Construction cost.
- Pedestrian and bicycle volumes.

Potts et al. developed an economic analysis procedure that can identify where installation of right-turn lanes at unsignalized intersections and major driveways would be cost-effective (Potts et al. 2006). The economic analysis procedure can be used to develop plots that indicate combinations of through-traffic volumes and right-turn volumes for which provision of a right-turn lane would be recommended. The economic analysis procedure can be applied by transportation agencies using site-specific values for average daily traffic, turning volumes, crash frequency, and construction cost for any specific location of interest.

Geometric Design Guidelines

The *Green Book* provides guidance on the geometric design of right-turn lanes. Right-turn lanes are typically 10 to 12 ft in width. Where substantial truck traffic turns right, a 12-ft width is preferable for right-turn lanes.

The *Green Book* also provides guidance on determining the length of right-turn lanes as the sum of a taper length, a deceleration length, and a storage length. The taper length and deceleration length are based on the assumption that a vehicle entering a right-turn lane should decelerate by no more than 10 mph in the through-traffic lanes before entering a right-turn lane. The storage length is based on consideration of peak-hour right-turn volumes to define the number of vehicles that typically need to be stored in the right-turn lane. Because of the extra length of trucks, longer right-turn lanes are a consideration to accommodate truck storage.

Sections 4.2.4 and 4.3.1 present guidelines on the design of curb return radii for right-turn maneuvers. Sections 5.1 and 5.2 discuss compatibility of designing to accommodate trucks in relation to pedestrians and bicyclists, respectively.

Table 5. Crash modification factors for right-turn lanes (AASHTO 2010).

Major Roadway Type	Three-Leg Intersection		Four-Leg Intersection[a]	
	Unsignalized	Signalized	Unsignalized	Signalized
Rural two-lane highway	0.86	NA	0.86^n	0.86^n
Rural multilane highway	0.86	NA	0.86^n	NA
Urban-suburban arterial	0.86	0.96	0.86^n	0.96^n

NA = Not Available.
[a] n = number of intersection approaches without stop-sign control that have right-turn lanes. For example, a four-leg unsignalized intersection with right-turn lanes on both major street approaches will have a crash modification factor of $(0.86)^2$, or 0.74.

Figure 21. Double right-turn lanes for trucks leaving Port Newark. **(Photo source: Google Earth.)**

Double and Triple Right-Turn Lanes

Turning maneuvers are one of the key challenges faced by trucks on urban and suburban arterials, and some transportation agencies have indicated that right turns at intersections are most problematic for trucks. Double right-turn lanes not only increase the capacity of right-turn movements, but the outside (left) right-turn lane can provide a larger turning radius for trucks. As an example, the Port Authority of New York and New Jersey (PANYNJ) implemented dual right-turn lanes to accommodate trucks leaving Port Newark. In constructing the double right-turn lanes, PANYNJ was able to construct each of the two right-turn lanes to be extra wide to accommodate truck swept path widths, as illustrated in Figure 21. This design worked effectively at this location because no pedestrians were present.

Triple right-turn lanes have also been used at a few locations, particularly for turns from a freeway off ramp to an arterial crossroad.

Offset Right-Turn Lanes

A challenge with providing right-turn lanes at unsignalized intersections is that vehicles, particularly trucks, in a right-turn lane on the major road may potentially block the view of drivers stopped on the minor-road approach and prevent them from being able to see traffic approaching from the left on the major road. This can lead to crashes between vehicles turning onto or crossing the major road and through vehicles on the major road. To mitigate this concern, a right-turn lane can be offset by separating it from the adjacent through lane so that vehicles in the right-turn lane no longer obstruct the view of the minor road driver, as illustrated in Figure 22. One transportation agency has indicated they have implemented an offset right-turn lane at a gas station entrance with substantial truck activity to prevent entering trucks from blocking the sightline of exiting passenger cars.

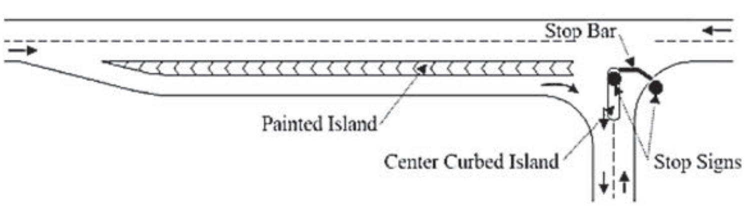


Figure 22. Typical offset right-turn lane.

4.3.5 Channelized Right-Turn Roadways

Right-turn maneuvers at intersections are a key challenge faced by trucks on urban and suburban arterials because of the potential for trucks to either encroach into the adjacent lane or mount the curb to negotiate a right turn. Channelized right-turn roadways can provide a larger curb return radius to accommodate turning vehicles, including large trucks, without unnecessarily increasing the intersection pavement area and the pedestrian crossing distance. Channelization can be provided in a variety of forms, including painted pavement areas and curbed islands. Figure 23 illustrates a typical channelized right-turn roadway. Channelized right-turn roadways may be appropriate in some quadrants of an intersection but not in others, depending on intersection geometry and traffic demands.

Channelized right-turn roadways provide advantages for trucks, in that a larger curb return radius can be used. The channelized right-turn roadway design provides a two-stage crossing for pedestrians, rather than increasing the pedestrian crossing distance at the main intersection. However, channelized right-turn roadways provide a disadvantage for pedestrians with vision disabilities who may have difficulty determining the correct path for crossing the channelized right-turn roadway.

Some transportation agencies have indicated that channelized right-turn roadways can be challenging for trucks and, in some cases, they have removed the channelizing island at an intersection. In these situations, it is likely that the channelized right-turn roadway was too narrow for trucks to traverse.

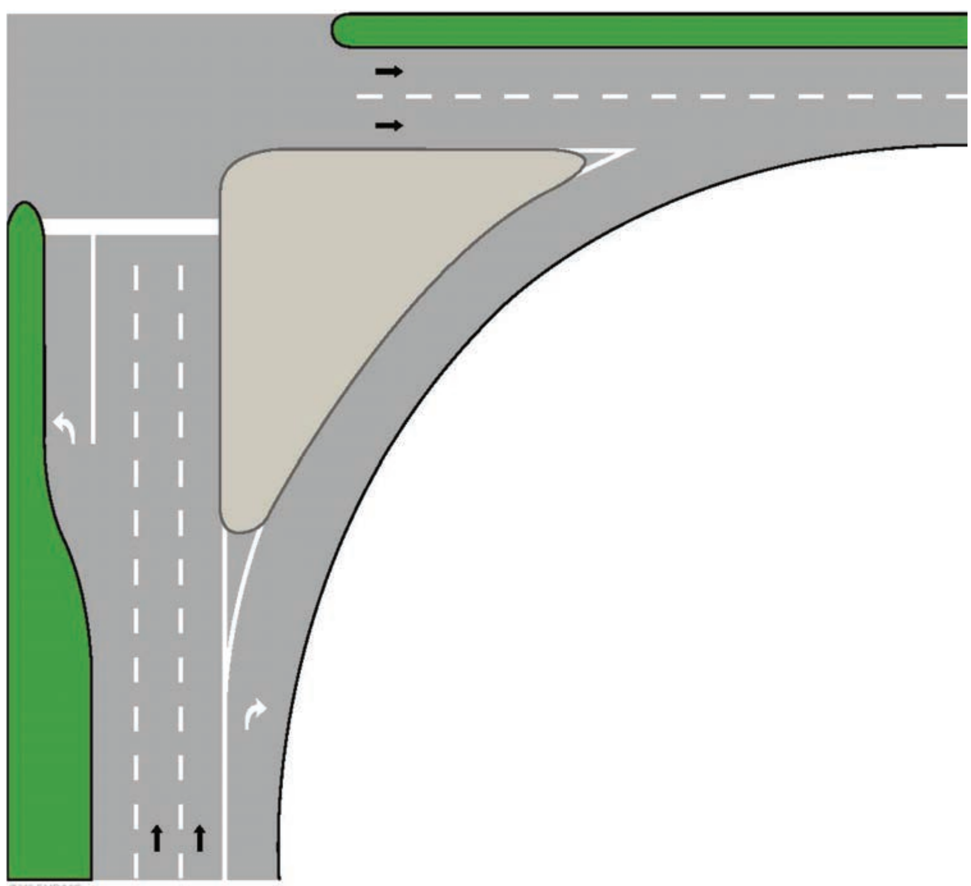


Figure 23. Typical channelized right-turn roadway.

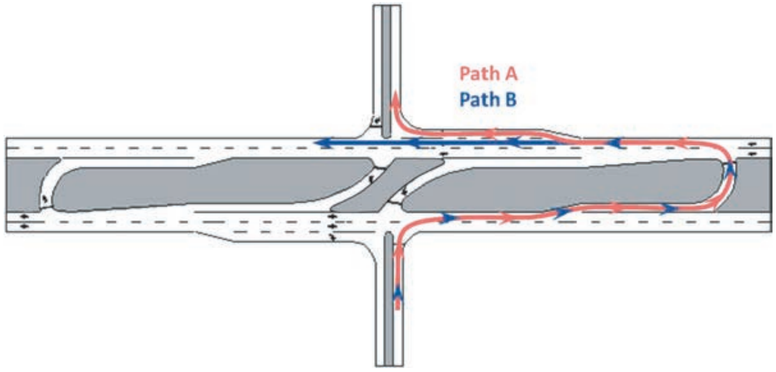


Figure 24. Illustration of side-street left-turn and through paths at RCUT intersection **(FHWA 2018a)*.***

4.3.6 Indirect Left-Turn Movements

Certain intersection designs remove direct left-turn paths and route left-turning traffic indirectly. Where medians are installed in the roadway to prevent direct left-turn movements, alternative routes should be provided to complete left-turn maneuvers. In some cases, these alternative routes include U-turn roadways through the roadway median. Such U-turn roadways should be designed to accommodate trucks that need to make the specific left-turn maneuver. Examples of intersections with indirect left-turn movements, including RCUT, MUT, continuous flow, and jughandle intersections, are provided in this section, with guidance on how they should be used on truck routes.

RCUT and MUT Intersections

RCUT and MUT intersections are innovative intersection types that are used in place of conventional at-grade intersections. At RCUT intersections, left-turn movements from a side street are required first to make a right turn onto the major street, followed by a U-turn in order to complete the left turn. Path B in Figure 24 shows the indirect left-turn path from the side street at an RCUT intersection. Through movements from the side street at an RCUT intersection follow a similar path (see Path A in Figure 24). The U-turn roadways of an RCUT intersection are often referred to as J-turns.

At MUT intersections, all left-turn movements are prohibited at the crossing of the intersecting roadways. Left turns are accomplished by either going through the intersection and making a U-turn followed by a right turn (Path A in Figure 25) or first turning right onto the intersecting

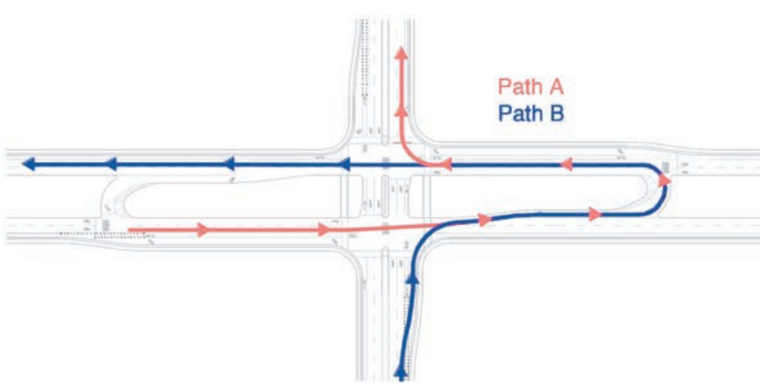


Figure 25. Illustration of indirect left-turn paths at MUT intersection **(FHWA 2018a).**

roadway followed by a U-turn (Path B in Figure 25). This design has been used extensively in Michigan and has been referred to as a Michigan U-turn intersection.

RCUTs and MUTs improve the operational performance of signalized intersections by reducing the number of critical phase-pairs. RCUTs and MUTs are often used to decrease delay and travel time on high-demand corridors. RCUTs are also used on rural high-speed divided roadways as a safety treatment to remove crossing maneuvers from the side-street approaches. RCUTs and MUTs can be used in conjunction with driveways and side streets that are limited to right-in/right-out operation, because these intersection types have U-turn roadways that can combine with the right-in/right-out maneuvers to create an indirect left-turn movement.

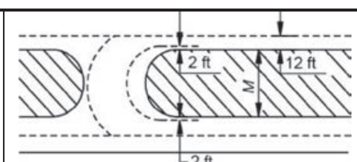
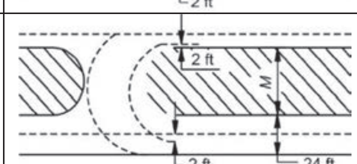
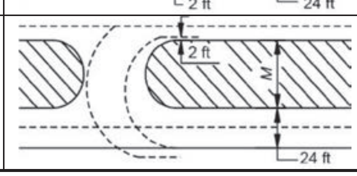
During the course of this research, some transportation agencies indicated that RCUT and MUT intersections can be designed to operate effectively for large trucks. Other agencies indicated they avoid the need for U-turns by large trucks by adjusting driveways and by encouraging effective onsite circulation design and effective truck delivery routes (Potts et al. 2019).

The U-turn maneuver at RCUT and MUT intersections can be challenging for trucks to traverse. The *Green Book* provides guidance, presented in Table 6, on the minimum median width to accommodate U-turn movements on four-lane divided arterials by specific design vehicles, including WB-40, SU-30, SU-40, WB-62, and WB-67 trucks. Three cases are addressed:

- U-turns from inner lane to inner lane
- U-turns from inner lane to outer lane
- U-turns from inner lane to shoulder (which also addresses U-turns from the inner lane to the outer lane of a six-lane divided arterial)

On a four-lane divided arterial with a median width such that a truck would run onto the shoulder of the receiving roadway while making a U-turn, a loon can be provided. A loon is a widened and strengthened portion of the paved shoulder marked specifically for use by trucks in making U-turn maneuvers. Figure 26 illustrates a typical loon on the shoulder opposite a median U-turn roadway.

Table 6. Minimum median width to accommodate U-turn movements (AASHTO 2018).

U.S. Customary								
Type of Maneuver		M—Minimum Width of Median (ft) for Design Vehicle						
		P	WB-40	SU-30	BUS	SU-40	WB-62	WB-67
		Length of Design Vehicle (ft)						
		19	50	30	40	40	63	68
Inner Lane to Inner Lane		30	61	63	63	76	69	69
Inner Lane to Outer Lane		18	49	51	51	64	57	57
Inner Lane to Shoulder		8	39	41	41	54	47	47

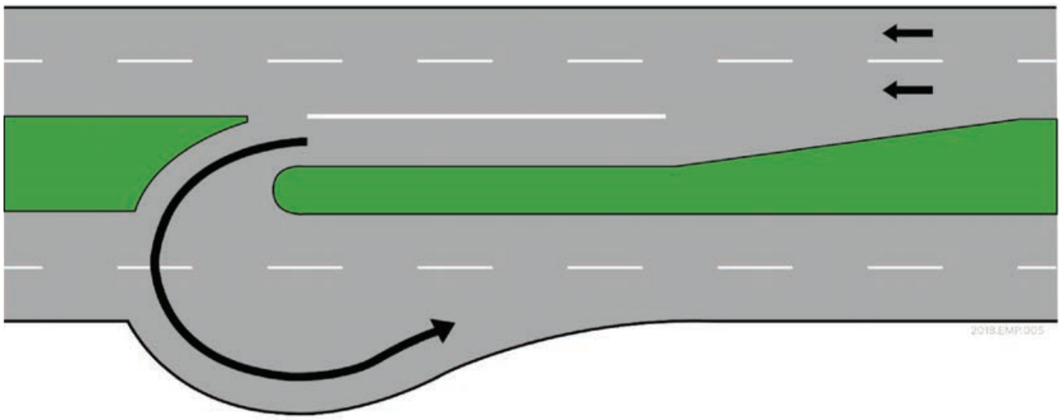


Figure 26. Illustration of a loon at a median U-turn roadway.

The following guidelines should be used when considering the design and placement of the loon:

- At U-turn roadways where trucks are present, provide loons where needed to accommodate truck-turning paths in completing a U-turn maneuver.
- Use turning templates in CADD software to ensure adequate design is provided for the design vehicle making a U-turn.
- Corridors do not necessarily need loons at every median U-turn roadway. Carefully consider which median U-turn locations will be used by trucks, and provide loons where needed at those locations. Other median U-turn locations may just serve smaller vehicles and may not need a loon.
- On corridors with limited right of way on one side of the roadway, jughandles can be used in lieu of loons.

Continuous Flow Intersections

Continuous flow intersections (CFIs) are an innovative intersection design that can be used in place of conventional at-grade intersections. CFIs consist of displaced left-turn movements that cross the opposing through movements upstream of the main intersection. CFIs can have displaced left-turn movements on all four approaches of the intersection; however, it is most common to have displaced left-turn movements on the major crossing roadway. Figure 27 shows a typical CFI with displaced left-turn movements on two of the four approaches. The indirect left-turn paths are shown in the figure. CFIs improve the operational performance of signalized intersections by reducing the number of critical phase-pairs. CFIs are often used to decrease delay and travel time on high-demand corridors.

The left-turn crossover must be placed far enough upstream of the main intersection to allow for adequate storage space for left-turning vehicles. Displaced left turns with high truck volumes must be designed to accommodate truck movements and to prevent queue spillback into the crossover intersection. Transportation agencies representatives interviewed during the course of this research indicated that this can be done effectively (Potts et al. 2019). Strategic signal timing can be used to coordinate the crossover and main intersections during times of day in which heavy truck volumes create the potential for sustained spillback.

Jughandles

A jughandle is a particular type of turning roadway used at at-grade intersections to route left- and right-turning traffic from the major roadway onto the minor roadway or to provide

Case Study: Selected Use of Loons at U-Turn Locations Along a Truck Route

Michigan DOT (MDOT) makes extensive use of the MUT design in which all left turns are prohibited at the main intersections where two streets cross and left turns are accomplished indirectly by means of median U-turn roadways ("crossovers"). Even on six-lane divided roadways, U-turns by the largest trucks that operate in Michigan can typically be accomplished only where loons are provided on the shoulder of the opposing roadway opposite the U-turn roadway. In one particular corridor on a suburban four-lane divided arterial with spacing of approximately 1 mi between signalized intersections, MDOT has made a careful study of which intersections have (and which intersections do not have) substantial left-turn demands. Where truck left-turn demands are present, loons are provided at the adjacent median U-turn roadway in each direction of travel to facilitate left turns by trucks. Where truck left-turn demands are not present, loons are not provided at the adjacent median U-turn roadway, and U-turns by trucks are prohibited by black-on-white signs that read NO LARGE TRUCKS THIS CROSSOVER (see photograph). If a truck desires to turn left using a U-turn roadway that prohibits truck use, it is typically no more than 1 mi to a median U-turn roadway with a loon that permits truck use.

(Photo source: MRIGlobal.)

(Photo source: adapted from Google Earth.)

a U-turn movement for the roadway. Nearside jughandles provide an indirect turning path upstream of the intersection (see Figure 28), while farside jughandles provide an indirect left-turning path downstream of the intersection (see Figure 29). Farside jughandles are also known as indirect left-turn loops. Jughandle intersections have been used extensively in New Jersey and are now in use in other states as well. Jughandles can be beneficial for providing a path for trucks to make U-turns and for providing a larger turning radius for turning trucks. Jughandles with inadequate storage can be challenging for trucks to navigate. Transportation agencies report that farside jughandles are more effective in facilitating truck movements than nearside jughandles (Potts et al. 2019).

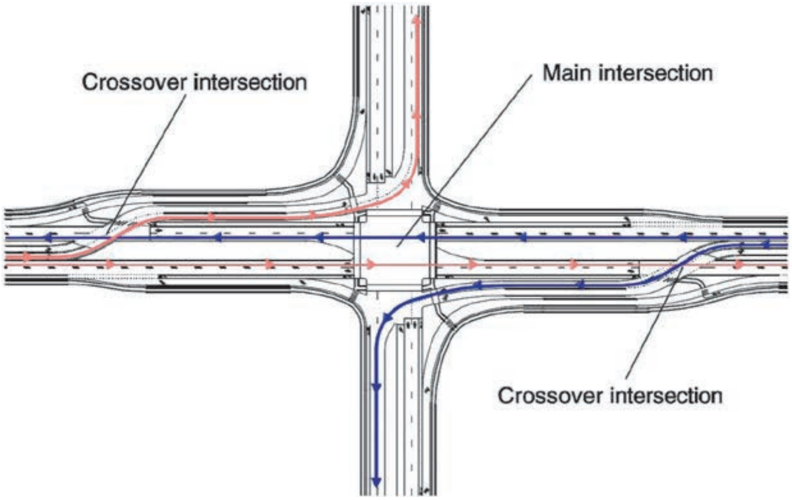


Figure 27. Illustration of CFI with displaced left turns on two of the four approaches* (FHWA 2018b)*.

The following guidelines should be used when considering jughandles for truck accommodation:

- For left-turn movements with high truck demand, use of farside jughandles is recommended.
- On corridors where left turns are prohibited, jughandles can work well for providing U-turns. Midblock locations and three-leg intersections are better suited than four-leg intersections as locations for jughandles that provide for U-turn movements by trucks.
- Nearside jughandles are not well suited for use at intersections where left-turning truck volumes are high because of the limited storage space between the jughandle intersection with the side street and the main intersection.

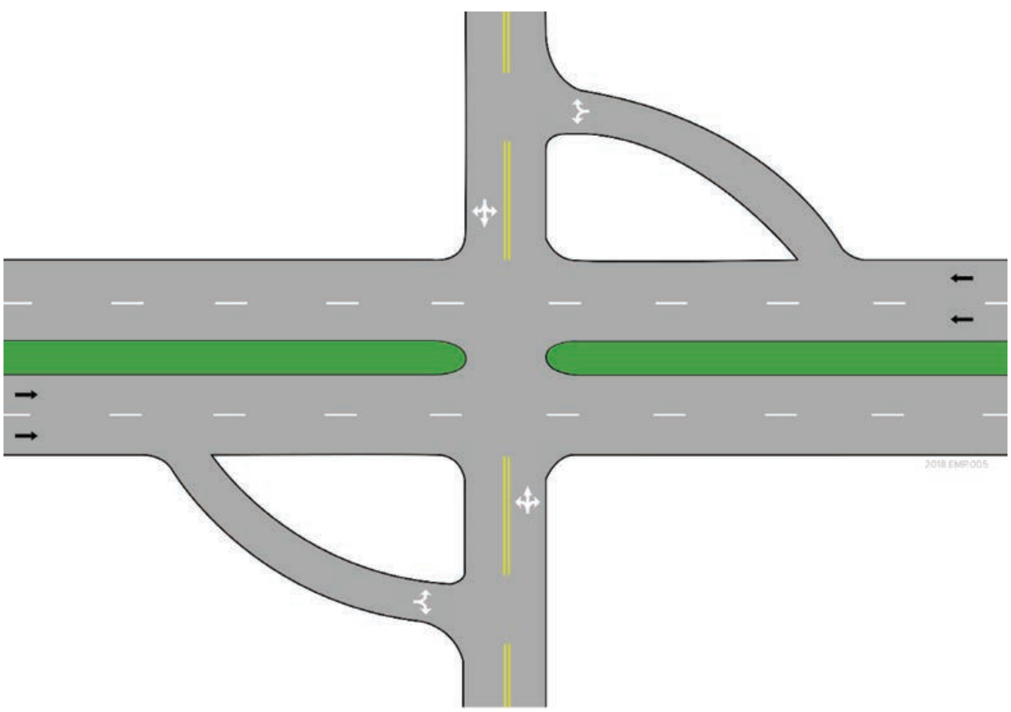


Figure 28. Illustration of a four-leg intersection with nearside jughandles.

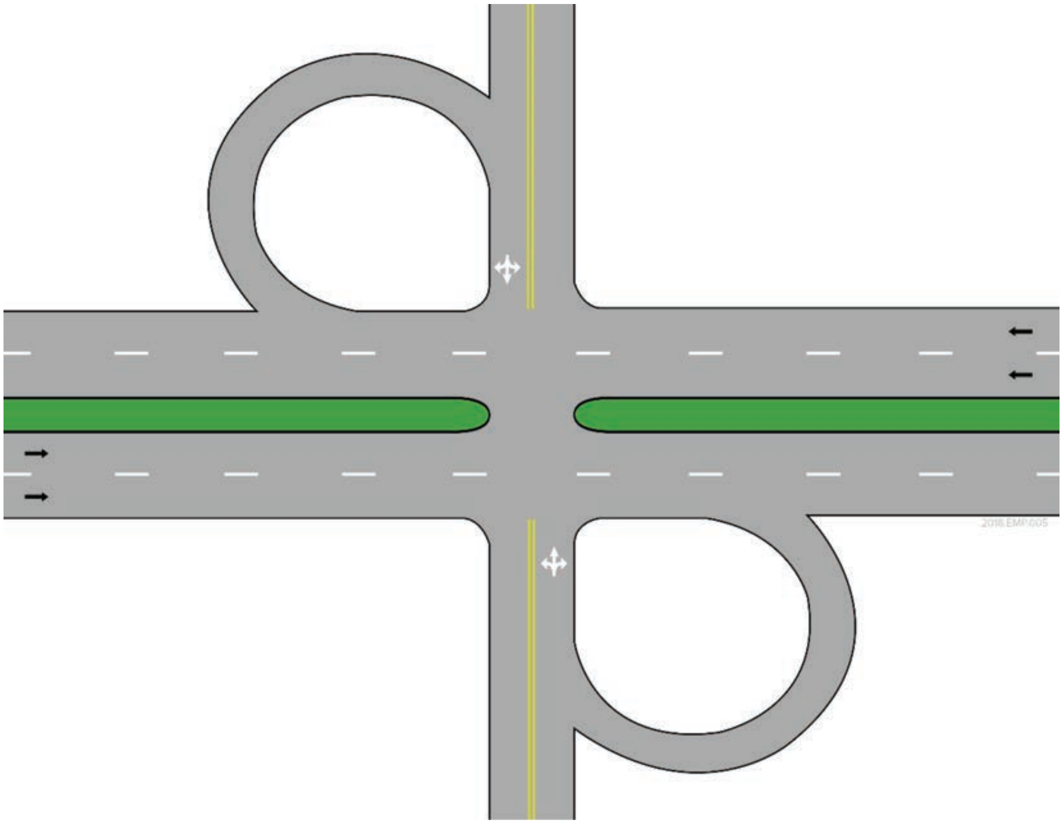


Figure 29. Illustration of a four-leg intersection with farside jughandles.

Jughandles are not ideal on facilities that accommodate pedestrians, because they provide an additional roadway that pedestrians must cross. If possible, it is best to provide pedestrian and bicycle facilities on parallel streets to eliminate conflicts between jughandle traffic and nonmotorists.

Quadrant Intersections

A quadrant intersection is an innovative intersection that is used in place of a conventional at-grade intersection. At quadrant intersections, there is a connector roadway that is positioned in one quadrant of the intersection, as shown in Figure 30. All left-turn movements at the main intersection are prohibited and must use the quadrant roadway to complete a left-turn maneuver. Quadrant intersections improve the operational performance of signalized intersections by reducing the number of critical phase-pairs. Similar to RCUTs and MUTs, quadrant intersections are often used to decrease delay and travel time on high-demand corridors.

The quadrant roadway must be placed far enough away from the main intersection to allow for adequate storage space for vehicles on both the main roadways and the quadrant roadway. Quadrant intersections with heavy truck volumes must be designed to accommodate truck movements. Strategic signal timing can be used to coordinate the main intersection with the two-quadrant roadway intersections during times of day in which heavy truck volumes create the potential for sustained spillback.

Pedestrians may find it easier to traverse a quadrant intersection rather than a conventional intersection because shorter cycle lengths at a quadrant intersection may reduce pedestrian

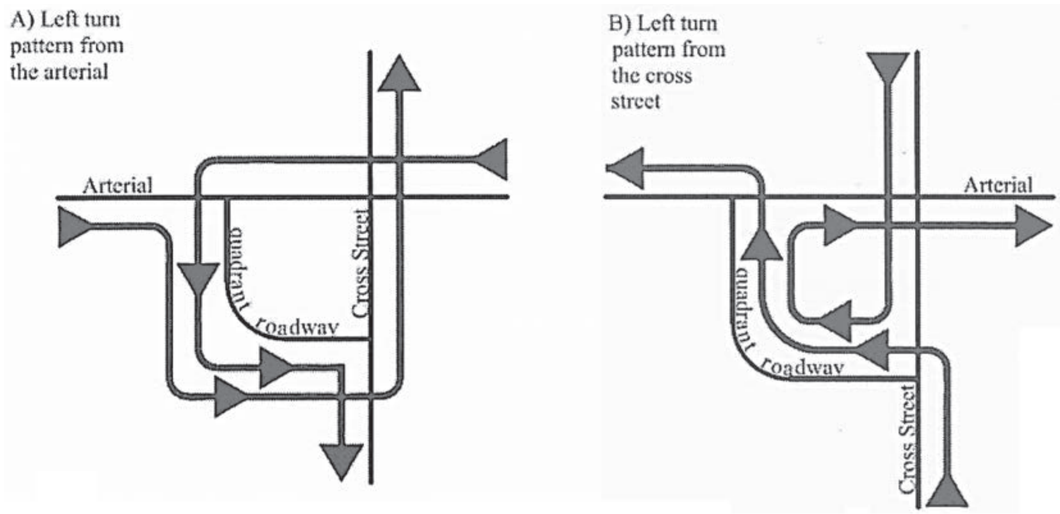


Figure 30. Paths of left turns at a quadrant intersection **(Hughes et al. 2010).**

delay. Crosswalk lengths may also be shorter at quadrant intersections because there are no left-turn lanes at the main intersection.

Other Special Considerations

In some cases, it may be necessary to prohibit trucks from making left turns at intersections as a result of inadequate turning radii or storage space, while still allowing other vehicles to make the direct left turn. At some locations, an indirect left turn should be provided downstream so that trucks have an alternate route to the desired roadway.

Roundabouts can be used on corridors to replace conventional intersections. This may be particularly appropriate where the corridor is being converted from an undivided to a divided cross section. In this situation, all vehicles that desire to turn left from driveways must now turn right and use a downstream roundabout to make a U-turn, thus creating an indirect left turn. This strategy can be beneficial on corridors with several driveways frequently used by trucks. An example of such a corridor is presented in the case study "Replacement of Closely Spaced Signalized Intersections with Roundabouts on Arterial Corridor."

4.3.7 Roundabouts

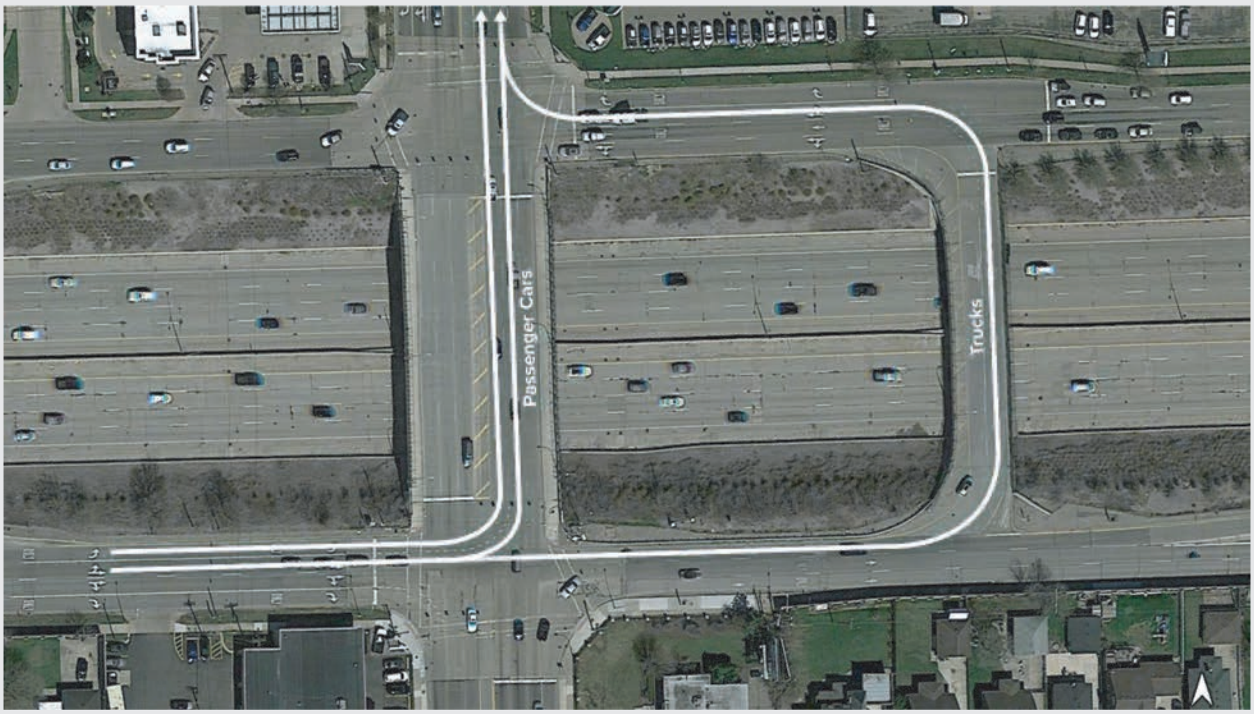
A roundabout is a form of circular intersection in which traffic travels around a central island and at which entering traffic must yield to circulating traffic (i.e., traffic already within the roundabout). Figure 31 presents the key features of a roundabout that make it operate effectively (Rodegerdts et al. 2010).

The Roundabouts: Informational Guide, Second Edition (Rodegerdts et al. 2010) separates roundabouts into three basic categories according to their size and number of lanes:

- **Mini-roundabouts**—small roundabouts with a fully traversable central island, most commonly used in low-speed urban environments.
- **Single-lane roundabouts**—roundabouts with a single-lane entry at all legs and one circulatory lane. Operating speeds may be slightly higher than at mini-roundabouts, and the central island is non-traversable.

Case Study: Alternative Paths for Passenger Cars and Trucks

MDOT uses some diamond interchanges with slip ramps to continuous frontage roads, similar to the interchange design that is also used commonly in Texas. At one location, MDOT found that the space between the crossroad ramp terminals was sufficient to store passenger cars making a direct left turn from one frontage road, but that large trucks turning left could not be stored in the space between the crossroad ramp terminals. In this case, MDOT decided to let passenger cars continue to make the direct left-turn maneuver, but to prohibit direct left turns by trucks. As an alternative, a U-turn roadway was constructed to provide an indirect left-turn routing for trucks (see photograph). This unique treatment may be applicable in only a limited number of sites, but it illustrates that separate turning paths can be used for passenger cars and trucks where appropriate.



(Photo Source: adapted from Google Earth.)

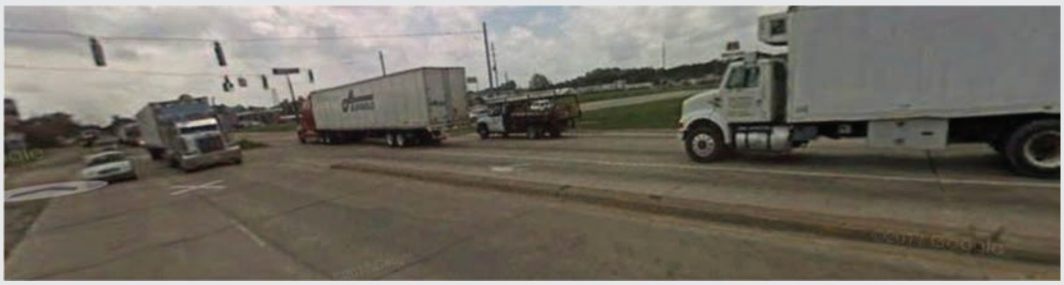
- **Multilane roundabouts**—roundabouts having at least one entry with two or more lanes. Geometric design includes raised splitter islands, a non-traversable central island, and appropriate entry path deflection.

Single-lane roundabouts are an effective safety treatment for at-grade intersections because they eliminate the right-angle and left-turn conflicts associated with traditional intersections. Furthermore, at single-lane roundabouts, drivers have no lane-use decisions to make, pedestrians only have to cross one lane of traffic at a time, and operating speeds are typically low enough to allow for bicyclists and motor vehicles to share the road comfortably.

Multilane roundabouts have an increased number of conflicting and interacting movements and, therefore, may not achieve the same safety performance as single-lane roundabouts. Drivers, pedestrians (particularly pedestrians with vision disabilities), and bicyclists each face more complex decisions and scenarios in multilane roundabouts. However, their overall safety performance is often better than comparable signalized intersections, particularly in terms of fatal and injury crashes (Rodegerdts et al. 2010).

Case Study: Replacement of Closely Spaced Signalized Intersections with Roundabouts on Arterial Corridor

A heavily traveled arterial corridor in Louisiana, with high truck volumes, experienced traffic operational and safety issues because of a series of closely spaced signalized and unsignalized intersections and driveways in the vicinity of an Interstate interchange. The high volumes of trucks, midblock left-turn movements, and closely spaced driveways and intersections contributed to congestion along the corridor. In addition, long queues at signalized intersections contributed to congestion and delays at unsignalized access points. Also contributing to the problem was a truck stop and truck wash, located within approximately 300 ft of the interchange, which led to traffic operational and safety issues related specifically to trucks turning into and out of these businesses.



(Photo source: adapted from Google Earth.)

To address the traffic operational and safety issues along the corridor, the Louisiana DOTD (LaDOTD) decided to replace three closely spaced signalized intersections (two located at the interchange with I-10 and one located approximately 1,000 ft from the interchange) with roundabouts. They also installed a raised median along this corridor, preventing left turns in and out of driveways.

The operation of the corridor has improved significantly since the construction of the roundabouts, and the raised median has eliminated several conflict points. Trucks are able to circulate around the roundabouts without issue, using the truck aprons as needed.

(Photo source: adapted from Google Earth.)

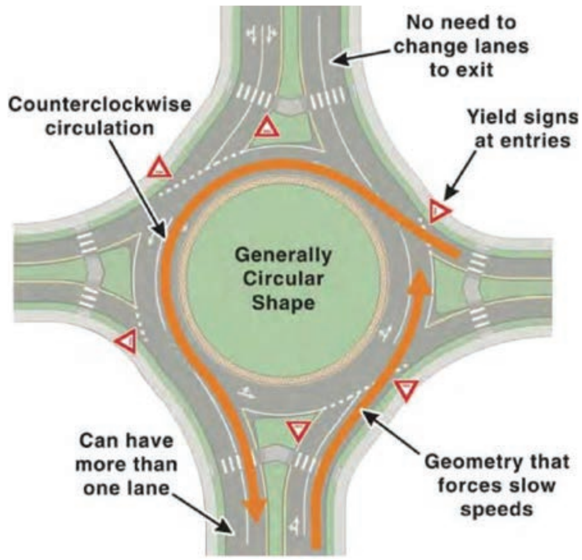


***Figure 31. Key features of a roundabout* (Rodegerdts et al. 2010).**

Research has shown that roundabouts can provide a reduction of 48% in all crashes and 78% in injury crashes where a signalized intersection is converted to a roundabout, and a reduction of 44% for all crashes and 82% in injury crashes where an intersection with minor-road Stop-control is converted to a roundabout (AASHTO 2010). These substantial safety benefits make roundabouts an attractive access management technique for transportation agencies to implement at these types of intersections. For crash reduction effectiveness estimates for conversion of other intersection types to roundabouts, see the AASHTO HSM or the FHWA Crash Modification Factors Clearinghouse (www.cmfclearinghouse.org).

Roundabouts can also be used as part of an overall access management strategy. Where roundabouts are implemented at key intersections and driveways to facilitate major movements, access points between roundabouts can be designed with partially restricted turning movements (e.g., right-in/right-out operation), because the roundabouts provide U-turn opportunities.

Geometric Design Considerations at Roundabouts

Figure 32 defines the basic geometric elements of a roundabout. The typical dimensions of geometric features for a roundabout are shown in Table 7. Entry widths up to 18 ft are typical for roundabouts. Exit widths and apron widths should be based on CADD analysis of design vehicle swept paths. Truck aprons surrounding the central island are typically designed so that the front wheels of the truck tractor remain in the circulating roadway, while the rear wheels may utilize the apron where needed.

Truck drivers have indicated that they like roundabouts because they improve safety and traffic operations (Potts et al. 2019); however, where truck traffic is anticipated, roundabouts need to be designed to accommodate trucks.

Since roundabouts are designed to intentionally reduce vehicle speeds, they typically include narrow cross sections and tight turning radii. However, if lane widths are too narrow and turning radii are too tight, this can be problematic for large trucks traversing the roundabout. An appropriate design vehicle needs to be selected for each roundabout and, if the design vehicle is a truck, its turning path requirements will determine many of the roundabout's dimensions, including the exit radius.

Case Study: Full-Scale Roundabout Demonstration

Many transportation agencies have encountered initial public resistance to installation of roundabouts. One frequently encountered concern from operators of large trucks and large farm equipment was that a roundabout would not be able to accommodate their vehicles. A California Department of Transportation (Caltrans) district office met these concerns by marking a full-scale roundabout on an unpaved area in a farm field and traversing the demonstration roundabout with typical large trucks and farm equipment. The demonstration showed clearly that the roundabout could accommodate the largest vehicles that were likely to use the roundabout without encroaching on the outside curb or the center island. An example of this demonstration, shown in the photograph below, can be seen in a video at https://www.youtube.com/watch?v=JoaB-gQCsD8.

(Photo source: Caltrans.)

At single-lane and multilane roundabouts, transportation agencies often use a traversable apron around the perimeter of the central island to provide the additional width needed to accommodate the swept path width of large vehicles. Initially, truck drivers did not like using these raised aprons because of concerns with truck rollover and tire blowouts. In fact, one transportation agency uses a wider single circulating roadway because the trucking industry in their state does not like using the apron surrounding the center island of a roundabout. Recent adjustments to roundabout design to accommodate trucks, however, have included flatter cross slopes and lower mountable curbs on the aprons to make this design better accommodate trucks. In many states, truck drivers seem to use aprons more fully now, and some truck drivers have indicated a desire for mountable aprons on the outside of roundabouts as well. This design, however, is not desirable where pedestrian activity is present.

Figure 33 illustrates a single-trailer combination truck traversing a roundabout, using the apron surrounding the central island. Figure 34 shows a double-trailer combination truck traversing a roundabout without using the apron, at least to this point in the turning maneuver.

Roundabouts may also be designed with a traversable center island in locations where OSOW permit trucks are common. One state has provided a roadway traversing the center island of a roundabout with lockable gates that can be opened by the transportation or law enforcement agency when the roadway is used for specific OSOW permit truck movements.

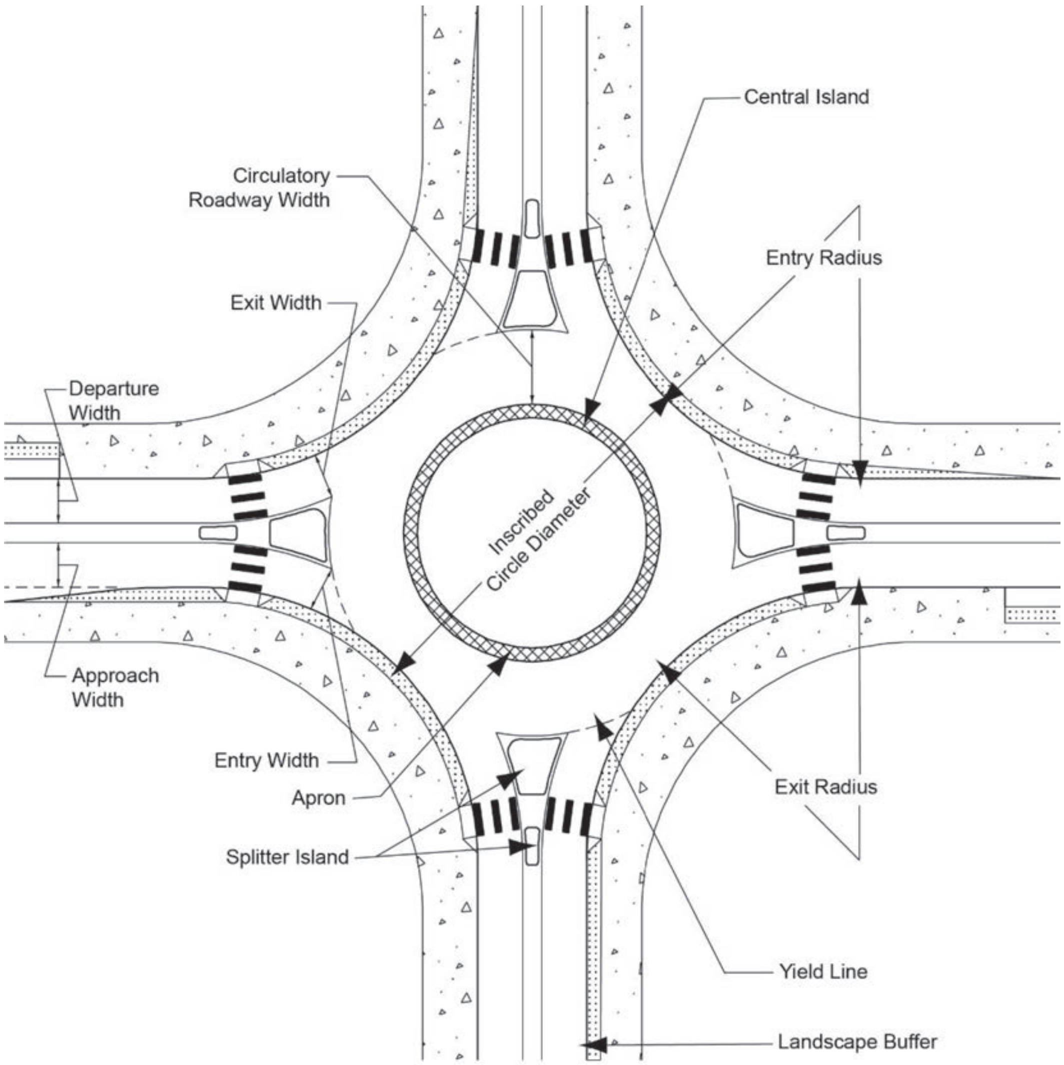


Figure 32. Basic geometric elements of a roundabout **(AASHTO 2018).**

Table 7. Comparison of typical geometric features by roundabout type (Rodegerdts et al. 2010; AASHTO 2018).

Design Element	Mini-Roundabout	Single-Lane Roundabout	Multilane Roundabout
Desirable maximum entry design speed	15 to 20 mph	20 to 25 mph	25 to 30 mph
Maximum number of entering lanes per approach	1	1	2+
Typical inscribed circle diameter[a]	45 to 90 ft	90 to 180 ft	150 to 300 ft
Central island treatment	Mountable	Raised	Raised
Typical daily service volumes for a four-leg roundabout below which the roundabout may be expected to operate without needing a detailed capacity analysis[b]	0 to 15,000	0 to 20,000	0 to 45,000 for a two-lane roundabout

[a]See Figure 32 for the definition of inscribed circle diameter.
[b]Operational analysis is needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.

Figure 33. Single-semitrailer truck using apron that surrounds the central island of a roundabout. **(Photo source: Rodegerdts et al. 2010.)**

To better accommodate trucks at roundabouts, some transportation agencies use slip ramps (bypass lanes) that allow vehicles to make a right-turn maneuver without ever entering the circulating roadway of the roundabout (see Figure 35). This treatment is desirable only where there is a high-volume right-turn movement with substantial congestion, constrained geometrics on the circulating roadway, or a documented pattern of right-turn crashes.

Horizontal clearances to roadside objects should be designed considering the capability of the roundabout to accommodate oversize permit vehicles. Selection of cross slopes for the entry and circulating roadways should consider the need to accommodate trucks with low vehicle undercarriage clearance, such as low-boy trailers.

Multilane roundabouts can be designed so that trucks can traverse the roundabout while remaining within a single lane, typically the outermost lane of the circulating roadway. However, this may result in a larger radius for the roundabout than is typically considered desirable. Because large trucks are often unable to avoid encroaching on adjacent lanes while turning, many multilane roundabouts are designed with the expectation that large vehicles will track across more than one lane while entering, circulating, and exiting the roundabout. Where multilane roundabouts are designed to allow tracking across more than one lane, public education is needed so that other drivers are aware of the need for trucks to use more than one lane.

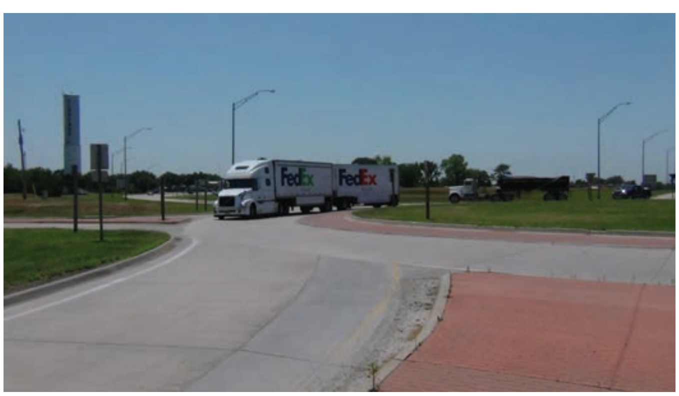


Figure 34. Double-trailer truck traversing a roundabout. **(Photo source: MRIGlobal.)**

Figure 35. Typical roundabout with right-turn bypass lane. **(Photo source: New Hampshire DOT.)**

In some cases, roundabouts have been designed with aprons or gated roadways through the central island to accommodate oversize trucks and emergency vehicles (see further discussion in Section 3.6 on OSOW permits for trucks). The needs of oversize trucks that are likely to use a particular roundabout should be considered in its design. For example, the location of poles, posts, and signs needs to be carefully considered so that oversize trucks can negotiate the roundabout without hitting them.

Pedestrian and Bicycle Usage

Roundabouts provide safer and more efficient operations with reduced crashes for motor vehicles, including passenger cars, trucks, and transit vehicles; however, roundabouts do present challenges for pedestrians and bicyclists. Roundabouts increase the length of the pedestrian travel path for through movements by pedestrians and result in crosswalk locations where nearly all motor vehicles are engaged in a turning maneuver. Roundabouts are particularly challenging for pedestrians with vision disabilities because vehicles approach from unexpected directions. Bicyclists using the circulating roadway encounter conflicts with motor vehicles that differ from those at conventional intersections. At single-lane roundabouts, operating speeds are typically low enough to allow for bicyclists and motor vehicles to share the road comfortably. Multilane roundabouts, with increased radii, higher volumes, and higher speeds, may be more difficult for bicyclists to traverse. Useful guidance on accommodation of pedestrians and bicyclists at roundabouts can be found in Roundabouts: An Informational Guide, Second Edition (Rodegerdts et al. 2010).

4.4 Crossroad and Ramp Terminal Design as Affected by Interchange Configuration

This section presents a range of interchange types that may be used in better accommodating trucks on the road network. Many of these interchange types have been used extensively for many years and are familiar to motorists and truck drivers. The discussion also includes some innovative interchange types that have come into general use only in recent years. Continuing public education may be desirable to familiarize motorists with these innovative interchange types and how trucks operate on them.

4.4.1 Conventional Diamond Interchanges and Closely Related Interchange Configurations

A conventional diamond interchange consists of four diagonal ramps, two exit ramps and two entrance ramps on either side of a freeway, that connect the freeway to an arterial crossroad. Figure 36 illustrates a typical conventional diamond interchange. For rural or low-volume interchanges, the two exit ramps may be Stop-controlled at the crossroad ramp terminals. For higher volume interchanges, the crossroad ramp terminals are often signalized.

Keys to design of effective conventional diamond interchanges include the following:

- Provision of an appropriate number of lanes on the exit ramps to serve the volume of traffic exiting the freeway and to store queues of stopped vehicles on the ramp approaches to the crossroad ramp terminal.
- Provision of an appropriate number of through and turning lanes on the arterial crossroad to serve traffic exiting the freeway, entering the freeway, and passing through the intersection on the crossroad.
- Provision of sufficient spacing between the crossroad ramp terminals to provide sufficient storage space within the interchange on the arterial crossroad.

At higher volume interchanges, effective operation of the interchange is dependent on appropriate phasing and timing of the traffic signals at the crossroad ramp terminals.

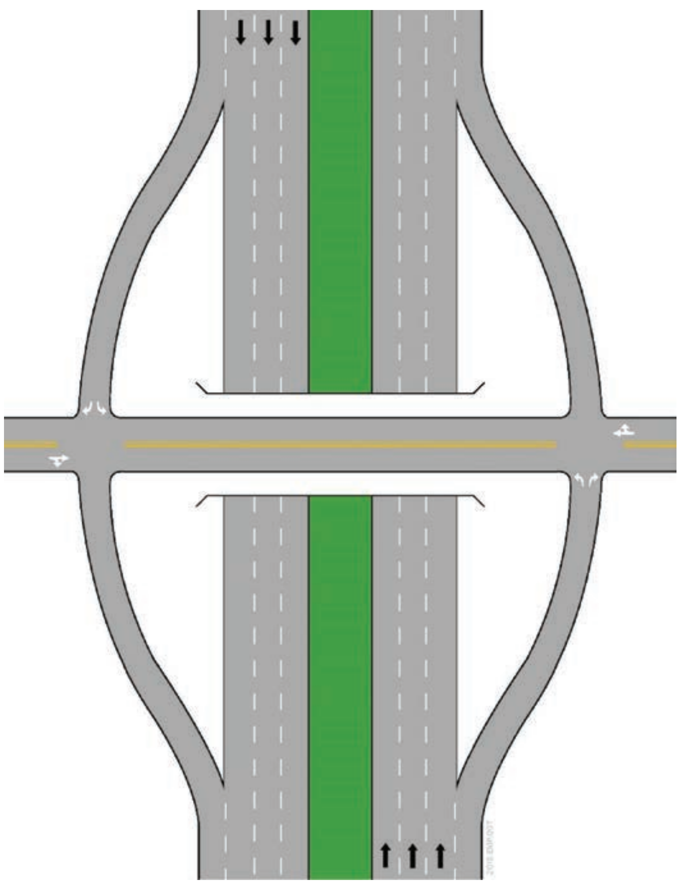


Figure 36. Typical conventional diamond interchange.

Key truck considerations in the design of conventional diamond interchanges include the following:

- Design of the ramp terminals to accommodate left and right turns by trucks (see Section 4.2 on design vehicles).
- Design of any double or triple left-turn lanes to accommodate trucks turning from the exit ramps to the crossroad and from the crossroad to the entrance ramps, including the potential for side-by-side turning maneuvers by trucks (see Section 4.3.3 on double and triple left-turn lanes).
- Design of the spacing between the ramp terminals and the cross section of the arterial crossroad to avoid spillback through the ramp terminals and spillback onto the freeway.
- Design of entrance ramps to avoid spillback onto the arterial crossroad and to accommodate any ramp-metering system that may be in place.

Each of these key design issues for accommodating trucks is traffic-volume dependent and is, therefore, dependent on appropriate analysis procedures rather than on formal design criteria.

For freeways with continuous frontage roads, full diamond interchanges can be designed with slip ramps to and from the parallel frontage roads, as illustrated in Figure 37. This design can have several advantages over a conventional diamond that can benefit trucks. First, the slip ramps can be located further from the crossroad, providing more storage space on the approach to the crossroad ramp terminal, if needed. Second, U-turn roadways between the frontage roads on opposite sides of the freeway can be provided either in advance of the crossroad or

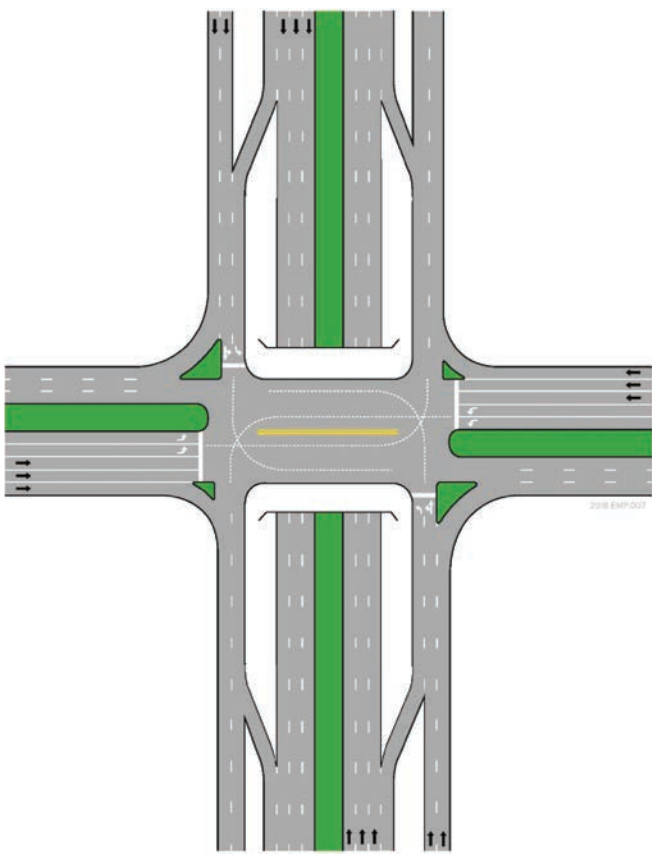


Figure 37. Diamond interchange with slip ramps to and from parallel frontage roads.

beyond the crossroad or both, thus minimizing the volume of left-turn movements that use the crossroad and the storage space needed between the ramp terminals on the crossroad.

The same key design and truck considerations that apply to conventional diamond interchanges also apply to tight diamond interchanges and “folded diamond” interchanges (also known as partial cloverleaf interchanges). Figure 38 illustrates a typical tight diamond interchange. Tight diamond interchanges have ramps closer to the freeway than the ramps in a conventional diamond and shorter spacing between the ramp terminals on the arterial crossroad. Tight diamond interchanges are used primarily in urban areas where available right of way is limited, and the interchange must be fitted into a constrained space. Truck considerations for tight diamond interchanges are more challenging than for conventional diamond interchanges because the ramps are often shorter and because there is less storage space on the arterial crossroad between the ramp terminals. Potential truck volumes and storage space needs should be considered by designers in making the decision between providing a conventional diamond or a tight diamond interchange.

A folded diamond or partial cloverleaf interchange is similar in concept to a conventional diamond except that one or more diagonal ramps are replaced by loop ramps. Figure 39 illustrates several typical configurations for partial cloverleaf interchanges. Partial cloverleaf interchanges are often used where ramp construction in one or more quadrants of the interchange is infeasible (e.g., due to a railroad or river parallel to the arterial crossroad) or where more than one exit or entrance ramp is needed to serve the traffic demands. The two-quadrant partial cloverleaf designs typically have Stop-sign or traffic-signal control at the crossroad ramp terminals, and thus, operate similarly to conventional diamond interchanges. Design and truck considerations for two-quadrant partial cloverleaf interchanges are essentially the same as for conventional diamond interchanges. Four-quadrant partial cloverleaf designs are essentially the same as a conventional diamond interchange with loop ramps added in one or more quadrants of the interchange. Such loop ramps operate with free-flow movement to or from the arterial crossroad, and thus, add design considerations similar to those for a full cloverleaf interchange.

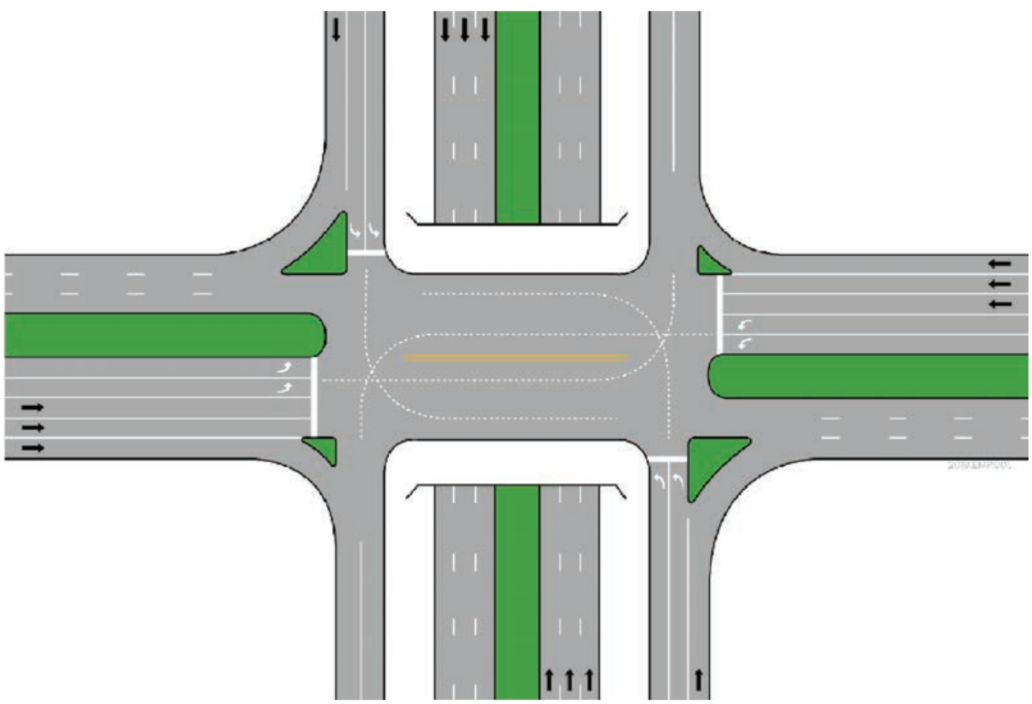
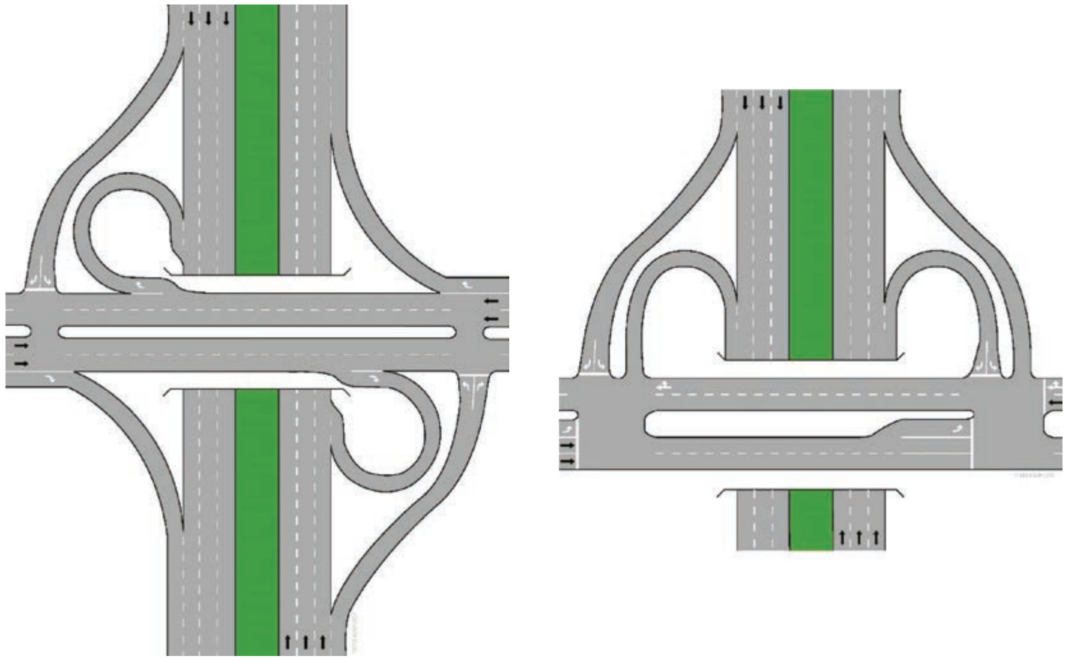


Figure 38. Crossroad area of a typical tight diamond interchange.



(a) (b)

Figure 39. Typical partial cloverleaf interchanges.

4.4.2 Single-Point Diamond Interchanges

SPDIs sometimes referred to as single-point urban interchanges (SPUIs) or just as single-point interchanges, are a modified form of a diamond interchange where opposing left turns from the ramps can flow simultaneously. The same is true for the left turns from the arterial crossroad. The ramp terminals that are controlled by separate, but coordinated, signal installations in a conventional diamond interchange are controlled as a single signalized intersection in a SPDI. Figure 40 shows the layout of a typical SPDI. SPDIs are beneficial for locations with high turning volumes as well as locations with restricted right of way. Larger bridge structures are required compared with other diamond interchange types, which may result in higher construction costs.

Agencies generally agree that SPDIs work well for trucks. SPDIs are preferred in situations where there are high volumes of left-turning trucks. Since there is only a single ramp terminal, there is no queuing or storage of left-turning trucks within the interchange. SPDIs also work well for turning trucks because the left- and right-turn radii are typically larger than those at conventional diamond interchanges. The left turns within a SPDI also typically work well, even for oversized permit trucks, because of the larger turning radii.

CADD systems can be used to ensure the turning paths of trucks are accommodated in the design of a SPDI. Queue storage on both the ramps and the crossroad needs to be adequate to prevent trucks from either spilling back onto the freeway facility or spilling back into upstream intersections on the crossroad.

Because of the traffic-signal phasing scheme of a SPDI, it is difficult to provide signalized pedestrian crossings across the crossroad at the interchange. However, this can be accomplished if two-stage pedestrian crossings are used and an adequately sized pedestrian refuge area is provided in the median of the crossroad. Many agencies opt not to provide a pedestrian crossing across the crossroad at the interchange, and instead, accommodate pedestrian crossings at another location along the crossroad.

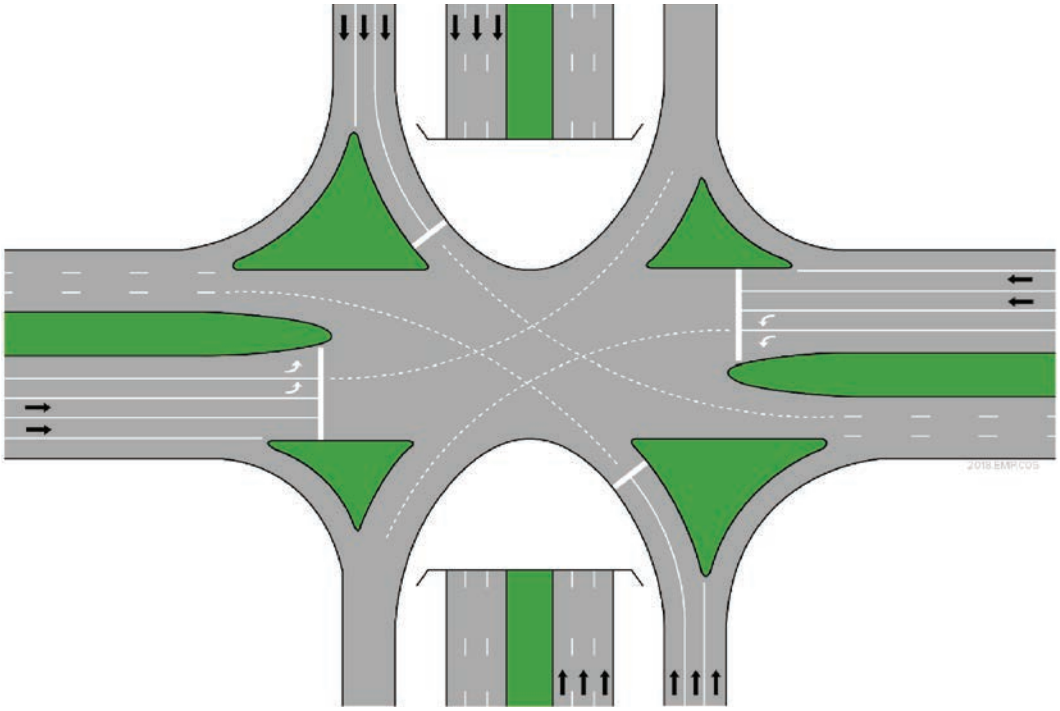


Figure 40. Typical layout of a single-point diamond interchange.

4.4.3 Full Cloverleaf Interchanges

A typical full cloverleaf interchange is illustrated in Figure 41. In this interchange configuration, all of the crossroad ramp terminals have free-flow operation, rather than Stop signs or traffic signals. The arterial crossroad is typically characterized by a free-flow ramp terminal with a loop exit ramp from the freeway followed by a free-flow ramp terminal with a loop entrance ramp to the freeway. This configuration creates a weaving area between the successive loop ramp terminals that can present traffic operational challenges on the arterial crossroad even in the absence of trucks. Substantial truck volumes on the loop ramps and the arterial crossroad can magnify the traffic operational problems. The most common treatment to ease traffic operational problems in such a weaving area is to include one or more auxiliary lanes extending from the loop exit ramp to the loop entrance ramp so that weaving maneuvers can be made more readily. It is also possible to include a collector-distributor (C-D) road along the arterial crossroad to which both loop ramps connect, although this treatment is more common at the freeway end of the ramps than at the crossroad end. The free-flow ramp terminals on the crossroad at the outer connection exit and entrance ramps are less likely to experience traffic operational problems on the crossroad unless there are intersections or driveways located very close to the ramp terminals, or the merge areas are not appropriately designed to accommodate merging maneuvers by trucks.

4.4.4 Diverging Diamond Interchanges

DDIs, also known as double crossover diamond interchanges, are a unique type of diamond interchange in which a portion of each direction of the arterial crossroad is positioned to the left of the centerline relative to their direction of flow. The two crossover points on the arterial crossroad occur at each ramp terminal. DDIs have fewer conflict points and provide greater capacity than conventional diamond interchanges. Each crossover point requires signalization; however, each signal only has two critical phases versus the three critical phases

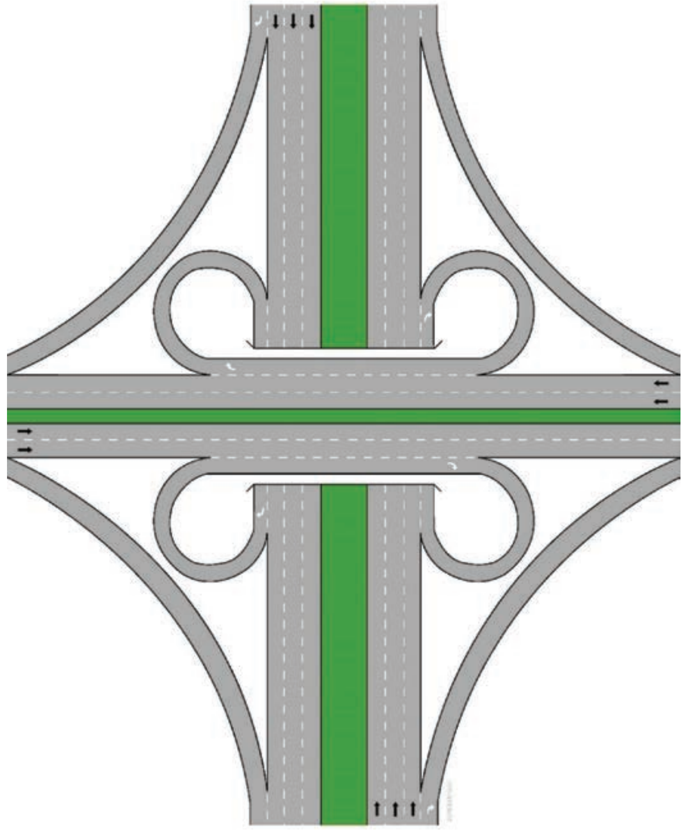


Figure 41. Typical full cloverleaf interchange.

of a conventional diamond ramp terminal. Figure 42 shows a basic plan view of the traffic flows at a DDI.

Transportation agencies and field observations indicate that DDIs work well for trucks (Potts et al. 2019). The primary reason for the success of DDIs in accommodating trucks is that queuing on the arterial crossroad between the ramp terminals is minimal. Traffic from the crossroad making a left turn onto the freeway facility has a free-flow or yield movement onto the ramp, preventing queuing onto the segment between the terminals. Also, because signal cycle lengths can be relatively short compared with those of a conventional diamond interchange, delay for traffic turning left from the ramp onto the arterial crossroad is reduced, which also minimizes long queues between the ramp terminals.

Figure 43 shows trucks traveling on the roadway segment between the crossover points. The horizontal curves at the ramp terminals of current DDI designs typically have sufficient radii that trucks can traverse the curves while remaining within their lane of traffic.

DDIs that are expected to accommodate trucks should be designed such that the turning paths of trucks are fully contained within the marked lane, especially on multilane approaches. This can be verified during the design process in CADD systems. Signal timing is another important aspect to consider. Coordination of the two signals will keep traffic movements with heavy truck volumes flowing without producing long queues between the ramp terminals.

DDIs commonly serve other modes of transportation including pedestrians and bicyclists. The Diverging Diamond Interchange Informational Guide (Schroeder et al. 2014) provides

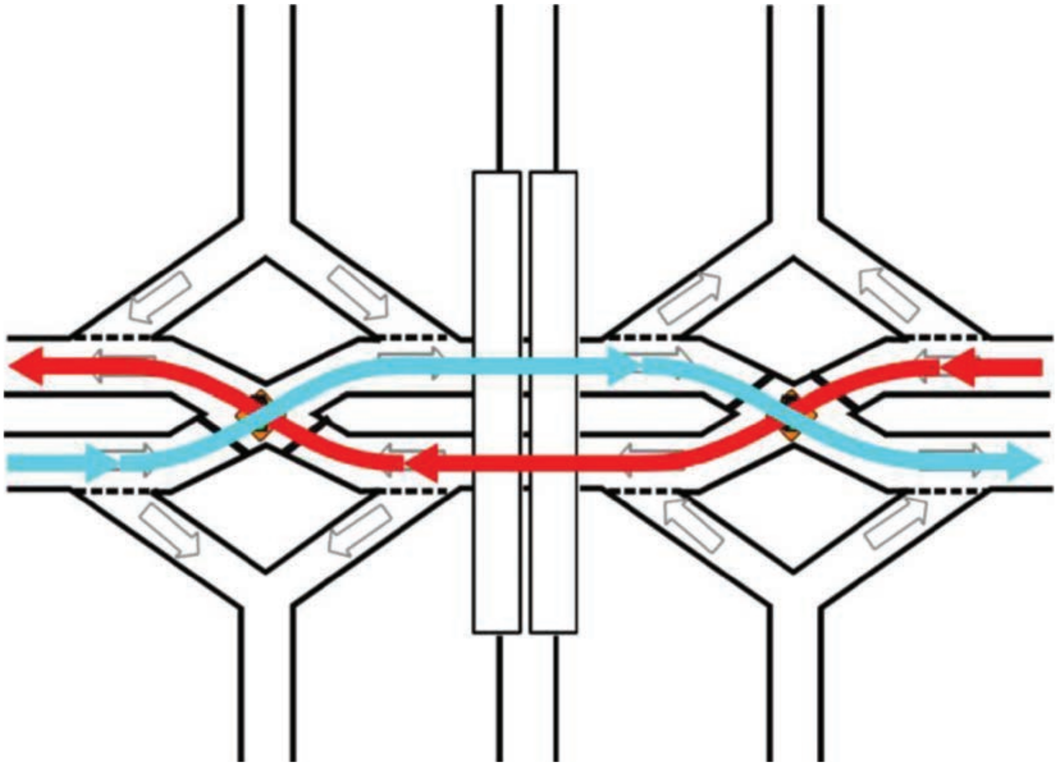


Figure 42. Basic schematic of traffic flows in DDI **(FHWA 2018b).**

a good resource for design alternatives to accommodate pedestrians and bicyclists as well as transit and heavy vehicles at a DDI.

4.4.5 Roundabout Interchanges

Roundabout interchanges are interchanges with roundabouts, rather than with signalized or Stop-controlled intersections at the ramp terminals, as illustrated in Figure 44. The most common type of roundabout interchange is a traditional diamond interchange with a roundabout

Figure 43. Trucks traversing segment between ramp terminals approaching the crossover at a DDI.
(Photo source: MRIGlobal.)

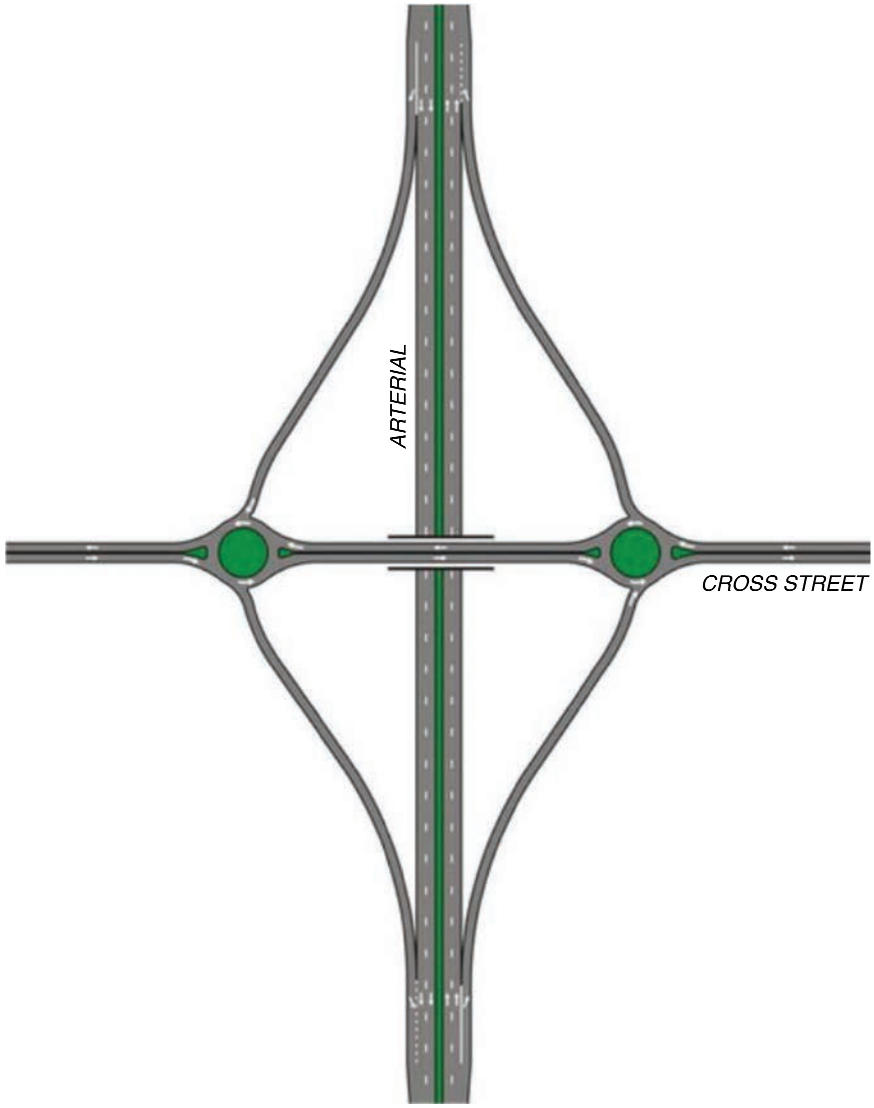


Figure 44. Typical roundabout interchange. **(Source: Applied Technology and Traffic Analysis Program, Maryland State Highway Administration.)**

on the arterial crossroad at each ramp terminal. The absence of traffic signals and Stop signs allows traffic to flow freely to, from, and along the arterial crossroad, reducing delays and congestion at the interchange. Providing roundabouts at ramp terminals can reduce traffic crashes by eliminating right-angle and left-turn conflicts, just as they do at noninterchange locations (see Section 4.3.7). A roundabout interchange can be beneficial where the interchange experiences high left-turn volumes from the exit ramps, entrance ramps, or both, and where only limited space is available for queue storage on the bridge crossing, exit ramp, or arterial approaches. Roundabout interchanges have become more common in recent years because they have the potential to improve safety and traffic operations and eliminate the need to widen bridges.

The roundabouts used in a roundabout interchange can have either a circular central island or a teardrop-shaped central island. Figure 45 illustrates a roundabout interchange with teardrop-shaped central islands. The circular central island is preferable where it is desirable to allow U-turns at each roundabout or to provide access to legs other than the cross street and ramps (Rodegerdts et al. 2010). Interchanges with teardrop-shaped roundabouts help

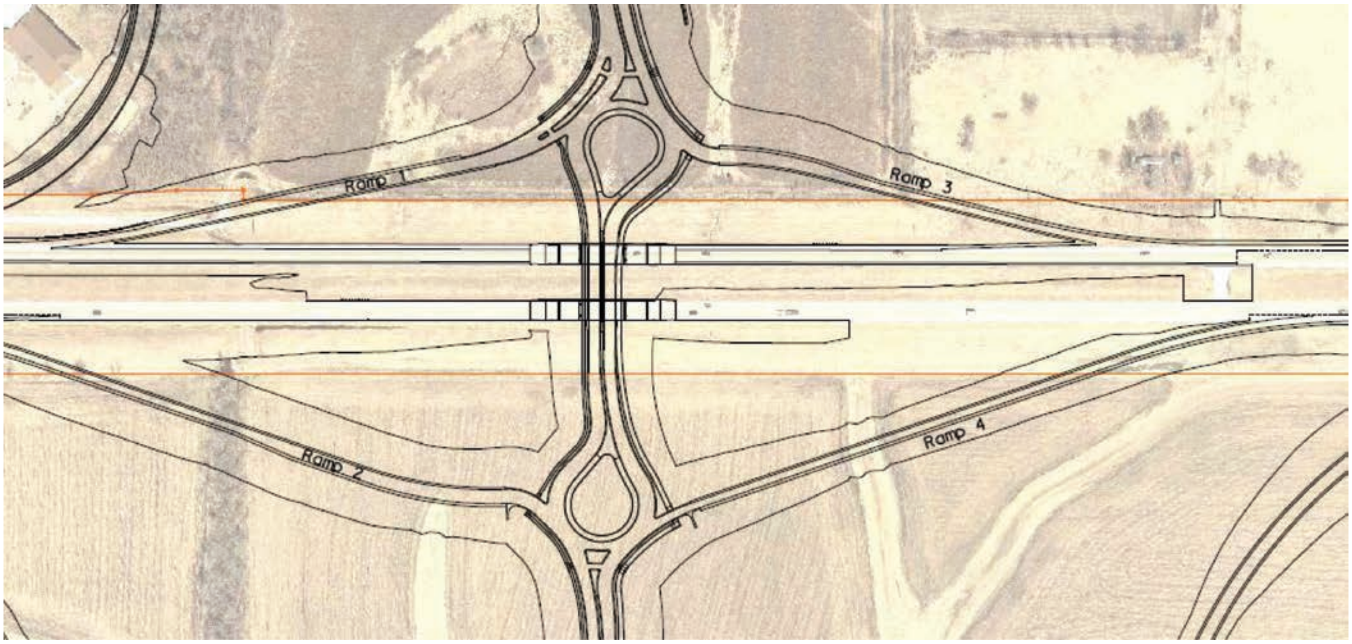


Figure 45. Roundabout interchange with teardrop-shaped central islands at each roundabout. **(Photo source: Missouri DOT.)**

prevent wrong-way movements onto the freeway. Because U-turns at interchanges with teardrop-shaped roundabouts require navigating two roundabouts, these interchanges are preferable where minimal U-turns are expected.

4.5 Driveways

Driveways are essentially private roads that provide access between public roadways and abutting development. However, the term *driveway* typically refers to just a part of a driveway—the area where the driveway intersects the public highway or street (Gattis et al. 2010). The *Green Book* refers to the point at which the driveway joins a public highway or street as a *driveway terminal*, and states that driveway terminals are, in effect, at-grade intersections.

Access points, including driveways, introduce conflicts and friction into the traffic stream. Vehicles entering and leaving the main roadway often slow the through traffic, and the difference in speeds between through and turning traffic increases crash potential.

The design of a driveway varies and depends on several factors, including the following:

- Type of development.
- Design vehicle.
- Traffic volume.
- Proximity to intersection.
- Exposure to bicyclists and pedestrians.

Some driveway design practices create challenges for pedestrians and bicyclists, while others are problematic for motorists. Where trucks are expected to use a driveway, particular consideration should be given to truck needs when designing various elements of the driveway. Koepke and Levinson (1992) note that for properties expecting moderate volumes of large truck traffic, it is desirable to provide one well-designed service or truck driveway to accommodate such vehicles, allowing only passenger-type vehicles to use other appropriately designed driveways within the development. Gattis et al. present design guidance on all aspects of driveways. Several driveway design elements that deserve particular attention when accommodating trucks are discussed as follows:

4.5.1 Driveway Throat Width

Koepke and Levinson recommend that, where a driveway is to be used by larger vehicles (e.g., farm equipment or trucks), a driveway width of at least 20 ft should be provided and entrances up to 30 ft wide may be permitted. Gattis et al. recommend that, for driveways often used by large trucks, driveway width should be at least 26 ft. At driveways with high existing or anticipated pedestrian activity, the driveway width should reflect the needs of both motor vehicle and pedestrian traffic.

4.5.2 Driveway Throat Length

The driveway throat length represents the distance from the outside edge of the traveled way to the first point along the driveway at which there are conflicting traffic movements (Gattis et al. 2010). Figure 46 illustrates driveway throat length. The driveway throat needs to be long enough for vehicles to enter, exit, or circulate on the site without interfering with each other or with through traffic on the abutting roadway. A longer throat length may be needed based on the volume and length of trucks projected for the site.

4.5.3 Driveway Profile

The vertical profile of a driveway should be designed such that the undercarriage of a truck or trailer does not hang up on the pavement. Williams et al. (2014) recommend consideration of trucks and their trailers when determining driveway vertical profiles, and Gattis et al. present guidelines on driveway vertical profiles, based on driveway type and intensity of use. At industrial driveways or other driveways frequently used by larger vehicles, and where low-body trailers are expected, crest breakover grade differences without a vertical curve should be limited to 3.5%. Gattis et al. also illustrate potential problems related to poorly designed crest and sag vertical curves at driveways (see Figure 47).

4.5.4 Curb Termination Treatments

Where a curb is present on either side of a driveway, the curb may be terminated in a variety of ways, including terminated with an abrupt end, terminated by means of a drop-down curb, or terminated by means of a return curb. Figure 48 illustrates each of these curb termination treatments.

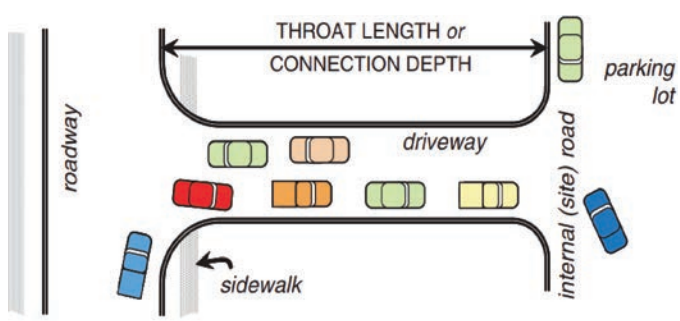


Figure 46. Definition of driveway throat length (Gattis et al. 2010).

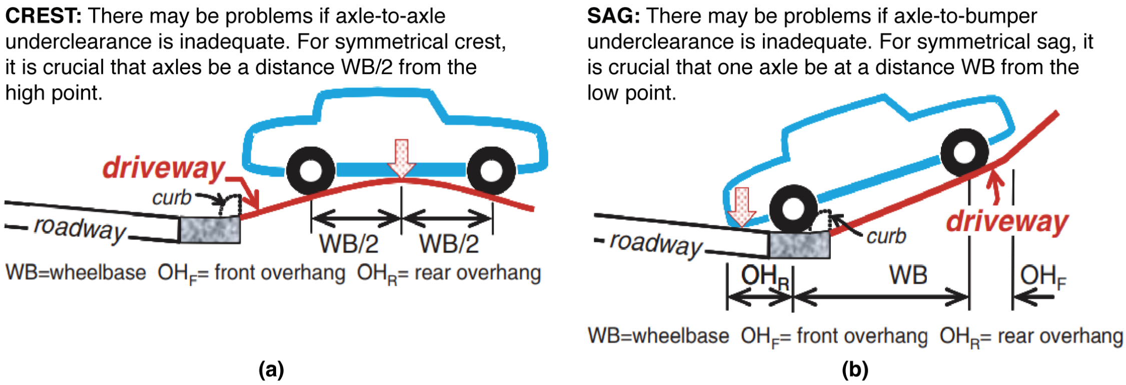


Figure 47. Design of driveway profiles to accommodate low-body vehicles **(Gattis et al. 2010).**

An abrupt end to a curb is undesirable because it is likely to snag a vehicle tire. The vertical face of a return curb provides entry-edge definition for an approaching motorist. Some truck drivers have suggested that flat or mountable curbs be provided for a short distance on either side of the driveway to facilitate trucks turning into and out of the driveway.

4.5.5 Curb Return Radii for Driveways

According to the survey conducted during this research, transportation agencies identified curb return radius as one of their most common concerns (Potts et al. 2019). Gattis et al. recommend using a curb return radius ranging from 40 to 75 ft for driveways with large trucks as the design vehicle; however, they note that accommodating trucks with a simple radius design (with sufficient radius to prevent encroachment on the curb) may result in a very wide driveway opening. To better accommodate the wheel paths of turning trucks without paving such a wide area, Gattis et al. recommend referring to the *Green Book* discussion of designing simple curves with a taper and designing three-centered compound curves. Figure 49 illustrates the geometry of a three-centered curve at a 90-degree curb return radius. Koepke and Levinson (1992) also state that the most efficient design for a large vehicle's turning transition can be made by constructing a curb return with a series of compound curves or by using a simple curb radius with transitioning tapers.

4.5.6 Medians in Driveways

Where medians are provided in driveways, the half-bullet nose design provides a larger turning radius, which in turn accommodates the swept path of a large truck (see Figure 50). If an island is located at the end of the driveway, mountable curbs and reinforced pavement

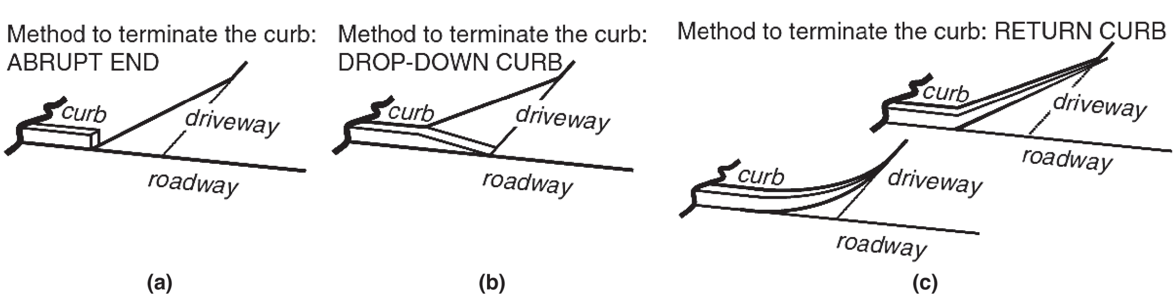


Figure 48. Methods to terminate the curb at a driveway **(Gattis et al. 2010).**

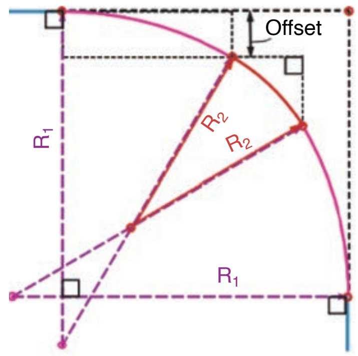


Figure 49. Geometry of a symmetrical three-centered curve **(Gattis et al. 2010).**

may need to be provided within the island to deal with large trucks overrunning the island (Gattis et al. 2010).

4.5.7 One-Way versus Two-Way Operations

If a driveway is to operate with two-way traffic, the designer needs to consider whether the driveway should be designed to accommodate simultaneous entry and exit maneuvers by trucks (and if so, what types of trucks). One-way operation simplifies the design of the driveway because there are no potential conflicts between trucks traveling in opposite directions. More guidance about this issue is presented in Section 3.1.6 on site layout.

4.5.8 Right-in/Right-out Operations

Both one-way and two-way driveways can be designed for right-in/right-out operation, where left turns in and out of the driveway are not permitted. Right-in/right-out operation reduces the number of traffic conflict points at the driveway, analogous to the difference between the number of conflict points at three-leg and four-leg intersections. On undivided streets, the left-turn restriction is communicated to drivers by signing. On divided streets, the left-turn restriction is communicated to drivers by not providing a median opening at the driveway; the lack of a median opening is typically reinforced by the provision of one-way signs in the median opposite a driveway restricted to right-out operation. Part of the decision to use right-in/right-out operations at a driveway should be an assessment of the appropriateness of alternative routes that trucks and other vehicles will use to reach or leave the driveway in question.

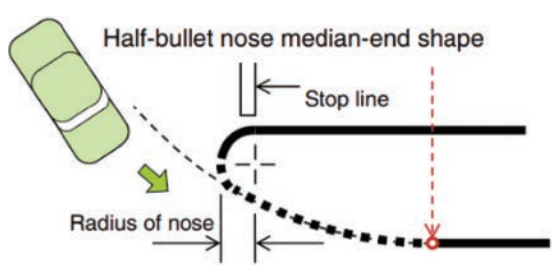


Figure 50. Design of a driveway median end with a half-bullet nose shape **(Gattis et al. 2010).**

4.5.9 Combining Driveways

A common access management solution is combining multiple driveways to reduce the number of driveways and the driveway density along a corridor and to minimize the conflicts between turning vehicles and through traffic. Combining driveways to a single commercial business establishment makes sense when three or more driveways or a continuous driveway frontage are provided. There are locations, however, where at least two driveways are needed to accommodate delivery truck circulation within the site. Combining driveways can also be accomplished by using a single driveway or a pair of driveways to provide access to two or more adjacent commercial business establishments.

One solution used by a transportation agency to reduce the apparent number of driveways during normal business hours (including peak traffic periods) is to provide one conventional driveway plus a textured concrete mountable curb/apron that can be used as a driveway by trucks during nonbusiness hours (see Figure 51). During business hours, parking is permitted along the apron, preventing its use as a driveway by customers. The textured and colored surface also discourages passenger-car use, while drivers arriving during nonbusiness hours become familiar with the textured concrete entrance. Pervious pavement may also be used for this application.

4.5.10 Parking Adjacent to Driveways

On-street parking should be restricted immediately adjacent to driveways. When vehicles are parked adjacent to a driveway, truck drivers indicate that it is nearly impossible to turn into and out of the driveway.

4.5.11 Location of Gates for Driveways

Some industrial facilities that are origins or destinations for truck shipments have gates to control access to the site and the loading dock. When the gate is closed, queues of trucks may form, waiting to enter the facility. Therefore, such gates should be located so that any queue of trucks will not extend into the traveled way of the adjacent street and delay through traffic or create traffic conflicts on the street. Gates can either be located on the driveway away from the street or a shoulder, parking, or waiting area for trucks can be created along the street outside of the traveled way. The location of any gates should be considered part of the site layout and internal circulation review (see Section 3.1.6). The storage needs for trucks waiting for the gate to open depend on the arrival rates of trucks and hours of service for the loading and unloading facility.

Figure 51. Mountable truck apron for use by delivery trucks. **(Photo source: Strand Associates, Inc.)**

4.5.12 Pedestrian and Bicycle Considerations

Every driveway creates a potential for conflicts between motor vehicles, pedestrians, and bicyclists. Driveways are crossed by pedestrians on sidewalks, and bicyclists cross the paths of vehicles entering and leaving driveways. A challenge in driveway design is to identify an appropriate balance between the sometimes conflicting needs of the anticipated user groups. Driveways should be designed so that the driveway is clearly visible to pedestrians (e.g., use of a paving material that contrasts with the sidewalk) and with sufficient sight distance that the sidewalk is visible to drivers of turning vehicles, including trucks. Bicycle lanes should be marked so that they are clearly visible to turning drivers.

4.6 Roadways

4.6.1 Lane Width

The *Green Book* provides substantial flexibility in the selection of lane widths, particularly for urban arterial streets. The *Green Book* permits the use of lane widths from 10 ft to 12 ft. Transportation agencies are increasingly converting existing roadways with 12-ft lanes to 10- or 11-ft lanes to provide space for other desirable roadway features, such as medians, turn lanes, bicycle lanes, and shorter pedestrian crossing distances. However, given widths of large trucks up to 8.5 ft, and up to 10.5 ft including mirrors, wider lanes are preferable on truck routes. It is desirable to provide 12-ft lanes on truck routes or to use differential lane widths with a 12-ft outside or curb lane and narrower center or left lanes.

4.6.2 Pavement Widening on Horizontal Curves

The traveled way may need to be widened at some locations on horizontal curves to fully accommodate trucks. The *Green Book* indicates that widening is needed on certain curves for one of the following reasons: (1) the design vehicle occupies a greater width because the rear wheels generally track inside front wheels (offtracking) in negotiating curves, or (2) drivers experience difficulty in steering their vehicles in the center of the lane. The added width occupied by the vehicle as it traverses the curve as compared with the width of the traveled way on a tangent can be computed by geometry for any combination of radius and wheelbase. The effect of variation in lateral placement of the rear wheels with respect to the front wheels and the resultant difficulty of steering should be accommodated by widening on curves, but the appropriate amount of widening cannot be determined as precisely as that for simple offtracking.

The traveled-way widening values for the assumed design condition for a WB-62 vehicle on a two-lane highway are presented in Table 8. Widening is costly and little is actually gained from a small amount of widening. It is suggested that a minimum widening of 2.0 ft be used and that values less than 2.0 ft in the shaded area of Table 8 can be disregarded. For design vehicles other than the WB-62 truck, an adjustment from Table 9 should be applied. The widening values in Tables 8 and 9 apply to both two-lane undivided highways and to the individual two-lane roadways of a four-lane divided highway. Traveled-way widening, where needed, is best provided in the original construction of a facility, because it is difficult to incorporate in projects on existing roads.

Widening should transition gradually on the approaches to the curve to provide a reasonably smooth alignment of the edge of the traveled way and to fit the paths of vehicles entering or leaving the curve. The principal points of concern in the design of curve widening, which apply to both ends of highway curves, as presented in the *Green Book,* are as follows:

- On simple (unspiraled) curves, widening should be applied on the inside edge of the traveled way only. On curves designed with spirals, widening may be applied on the inside edge or

Table 8. Design values for traveled-way widening on open highway curves for two-lane undivided and four-lane divided highways (AASHTO 2018).

U.S. Customary																					
Radius of Curve (ft)	Traveled-way width = 24 ft							Traveled-way width = 22 ft							Traveled-way width = 20 ft						
	Design speed (mph)							Design speed (mph)							Design speed (mph)						
	30	35	40	45	50	55	60	30	35	40	45	50	55	60	30	35	40	45	50	55	60
7,000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.7	1.7	1.8	1.8	1.9	2.0	2.0
6,500	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.7	1.8	1.8	1.9	2.0	2.0	2.1
6,000	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.7	0.8	0.9	0.9	1.0	1.1	1.1	1.7	1.8	1.9	1.9	2.0	2.1	2.1
5,500	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.8	1.9	1.9	2.0	2.1	2.1	2.2
5,000	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.9	1.9	2.0	2.1	2.1	2.2	2.3
4,500	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.9	2.0	2.1	2.1	2.2	2.3	2.4
4,000	0.0	0.1	0.2	0.2	0.3	0.4	0.5	1.0	1.1	1.2	1.2	1.3	1.4	1.5	2.0	2.1	2.2	2.2	2.3	2.4	2.5
3,500	0.1	0.2	0.3	0.4	0.5	0.5	0.6	1.1	1.2	1.3	1.4	1.5	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.5	2.6
3,000	0.3	0.4	0.4	0.5	0.6	0.7	0.8	1.3	1.4	1.4	1.5	1.6	1.7	1.8	2.3	2.4	2.4	2.5	2.6	2.7	2.8
2,500	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.5	2.6	2.7	2.8	2.9	3.0	3.1
2,000	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.7	2.9	3.0	3.1	3.2	3.3	3.4
1,800	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.9	2.0	2.1	2.3	2.4	2.5	2.6	2.9	3.0	3.1	3.3	3.4	3.5	3.6
1,600	1.1	1.2	1.3	1.5	1.6	1.7	1.8	2.1	2.2	2.3	2.5	2.6	2.7	2.8	3.1	3.2	3.3	3.5	3.6	3.7	3.8
1,400	1.3	1.5	1.6	1.7	1.9	2.0	2.1	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.3	3.5	3.6	3.7	3.9	4.0	4.1
1,200	1.7	1.8	1.9	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	3.9	4.1	4.2	4.4	4.5
1,000	2.1	2.3	2.4	2.6	2.7	2.9	3.0	3.1	3.3	3.4	3.6	3.7	3.9	4.0	4.1	4.3	4.4	4.6	4.7	4.9	5.0
900	2.4	2.6	2.7	2.9	3.1	3.2		3.4	3.6	3.7	3.9	4.1	4.2		4.4	4.6	4.7	4.9	5.1	5.2	
800	2.7	2.9	3.1	3.3	3.5	3.6		3.7	3.9	4.1	4.3	4.5	4.6		4.7	4.9	5.1	5.3	5.5	5.6	
700	3.2	3.4	3.6	3.8	4.0			4.2	4.4	4.6	4.8	5.0			5.2	5.4	5.6	5.8	6.0		
600	3.8	4.0	4.2	4.4	4.6			4.8	5.0	5.2	5.4	5.6			5.8	6.0	6.2	6.4	6.6		
500	4.6	4.9	5.1	5.3				5.6	5.9	6.1	6.3				6.6	6.9	7.1	7.3			
450	5.2	5.4	5.7					6.2	6.4	6.7					7.2	7.4	7.7				
400	5.9	6.1	6.4					6.9	7.1	7.4					7.9	8.1	8.4				
350	6.8	7.0	7.3					7.8	8.0	8.3					8.8	9.0	9.3				
300	7.9	8.2						8.9	9.2						9.9	10.2					
250	9.6							10.6							11.6						
200	12.0							13.0							14.0						

NOTES:
Values shown are for WB-62 design vehicle and represent widening in feet. For other design vehicles, use adjustments in Table 3-25 in the *Green Book*.
Values less than 2.0 ft may be disregarded.
For 3-lane roadways, multiply above values by 1.5.
For 4-lane roadways, multiply above values by 2.

Table 9. Adjustments for traveled-way widening values on open highway curves for two-lane undivided and four-lane divided highways (AASHTO 2018).

U.S. Customary								
Radius of Curve (ft)	Design Vehicle							
	SU-30	SU-40	WB-40	WB-67	WB-67D	WB-92D	WB-100T	WB-109D
7,000	–1.2	–1.2	–1.2	0.1	–0.1	0.1	–0.1	0.2
6,500	–1.3	–1.2	–1.2	0.1	–0.1	0.1	–0.1	0.2
6,000	–1.3	–1.2	–1.2	0.1	–0.1	0.1	–0.1	0.2
5,500	–1.3	–1.3	–1.2	0.1	–0.2	0.1	–0.1	0.2
5,000	–1.3	–1.3	–1.3	0.1	–0.2	0.1	–0.1	0.3
4,500	–1.4	–1.3	–1.3	0.1	–0.2	0.1	–0.1	0.3
4,000	–1.4	–1.4	–1.3	0.1	–0.2	0.1	–0.1	0.3
3,500	–1.5	–1.4	–1.4	0.1	–0.3	0.1	–0.1	0.4
3,000	–1.6	–1.5	–1.4	0.1	–0.3	0.1	–0.1	0.5
2,500	–1.7	–1.6	–1.5	0.2	–0.4	0.2	–0.1	0.5
2,000	–1.8	–1.7	–1.6	0.2	–0.5	0.2	–0.2	0.7
1,800	–1.9	–1.8	–1.7	0.2	–0.5	0.2	–0.2	0.8
1,600	–2.0	–1.9	–1.8	0.2	–0.6	0.3	–0.2	0.8
1,400	–2.2	–2.0	–1.9	0.3	–0.6	0.3	–0.3	1.0
1,200	–2.4	–2.2	–2.1	0.3	–0.8	0.3	–0.3	1.1
1,000	–2.7	–2.4	–2.3	0.4	–0.9	0.4	–0.4	1.4
900	–2.8	–2.6	–2.4	0.4	–1.0	0.5	–0.4	1.5
800	–3.1	–2.8	–2.6	0.5	–1.1	0.5	–0.4	1.7
700	–3.4	–3.0	–2.9	0.6	–1.3	0.6	–0.5	1.9
600	–3.8	–3.4	–3.2	0.7	–1.5	0.7	–0.6	2.3
500	–4.3	–3.8	–3.6	0.8	–1.8	0.8	–0.7	2.7
450	–4.7	–4.2	–3.9	0.9	–2.0	0.9	–0.8	3.0
400	–5.2	–4.6	–4.3	1.0	–2.3	1.0	–0.9	3.4
350	–5.8	–5.1	–4.7	1.1	–2.6	1.2	–1.0	3.9
300	–6.6	–5.8	–5.4	1.3	–3.0	1.4	–1.2	4.6
250	–7.7	–6.7	–6.3	1.6	–3.6	1.7	–1.4	5.5
200	–9.4	–8.2	–7.6	2.0	–4.6	2.1	–1.8	7.0

NOTES:
Adjustments are applied by adding to or subtracting from the values in Table 3-24 in the *Green Book*.
Adjustments depend only on radius and design vehicle; they are independent of roadway width and design speed.
For 3-lane roadways, multiply above values by 1.5.
For 4-lane roadways, multiply above values by 2.0.

divided equally on either side of the centerline. In the latter method, extension of the outer edge tangent avoids a slight reverse curve on the outer edge. In either case, the final marked centerline, and preferably any central longitudinal joint, should be placed midway between the edges of the widened traveled way.

- Curve widening should transition gradually over a length sufficient to make the whole traveled way fully usable. Although a long transition is desirable for traffic operation, it may result in narrow pavement slivers that are difficult and expensive to construct. Preferably, widening should transition over the superelevation runoff length, but shorter lengths are sometimes used. Changes in width normally should be affected over a distance of 100 ft to 200 ft.

4.6.3 Lateral Offset

The *Green Book* and most transportation agency geometric design criteria call for a 1.5-ft area outside the edge of the traveled way or shoulder to be clear of roadside obstacles, such as poles, signs, and other roadside hardware. This 1.5-ft lateral offset provides an allowance for truck and bus mirrors and also provides space for opening the doors of parked vehicles. This lateral offset is important to accommodate trucks on the roadway at all locations, but especially where lanes are narrower than 12 ft or where trucks frequently make right turns. The AASHTO Roadside Design Guide (AASHTO 2011) recommends that the 1.5-ft lateral offset be increased to 3 ft at intersections. Additional lateral offset to roadside safety hardware may be needed at the crossroad ramp terminals within interchanges.

4.6.4 Shoulders

Paved shoulders at least 10 ft wide are desirable on truck routes in rural areas to provide a recovery area for vehicles that leave the roadway and to accommodate large trucks that need to stop because of breakdowns or law enforcement activities. Unpaved shoulders may be provided, if well stabilized, to support the weight of a truck without settlement. Large trucks are allowed to have widths up to 8.5 ft, so a wide truck that stops on a shoulder with a width of 8 ft or less is likely to encroach on the traveled way or an unpaved roadside area not suitable to support the weight of a large truck.

Shoulders are desirable to accommodate trucks on urban roadways with design speeds of 50 mph or higher. However, many urban streets with design speeds of 45 mph or less have curb-and-gutter cross sections, rather than shoulders. This cross section can accommodate trucks, because speeds are lower in urban than in rural areas, and alternative stopping places for trucks are more frequent. Where shoulders are not provided, the provision of a 1.5-ft lateral offset outside the curb that is clear of signs, poles, or other roadside objects is especially important to prevent the mirrors of trucks from striking roadside objects.

The *Green Book* specifies a maximum 8% algebraic difference in cross slope between a shoulder and the adjacent traveled-way pavement surface. This maximum cross-slope break is most critical on superelevated cross sections on the outside edge of a horizontal curve, where the shoulder typically slopes in the opposite direction to the adjacent traveled-way pavement surface. The maximum cross-slope break is particularly important for large trucks, which may lose control when traversing a large change in cross slopes (Torbic et al. 2017).

4.6.5 Horizontal and Vertical Clearance at Structures

The minimum clear width for new bridges on arterials, including truck routes, should be the same as the curb-to-curb width on the approach roadway (AASHTO 2018). New or reconstructed structures on arterials, including truck routes, should provide at least 16 ft of vertical clearance. The *Green Book* allows existing structures with 14-ft vertical clearance to be retained, where permitted by local statute, although such reduced clearances are undesirable on truck routes.

4.6.6 Turnouts for Law Enforcement Activities

Where paved shoulders wider than 8.5 ft are not provided on truck routes, it may be desirable for transportation agencies to provide paved turnouts, at intervals, so that trucks can stop outside the traveled way for law enforcement activities.

4.7 Intersection Sight Distance

Chapter 9 of the *Green Book* presents design criteria for intersection sight distance (ISD). Seven cases for ISD design are addressed in the *Green Book* based on the type of traffic control present:

- Case A—Intersections with no control.
- Case B—Intersections with Stop-control on the minor road.
- Case C—Intersections with yield control on the minor road.
- Case D—Intersections with traffic-signal control.
- Case E—Intersections with all-way Stop-control.
- Case F—Left turns from the major road.
- Case G—Roundabouts.

Since trucks accelerate from a stop more slowly than passenger cars, the models for three of the seven cases (Cases B, C, and F) include alternative parameter values suitable for accommodating trucks. Sight distances for these three cases are based on a gap-acceptance model, and the value for the accepted gap is increased by 2 s above the passenger-car value for single-unit trucks and 4 s above the passenger-car value for combination trucks.

4.8 Highway-Railroad Grade Crossings

Trucks are an important consideration in the design of highway-railroad grade crossings on truck routes. Geometric design policies for highway-railroad grade crossings are established in the *Green Book*. The geometric design criteria in the *Green Book* that can incorporate truck considerations include the following:

- Sight distance for motor vehicles stopped at a grade crossing. Accommodation of trucks is addressed in Case B in *Green Book* Section 9.12.4, which addresses the sight distance needed for a 73.5-ft truck to cross a single set of tracks from a stopped position.
- Distance between grade crossing and adjacent intersections. This distance should be long enough to accommodate a truck or so short that truck drivers will pass through both the grade crossing and the intersection without stopping.
- Vertical profile of crossing. Trucks, even those with low ground clearance, should be able to pass through the crossing without contacting the roadway surface.

4.9 Sidewalks

Curb-attached sidewalks are undesirable on truck routes where the traveled way is immediately adjacent to the curb. Based on *Green Book* criteria, separation of at least 2 ft between the traveled way and sidewalk is desirable for sidewalks. This criterion appears appropriate for sidewalks along truck routes, just as it is for any roadway without shoulders.

4.10 Bicycle Facilities

In the multimodal planning process, it may be desirable, where practical, to locate truck routes and bicycle facilities on different roads or streets within a corridor. Where bicycle facilities are provided along a truck route, the bicycle facilities should be designed to minimize conflicts between bicycles and trucks or other vehicles. This may be accomplished by the following:

- Providing an off-road bicycle path or shared-use path.
- Providing a buffer to separate on-road bicycle lanes from adjacent travel lanes to accommodate greater separation between bicycles and trucks.
- Providing wider lanes, especially wider curb lanes, to accommodate greater separation between bicycles and trucks.

Where buffered bicycle lanes are provided, a minimum buffer width of 1.5 ft to 2.0 ft is appropriate (Torbic et al. 2014), but buffer widths of 3 ft are increasingly being used even along roadways that are not truck routes. Where neither on-road nor roadside bicycle facilities are provided, bicyclists can ride on paved shoulders to keep away from motor vehicle traffic.

It is undesirable to place a bicycle lane on a route where frequent pickup and delivery operations occur, because the presence of parked vehicles in a bicycle lane would create a challenge for bicyclists.

4.11 Work Zones

Work zones on truck routes should be designed to accommodate the appropriate truck design vehicle, selected based on the vehicle mix expected to travel through the work zone. Where turning trucks are expected to be present in work zones, CADD software should be used to verify that the turning path of the truck can be accommodated within the work zone. Lane widths equivalent to those on the upstream roadway should be used in work zones. Where lane width restrictions are present in a work zone, signs indicating the lane width restrictions in the work zone should be placed far enough upstream of the work zone to allow the truck driver the opportunity to seek alternate routes if needed. Lane widening on horizontal curves within the work zone should be provided where needed (see Section 4.6.2).

Some construction projects may temporarily close a road to allow the work to be completed more quickly than if traffic were maintained through the work zone. In other cases, perhaps because of vertical clearance restrictions, a decision may be made to prohibit trucks through a work zone, while keeping the work zone open to other traffic. In such cases, a suitable detour route that can accommodate the appropriate design vehicle should be established and signed. Some agencies have reported problems near road closures in which truck drivers chose to use roadways not designed for trucks or where trucks are prohibited. Enforcement in the vicinity of detours may be needed to make sure trucks are following the signed detour route.

CHAPTER 5

Balancing Truck Considerations with Other Modes

The *Green Book* indicates that the design of every roadway project should consider the needs of all travel modes: automobiles, bicycles, pedestrians, transit, and trucks (AASHTO 2018). This does not necessarily mean that facilities for every mode are provided as part of every project, but rather that the appropriate balance among the needs of each mode be sought for every project. The appropriate balance will vary between corridors and projects, and corridor-specific and project-specific priorities should be assigned.

This Guide has dealt extensively with automobile and truck considerations, and has discussed truck considerations with respect to pedestrians, bicyclists, and transit where appropriate. This chapter summarizes the key issues in balancing truck considerations with the needs of pedestrians, bicyclists, and transit.

5.1 Pedestrian Considerations

An appropriate balance between the needs of trucks and pedestrians should be sought for every project where both trucks and pedestrians are present. Rural projects on truck routes often serve corridors where pedestrian travel is minimal, and there may be substantial flexibility to design roadways and intersections to accommodate trucks. Even where design for trucks generally has priority, specific consideration should be given to school zones and school bus stops where students should be provided with a safe route between the school, the bus stop, and their homes. This may include consideration of advisory speed signing, bus stop signing, and marked crosswalks where appropriate.

At the other extreme, the needs of pedestrians should generally be assigned priority over trucks in the design of collector and local streets, particularly in urban areas. Pedestrian volumes are often medium to high, indicating a need for sidewalks and crosswalks designed with limited crossing distances. Truck volumes are typically low on urban collector and local streets and, even where they are not, trucks generally need to travel only short distances to reach an arterial street where design for trucks may be assigned a higher priority.

The greatest challenges in balancing the needs of trucks and pedestrians occur on urban arterials and on extensions of rural highways through small towns. In these areas, the demands for both truck and pedestrian travel are likely to be high, and there are definite tradeoffs in design for trucks and pedestrians that need to be addressed. The most satisfactory solutions can be achieved where truck and pedestrian movements can be separated in space, so that they do not conflict. Less satisfactory, but still desirable, solutions can be achieved where truck and pedestrian movements can be separated in time, as with the use of exclusive pedestrian phases at signalized intersections. Where truck and pedestrian movements cannot be separated in space or time, design decisions should be made on a case-by-case basis considering truck and pedestrian demand volumes and consistency within corridors.

A key to achieving the appropriate balance between the infrastructure and operational needs of trucks and pedestrians is appropriate corridor planning identifying particular corridors as priorities for truck movements and other corridors as priorities for pedestrian movements (see Section 3.1 on Planning). Most corridors will always serve a mix of truck and pedestrian demand volumes, but good planning can identify which mode should be assigned priority in design and operations of particular corridors.

Key design considerations for truck routes and other corridors where both truck and pedestrian movements are present include the following:

- Provide sidewalks on both sides of the road to facilitate pedestrian movements along the corridor separated from the traveled way that serves truck as well as other motor vehicle movements.
- Provide marked crosswalks as extensions of the sidewalk at intersections.
- Establish truck routes that avoid existing or anticipated high-volume pedestrian corridors where possible, keeping in mind that limited amounts of out-of-direction travel are more tolerable to motor vehicle drivers than to pedestrians.
- Provide medians on multilane roadways to create an opportunity for two-stage pedestrian crossing maneuvers that minimize pedestrian crossing distances.
- Provide short curb return radii for right turns that minimize pedestrian crossing distances except where truck right-turn volumes are substantial.
- Route truck and pedestrian movements on different paths through major intersections where feasible. Figure 52 illustrates how crosswalks can create a pedestrian path through an at-grade intersection that minimizes conflict with a high truck movement.
- Provide channelized right-turn roadways for high-volume right-turn movements by trucks. This design provides a large curb return radius to facilitate right turns by trucks. Pedestrians cross the right-turn roadway and the main roadway in separate movements, which should minimize pedestrian crossing distances. The major disadvantage of this design is for pedestrians with vision disabilities who may have difficulty determining the correct path for crossing the channelized right-turn roadway.

For additional guidance on roadway and intersection design to accommodate pedestrians, see the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities (AASHTO 2004).

5.2 Bicycle Considerations

Similar to the previous discussion of pedestrians, an appropriate balance between the needs of trucks and bicyclists should be sought for every project where both trucks and bicyclists are present. Bicycle travel on rural truck routes may be minimal, and there may be substantial flexibility to design roadways and intersections to accommodate trucks. However, in urban areas, the needs of bicyclists should be given higher priority over trucks in the design of collector and local streets. Truck volumes are typically low on urban collector and local streets and, even where they are not, trucks generally need to travel only short distances to reach an arterial street where design for trucks may be assigned a higher priority.

Where bicycle facilities are provided along a truck route, the bicycle facilities should be designed to minimize conflicts between bicycles and trucks or other vehicles. This may be accomplished by the following:

- Providing an off-road bicycle path or shared-use path.
- Providing a buffer to separate on-road bicycle lanes from adjacent travel lanes to accommodate greater separation between bicycles and trucks.

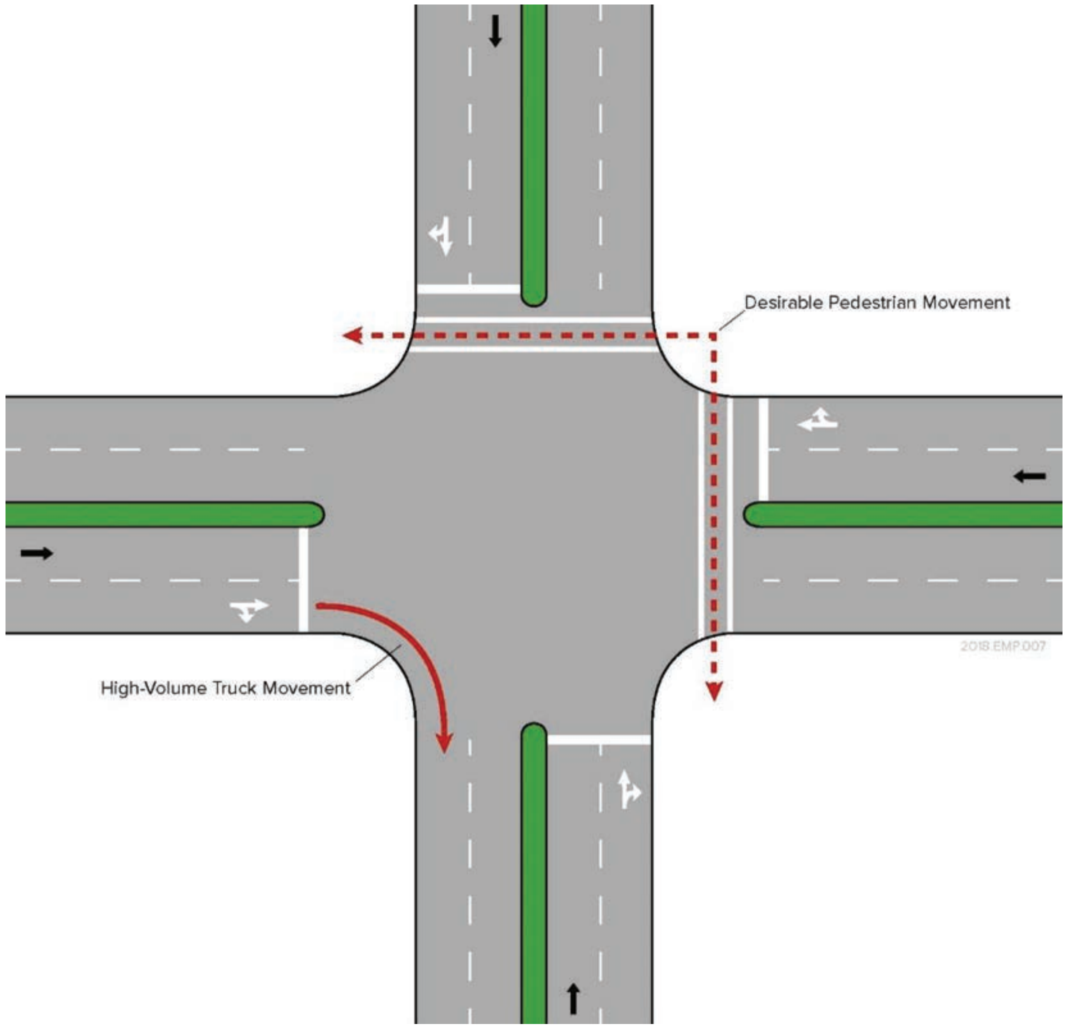


Figure 52. Separation of truck and pedestrian movements through an intersection.

- Providing wider lanes, especially wider curb lanes, to accommodate greater separation between bicycles and trucks.

The greatest challenges in balancing the needs of trucks and bicyclists occur on urban arterials and on extensions of rural highways through small towns. In these areas, there are definite tradeoffs in design for trucks and bicyclists that need to be addressed. Where bicycle volumes are medium to high, an on-road bike lane is one of several types of bicycle facilities that may be appropriate (see previous list). While this solution is desirable in that it physically separates truck and bicycle movements, coordination is needed between the transportation agency, trucking companies, and businesses so that the bike lane is strategically placed in a location that minimizes conflict with trucks parking for deliveries. In some cases, such as one-way streets, this may be as straightforward as locating the bike lane on the other side of the street. Where truck and bicycle movements cannot be separated in space or time, design decisions should be made on a case-by-case basis considering truck and bicycle demand volumes and consistency within corridors.

A key to achieving the appropriate balance between trucks and bicyclists is appropriate corridor planning identifying particular corridors as priorities for truck movements and other corridors as priorities for bicycle movements (see Section 3.1 on Planning). Some corridors will always serve a mix of truck and bicycle demand volumes, but good planning can identify which mode should be assigned priority in design and operations of particular corridors.

Key design considerations for truck routes and other corridors where both truck and bicycle movements are present include the following:

- When locating bicycle routes, avoid industrial areas (e.g., UPS entrances).
- Establish truck routes that avoid high-volume bicycle corridors where possible, keeping in mind that limited amounts of out-of-direction travel are more tolerable to motor vehicle drivers than to bicyclists.
- Place bike lanes in locations with minimal truck parking for deliveries.
- Place bike lanes away from wide driveways to reduce bicyclist exposure to motor vehicles entering or exiting.
- Improve shoulders where bicyclists are prevalent or where the corridor has destinations likely to be accessed by bicyclists.

For additional guidance on roadway and intersection design to accommodate bicyclists, see the AASHTO Guide for the Development of Bicycle Facilities (AASHTO 2012).

5.3 Transit Considerations

Where transit is present on a truck route, planning for bus stops and transit station locations should take into account adjacent truck access points on the truck route. For light rail transit stations placed in the median of a truck facility, stations should be placed out of the path of turning trucks to prohibit trucks from turning onto the facility at that access point, and an alternative route should be provided to an access point at which the turning path of the truck can be accommodated.

Truck routes that also serve as transit routes, including buses or light rail, inherently must accommodate pedestrians. Care should be taken, especially in industrial areas where workers use public transportation, to design truck facilities that can also accommodate pedestrians accessing adjacent areas and developments. It is recommended to separate trucks and pedestrians in space or in time as much as possible to minimize conflicts between pedestrians and trucks (see Section 5.1).

Case Study: Positioning Light Rail Stations to Avoid Conflicts with Turning Trucks

An MPO noted that truck movements were one key consideration in choosing station locations for a recent light rail project. Stations were purposely located away from intersections of the light rail tracks with truck routes to avoid truck-pedestrian conflicts.

(Photo source: Google Earth.)

Acronyms

AMAG	Access Management Application Guidelines
AMM	Access Management Manual
C-D	Collector-Distributor
CADD	Computer-Aided Design and Drafting
Caltrans	California Department of Transportation
CFI	Continuous Flow Intersection
CFR	Code of Federal Regulations
CRFC	Critical Rural Freight Corridor
CTR	Centerline Turning Radius
CUFC	Critical Urban Freight Corridor
DDI	Diverging Diamond Interchange
DOTD	Department of Transportation and Development (Louisiana)
EDL	Electronic Data Logger
FAP	Federal-Aid Primary System
FAST	Fixing America's Surface Transportation Act of 2015
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
HSM	Highway Safety Manual
ITE	Institute of Transportation Engineers
ISD	Intersection Sight Distance
KPRA	Kingpin-to-Rear-Axle Distance
LCV	Longer Combination Vehicle
MDOT	Michigan Department of Transportation
MPO	Metropolitan Planning Organization
MUT	Median U-Turn Intersection
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*
NHFN	National Highway Freight Network
NHS	National Highway System
NN	National Network
OSOW	Oversize/Overweight
PANYNJ	Port Authority of New York and New Jersey
PHFS	Primary Highway Freight System
RCUT	Restricted Crossing U-Turn Intersection
RPO	Regional Planning Organization
SPDI	Single-Point Diamond Interchange

SPUI	Single-Point Urban Interchange (obsolete term for an SPDI)
STAA	Surface Transportation Assistance Act of 1982
STRAHNET	Strategic Highway Network
SU	Single-Unit Truck
UPS	United Parcel Service
USC	United States Code
WB	Wheel Base

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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ISBN 978-0-309-48179-3
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