CHAPTER 2
HIGHWAY DESIGN STANDARDS

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2-1.0 GENERAL

The classification of multi-modal highways into different operational systems, functional classes, or geometric types is necessary for communication between engineers, administrators, and the public. Different schemes exist for urban and rural regions.

Many factors are incorporated into the design criteria that highway engineers use. These factors are based on the physical characteristics of vehicles and topography, the psychological characteristics of drivers, the safety and operating characteristics of the traffic stream, the desire to provide a level of service acceptable to the traveling public, the desire to integrate community and environmental values, the natural and cultural characteristics of setting and context, and the fiscal resources of the highway agency.

2-1.01 Design Flexibility

The designer must understand the principles and essence of design flexibility with regard to project development. The need for design flexibility has become increasingly apparent since the initiation of the interstate highway program. The effects that the expanded highway network have had on ecological systems, individual communities, and general society, have prompted recognition of the need for carefully considered and broadly informed measures to address transportation needs. MnDOT's obligation to reflect societal values in its work necessitates a flexible approach to road design that supports balance among safety, mobility, economy, design consistency, community, environmental concerns, and aesthetics.

MnDOT's vision is to develop "A coordinated transportation network that meets the needs of Minnesota's citizens and business for safe, timely, and predictable travel." The policy to use a context-sensitive approach that integrates design standards and criteria, safety concerns, cost considerations, environmental stewardship, and aesthetics with community-sensitive planning and design to create excellence in project development, supports this vision. This approach relies upon collaborative and interdisciplinary processes that involve stakeholders and public interests early and continuously in project development. Identification and resolution of important concerns early in project development often eliminate costly rework cycles later on when design options are reflective of and constrained by earlier decisions.

The six key principles of successful project development have been identified as follows:

1. Balance safety, mobility, community, and environmental goals in all projects.
2. Involve the public and affected agencies early and continuously.
3. Address all modes of travel.
4. Use an interdisciplinary team tailored to project needs.
5. Apply flexibility inherent in design standards.
6. Incorporate aesthetics as an integral part of good design.

The Foreword of the American Association of State Highway and Transportation Officials' (AASHTO) 2004 "A Policy on Geometric Design of Highways and Streets" (the Green Book) states:

> "As highway designers, highway engineers strive to provide for the needs of highway users while maintaining the integrity of the environment. Unique combinations of design requirements that are often conflicting result in unique solutions to the design problems…Sufficient flexibility is permitted to encourage independent designs tailored to particular situations."

Consistent with AASHTO guidance, including their May 2004 "A Guide for Achieving Flexibility in Highway Design," and the Federal Highway Administration's (FHWA) 1997 "Flexibility in Highway Design," the design guidance in this manual provides substantial flexibility and encourages designers to carefully consider the advantages of the options provided herein.

2-2.0 HIGHWAY SYSTEMS

2-2.01 Jurisdictional Systems

Each highway network has been classified according to the agency that has responsibility for its improvement, maintenance, and traffic regulation enforcement. The jurisdictional divisions are listed below:

1. **Trunk Highway System**
   The Trunk Highway System consists of all highways, including the interstate routes, under the jurisdiction of the State of Minnesota. These routes generally have statewide importance, are the most heavily traveled roads, carry the greatest traffic volumes, and operate at the highest speeds.
2. **County Highway System**
   The County Highway System is made up of those roads established and designated under the authority of a county board. They generally are the more important routes within a county that are not part of the Trunk Highway System.
3. **Township Road System**
   The Township Road System is made up of the roads established under the authority of a town board. They may also be reverted to township jurisdiction by the county board. They are generally of local importance.
4. **Municipal City Street System**
   The Municipal City Street System consists of all roads within a municipality not otherwise designated as a trunk highway or county road. They are generally of local importance.

2-2.02 State Aid Systems

The State of Minnesota has made state funds available to county and urban municipal governments to improve their systems. The MnDOT State Aid Manual describes the legal, administrative, and technical information needed to properly use these funds on the approved State Aid system. The two State Aid systems are:

1. County State Aid Highways (CSAH).
2. Municipal State Aid Streets (MSAS).

The CSAH system is under county jurisdiction. The size of this system is about 50,000 km **(31,000 mi)**. The system includes all routes that carry relatively heavy traffic volumes or are classified as arterial or collector routes. They must also connect towns, communities, shipping points, and markets within a county or between adjacent counties.

The MSAS system is established by a municipality that has a population of 5,000 or more. The size of this system is about 5,000 km **(3,100 mi)**. The system cannot exceed 20 percent of the total mileage within urban boundaries, excluding trunk highway turnback mileage. These streets must connect points of major traffic interest and be part of the integrated street system consistent with traffic demand.

2-3.0 DESIGN CONTROLS

2-3.01 Drivers

The designer must accommodate the physical and psychological characteristics of vehicle operators. Even where the highway design cannot reasonably prevent errors due to adverse physiological effects from alcohol, drugs, or fatigue, the highway should be as forgiving as possible. The following list contains certain principles and driver traits that should be incorporated into highway design:

1. Drivers are limited in the amount and complexity of highway information they can receive and use in a given time. Furthermore, they vary widely in their operating skills, experience, and mental and physical condition. They must process information related to lane placement, speed, traffic control devices, highway alignment, roadside conflicts, and weather. If the total effect of information received reaches a certain threshold, driver error can result and may lead to a crash. This threshold will vary depending on a particular driver's reaction time and current physiological state.
2. Certain driving components are more important to performance than others. When these components are listed in order of task, complexity, and importance to safety, they are:
    a. Control: activities related to the physical control of the vehicle through the steering wheel, brake, and accelerator;
    b. Guidance: activities related to selecting a safe speed and vehicle path on the highway, including receiving information and making a decision that translates into a control action. Design and traffic operations have the greatest effect on guidance, however, be aware of the relative importance of all other guidance-related activities, and ensure that the most important highway information is properly conveyed to the driver. Low-priority information may need to be removed or relocated if it is likely to interfere with higher priority information; and
    c. Navigation: activities related to planning and executing a trip from origin to destination.
3. Drivers are conditioned through experience and training to expect and anticipate what lies ahead on the highway. If this expectation is violated, it will increase the time a driver needs to assess the situation and make the correct decision. Avoid these violations, but where they are unavoidable allow increased warning time.
4. Speed must be factored into accommodating the driver. Because high speeds reduce the visual field, restrict peripheral vision, and increase stopping time, they require longer reaction times than low speeds.
5. Older drivers need special consideration in design. For example, recent studies have shown that designing turn lanes that provide more direct sight lines greatly improve the ability of older drivers to execute turning movements. The FHWA publication, "Older Driver Highway Design Handbook," provides more information on how to meet the needs of older drivers.

2-3.02 Vehicles

Motorized and non-motorized highway vehicles have certain physical characteristics that must be considered in design. These characteristics vary by vehicle type. Table 2-3.02A presents basic information on the dimensions of three design vehicles: passenger cars (P), city transit buses (BUS), and trucks (SU or WB). Recreational vehicle (RV) design information is not included in this manual. If vehicle information for RVs is required, the designer should refer to AASHTO's "A Policy on Geometric Design of Highways and Streets." When considering a highway facility or intersection, the designer should use the largest design vehicle likely to frequent that facility to determine the design values. Typically, the WB-19 **(WB-62)** is used to design highway facilities and intersections; however, the designer may encounter locations and situations where the use of a smaller design vehicle should be considered. County State Aid Highways (CSAH), County Roads (CR), and local roadways are examples of such locations. Designers should consult the responsible agency when impacting their facilities.

The vehicle characteristics incorporated into design values are discussed below:

1. Vehicles are limited by how sharply they can negotiate turns. Figures 2-3.02A through D illustrate the turning paths of four design vehicles that are attainable at speeds of 16 km/h (**10 mph**) or less. Turning paths for other design vehicles can be found in the most current version of AASHTO's "A Policy on Geometric Design of Highways and Streets." The minimum turning paths lead directly to the required curb radii at intersections, which are discussed in detail in Chapter 5.
2. The design of traffic barriers and other safety appurtenances is directly related to many vehicle features including weight, height, bumper height, and suspension systems. It is difficult, if not impossible, to design barriers that will properly accommodate the entire range of vehicles within all performance measurements. Besides safety appurtenances, the crash characteristics of vehicles are reflected in the design of all highway roadside elements.
3. Vehicle noise and air pollution rates vary with different traffic operating conditions. Smoother and more efficient traffic flow reduce the amount of pollution. Vehicle speed will also influence noise and air pollution.
4. Acceleration and deceleration rates of vehicles are often critical in determining highway design. These rates usually govern the dimensions of intersections, freeway ramps**,** and climbing or passing lanes. Trucks are usually the critical vehicles for these designs. See Chapter 3 for typical heavy truck deceleration and acceleration values. Recreational vehicles may be considered in recreational areas.

Table 2-3.02A (Dual Units)

DESIGN VEHICLE DIMENSIONS

Metric

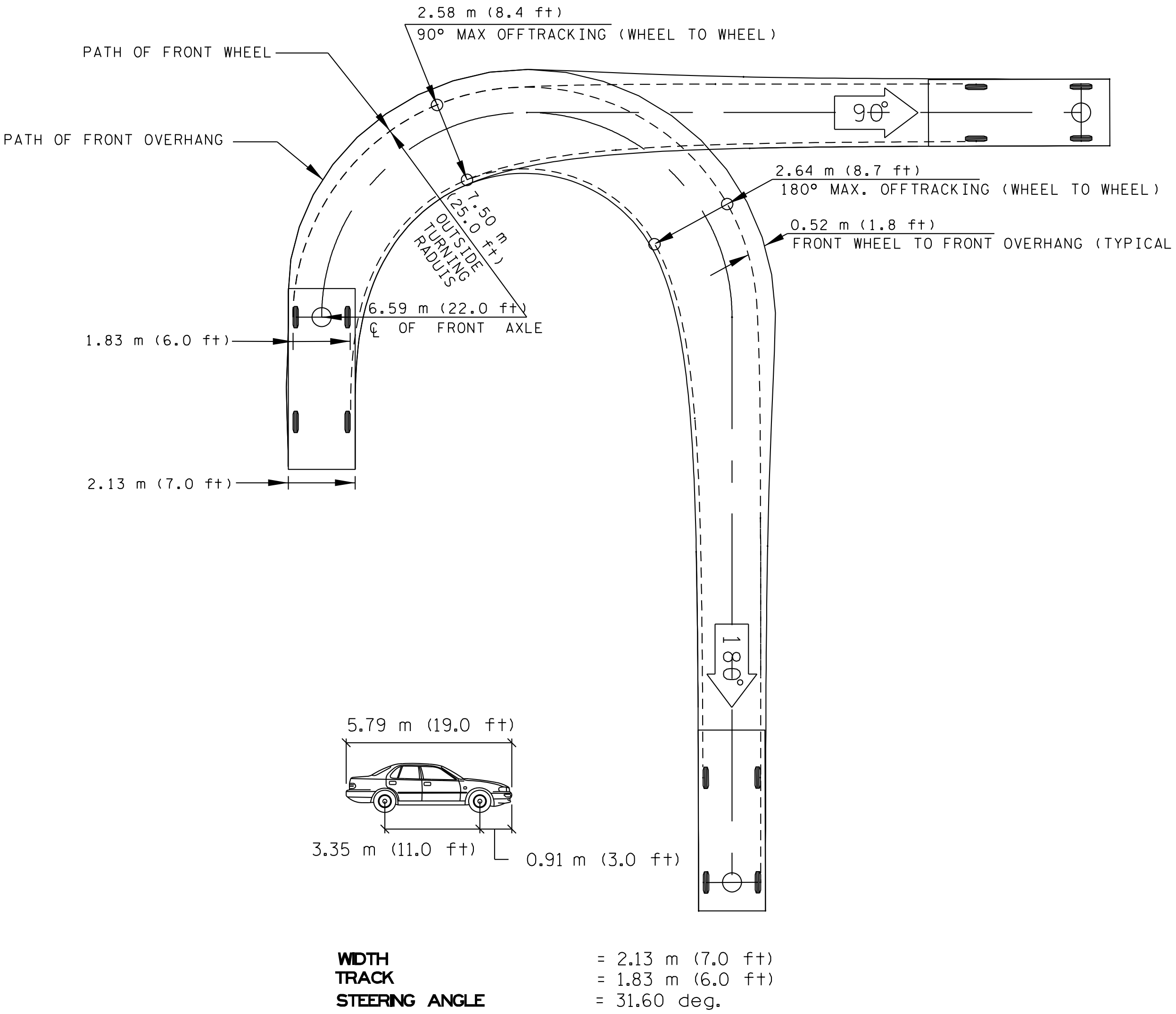
Design Vehicle Type	**Symbol**	**Wheelbase (m)**	**Dimensions (m)**			
			Overhang		**Total**	
			Front	**Rear**	**Length**	**Width**
Passenger Car	P	3.35	0.91	1.52	5.78	2.13
Single-Unit Truck	SU	6.10	1.22	1.83	9.15	2.44
City Transit Bus	BUS	7.62	2.13	2.44	12.19	2.59
Interstate Semitrailer[a]	WB-19	6.6 + 12.3 = 18.9	1.22	0.76[b]	20.88	2.59

English

Design Vehicle Type	**Symbol**	**Wheelbase (ft)**	**Dimensions (ft)**			
			Overhang		**Total**	
			Front	**Rear**	**Length**	**Width**
Passenger Car	P	11.0	3.0	5.0	19.0	7.0
Single-Unit Truck	SU	20.0	4.0	6.0	30.0	8.0
City Transit Bus	BUS	25.0	7.0	8.0	40.0	8.5
Interstate Semitrailer[a]	WB-62	21.6 + 40.4 = 62.0	4.0	2.5[b]	68.5	8.5

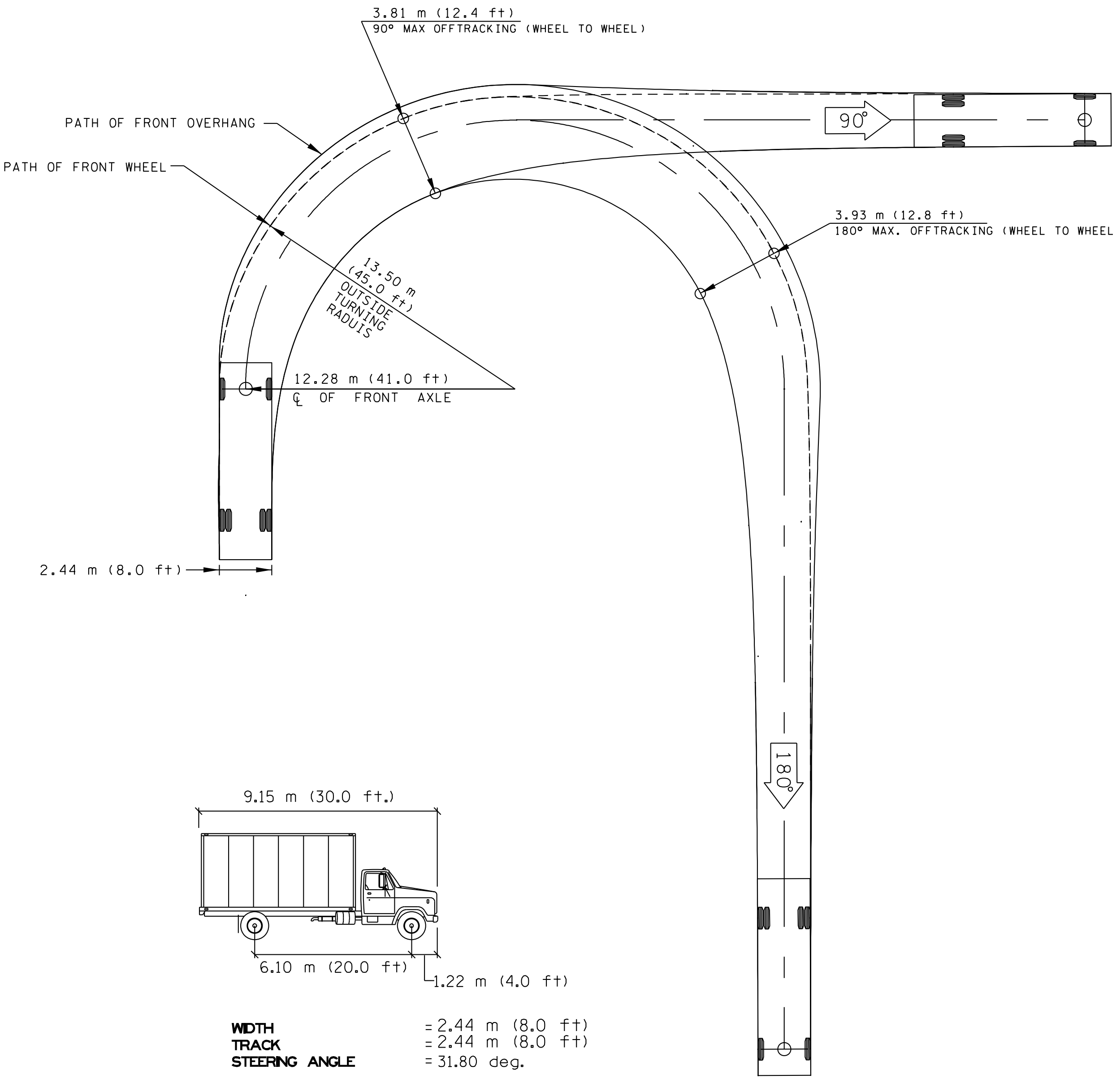
[a] Design vehicle with 14.63 m **(48.0 ft)** trailer as adopted in the 1982 Surface Transportation Assistance Act (STAA).

[b] This is overhang from the back axle of the tandem axle assembly.



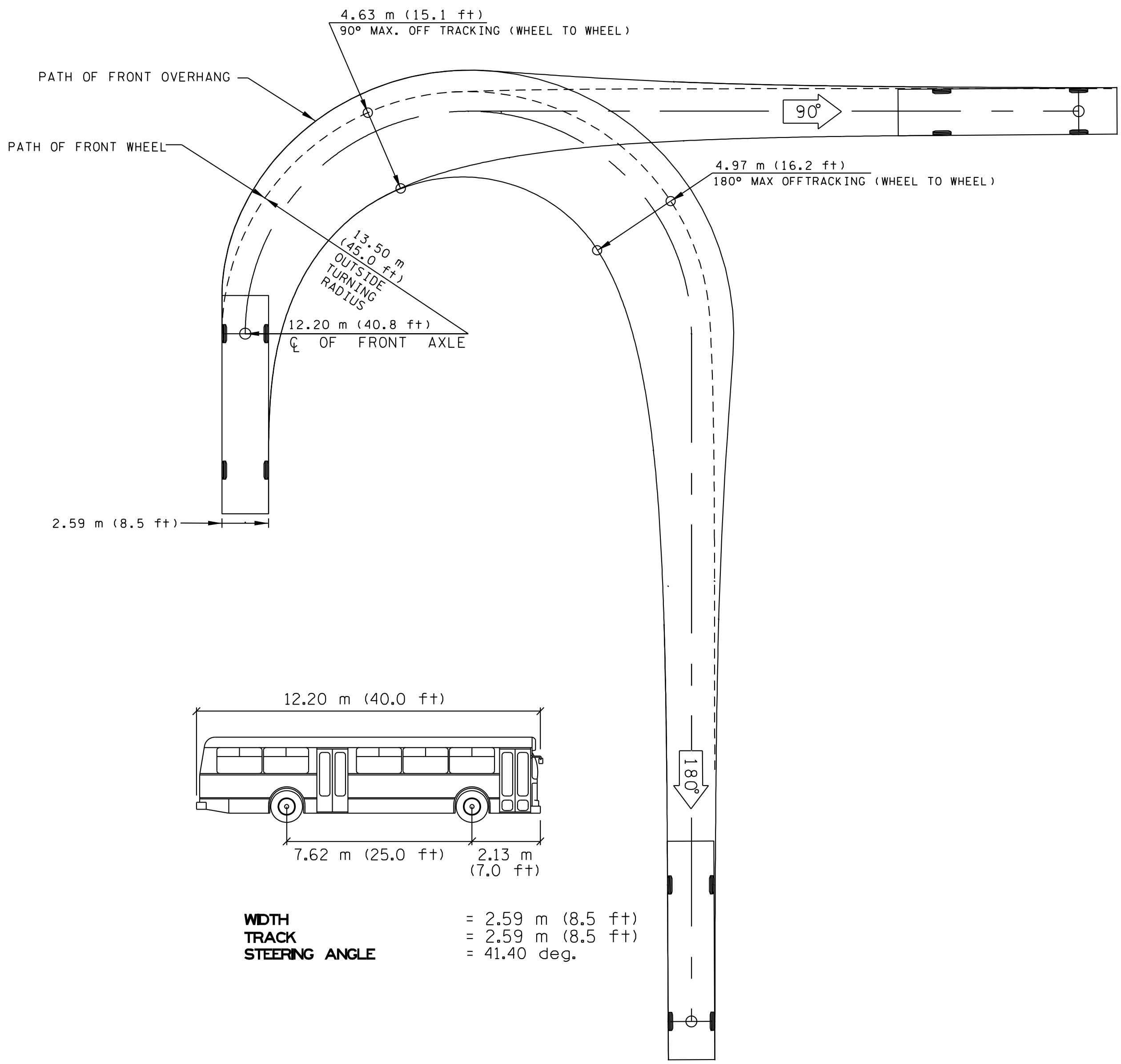
Note: Metric and English dimensions are based on hard converted outside turning radius design values and are therefore not exactly numerically equivalent.

MINIMUM TURNING PATH OF PASSENGER CAR (P)
Figure 2-3.02A (Dual Units)



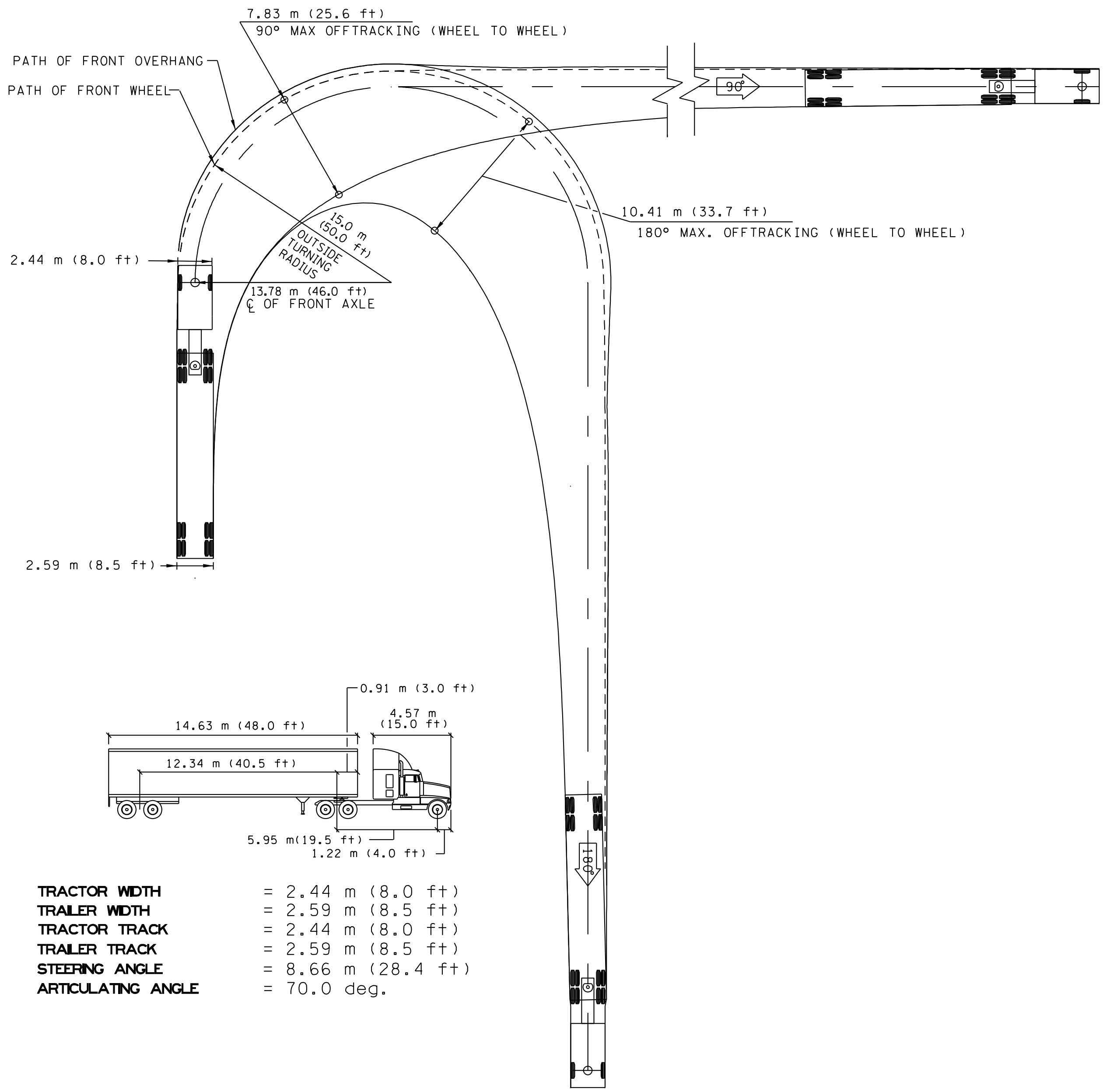
Note: Metric and English dimensions are based on hard converted outside turning radius design values and are therefore not exactly numerically equivalent.

MINIMUM TURNING PATH OF SINGLE-UNIT (SU)
Figure 2-3.02B (Dual Units)



Note: Metric and English dimensions are based on hard converted outside turning radius design values and are therefore not exactly numerically equivalent.

MINIMUM TURNING PATH OF
CITY BUS (BUS)
Figure 2-3.02C (Dual Units)



Note: Metric and English dimensions are based on hard converted outside turning radius design values and are therefore not exactly numerically equivalent.

MINIMUM TURNING PATH OF
INTERSTATE SEMITRAILER (WB-19 (WB-62))
Figure 2-3.02D (Dual Units)

2-3.03 Pedestrian and Bicycle Traffic

Pedestrian and bicycle traffic should be addressed as modes of transportation in the early stages of project development. Designers should include pedestrian accommodations in the total design process by considering factors such as typical pedestrian walking distance and speed, vehicle startup time, traffic signal timing, and the intersection sight distance. Roadway functional class and land use are useful tools when determining the appropriate type of sidewalks and paths. For more discussion, see Chapter 11.

The type and volume of bicycle (non-motorized vehicle) traffic along the roadside affects the roadway and corridor design. Wide parallel shoulders, designated bike lanes, wide curb lanes, shared streets, and multi-use paths are ways to accommodate bicyclists safely. Chapter 11 of this manual and the MnDOT Bikeway Facility Design Manual address the planning and design issues associated with bicycle traffic.

2-3.04 Mass Transit

Bus travel is an important mode of mass transportation. Facilities to accommodate buses should be considered in design. For more discussion, see Chapter 4.

High Occupancy Vehicle (HOV) travel is becoming more common in large cities. Combining HOV facilities with freeways may optimize transportation services. See Chapter 6 for more discussion.

Rail transit may be incorporated into the freeway or highway right of way and the separate right of way of larger metropolitan areas to optimize transportation service, provide multi-modal options, and help reduce system congestion. See Chapter 11 for further discussion.

2-3.05 Safety

Congress has identified highway safety as a priority for many years. The procedures in this manual incorporate many highway safety considerations into the various design and operational practices.

2-3.06 Access Management

Access management is the planning, design, and implementation of land use and transportation strategies that control the flow of traffic between the road and adjacent land uses. The proper location and design of public street and private driveway connections to the highway can greatly enhance the safety and mobility of the traveling public, preserve capacity, and extend the useful life of the facility. Where access to a highway is managed, entrances and exits are located at points best suited to fit the traffic and land-use needs. The goal is to allow vehicles to enter and leave safely with minimum interference to through traffic, preserving service and reducing the potential for crashes.

Figures 2-3.06A to 2-3.06H detail typical access control for at-grade intersections and interchanges.

Access management involves three related activities: Access Management System Planning, Access Control, and Access Regulation.

2-3.06.01 Access Management System Planning

Access Management System Planning views the highway and its surrounding elements as part of a single system. Individual parts of the system include the land uses and their circulation systems as well as access to and circulation among the land uses provided by the system of local streets and highways. Careful coordination of the planning and design of each land use in relation to the supporting road network is critical to preserve the capacity of the overall system and to allow efficient access to and from the surrounding elements.

To provide a framework for system planning, MnDOT has adopted a Highway Access Category System and Spacing Guidelines. Every highway segment is assigned to an Access Category based on its functional classification, strategic importance in the statewide transportation system, and the existing and planned land use of the surrounding area. The recommended spacing and allowance of public street intersections and private access varies by category, with the most restrictive access recommended for the higher order roadways. The designer or District Traffic Engineer should consult these guidelines during the planning and design of new roads and the retrofitting of existing roads and accesses.

2-3.06.02 Access Control

Access Control is the condition where the right of access of abutting properties is fully or partially acquired by a public authority, usually at the time of purchase of right of way. Full control of access gives priority to through traffic by providing access only at grade-separated interchanges with selected public roads. At-grade crossing and private driveway connections are not allowed. These facilities are typically called “freeways.” The highly restricted access to freeways has made them the most efficient motor vehicle traffic movers and safest highway systems in the nation. At interchanges, access should also be managed along the intersecting cross street to ensure safe movement to and from the freeway ramps. The appropriate access management plan for cross streets at interchanges will depend on the function of the cross street, projected traffic volumes and turning movements, and the character of the existing and planned surrounding land use. As such, the access management plan should be coordinated with the local land use and road authorities.

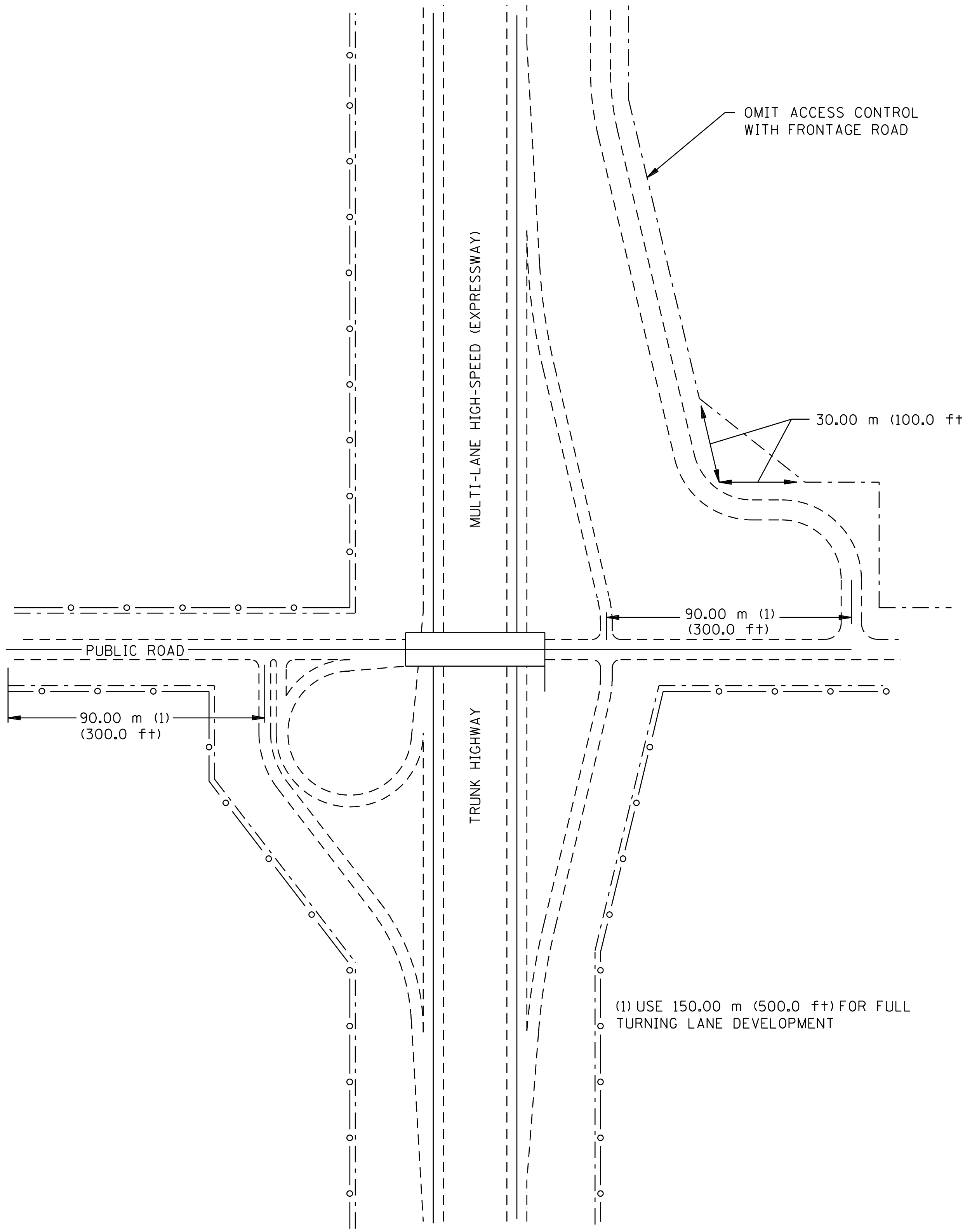
Partial control of access also gives priority to through traffic but maintains some at-grade intersections and private access connections. Partial control of access may be provided for certain major urban and rural arterials.

2-3.06.03 Access Regulation

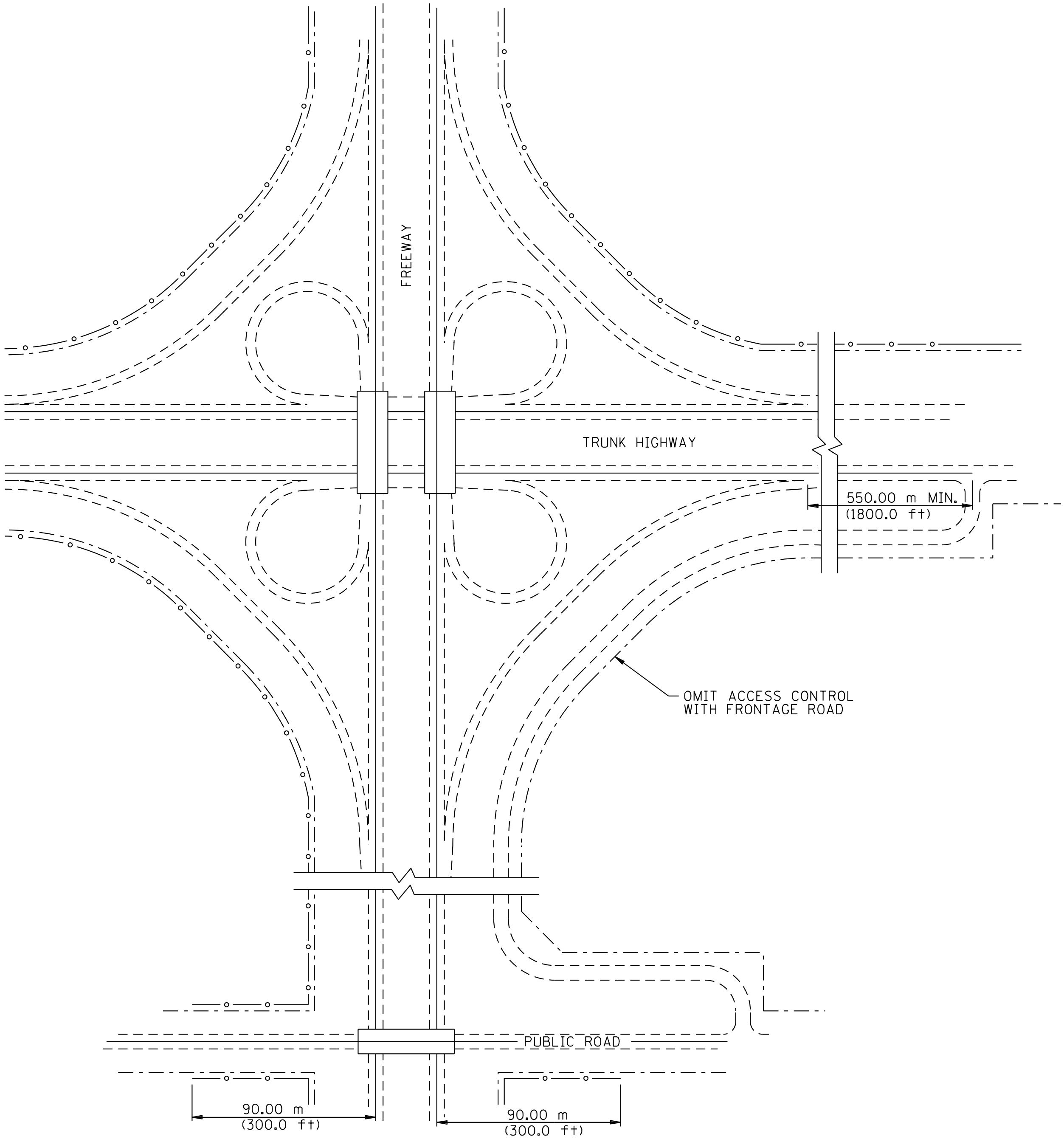
Access may also be managed through the police power of the road authority to regulate access by either geometric design or access permit. Geometric design features such as medians, turn lanes, and turning restrictions regulate the direction and flow of traffic within the right of way. Access to the highway from private property or the local street network is regulated by permit. The location and design of access to an individual property may be restricted to the extent that reasonably convenient and suitable access is provided. Individual property access may be required to obtain access to the adjacent highway by means of the available local supporting street network or frontage road, rather than by direct driveway connection.

Local governments exercising statutory land use planning authority may also regulate access through the provisions of their zoning and/or subdivision ordinance. Local governments are required by statute to provide MnDOT the opportunity to review and comment on all preliminary plats of land abutting trunk highways. MnDOT Districts also encourage local governments to submit other development proposals affecting the trunk highway for review and comment. Local governments may incorporate MnDOT’s comments and recommendations as conditions of zoning or subdivision/plat approval.

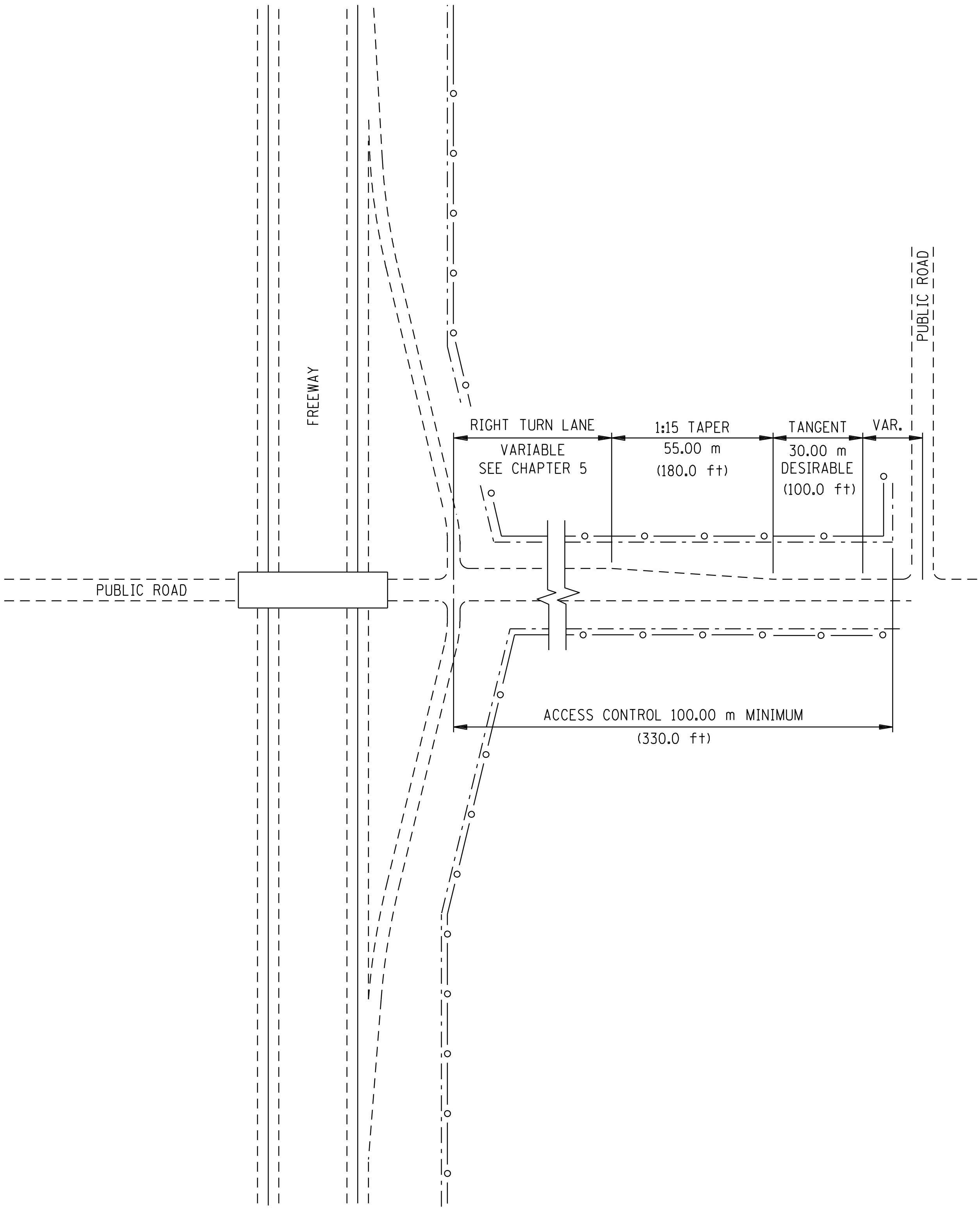
The Highway Access Category System and Spacing Guidelines provide the framework for reviewing the location and general design of the access for proposed development. Chapter 5 provides more specific guidance for the design of at-grade intersections and private driveways. Minnesota Rules Chapter 8810 describes the general regulations governing driveway permits.



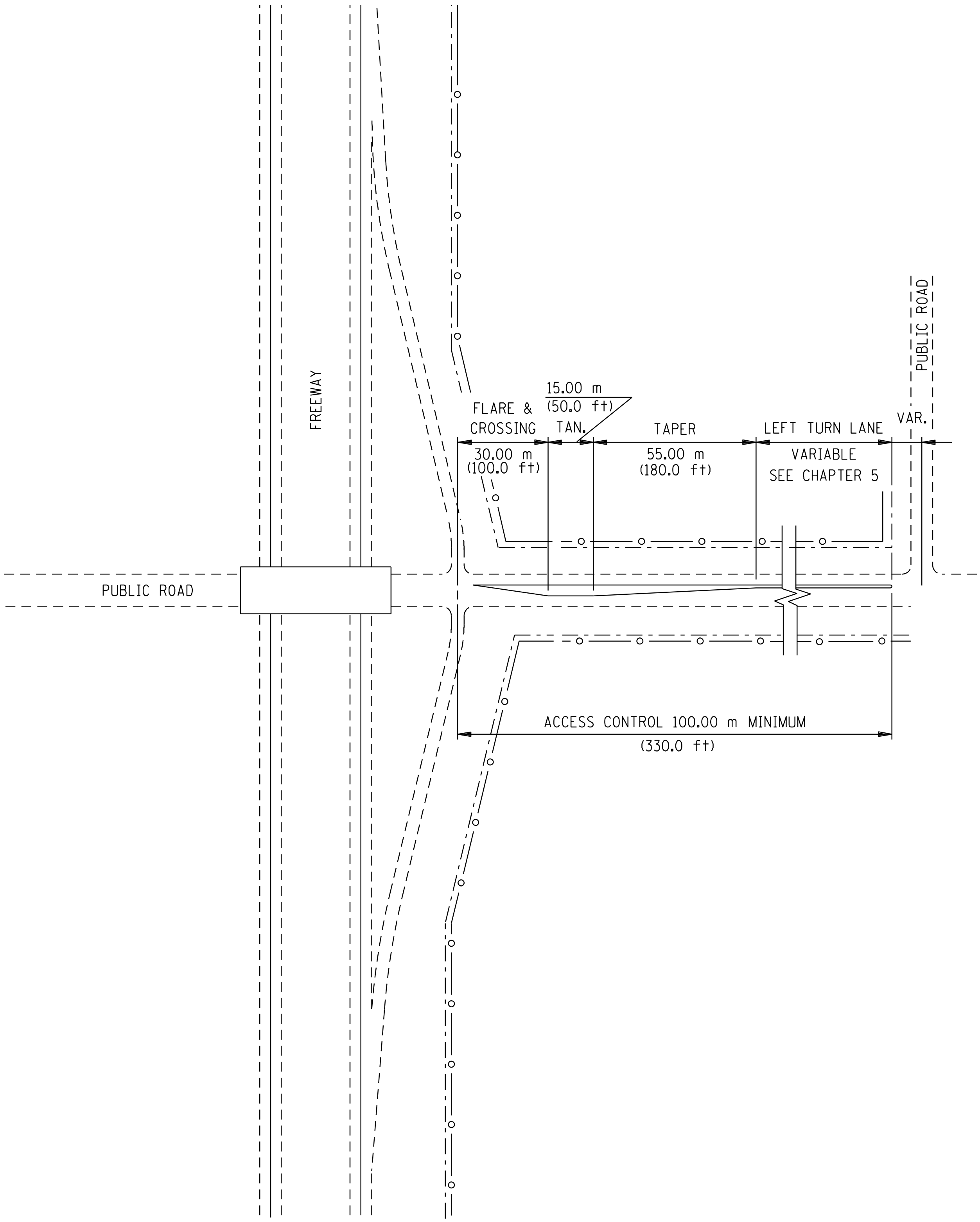
TYPICAL ACCESS CONTROL
HALF DIAMOND AND LOOP RAMP
PUBLIC ROAD WITH MULTI-LANE HIGH-SPEED TRUNK HIGHWAY (EXPRESSWAY)
AND FRONTAGE ROAD
Figure 2-3.06A (Dual Units)



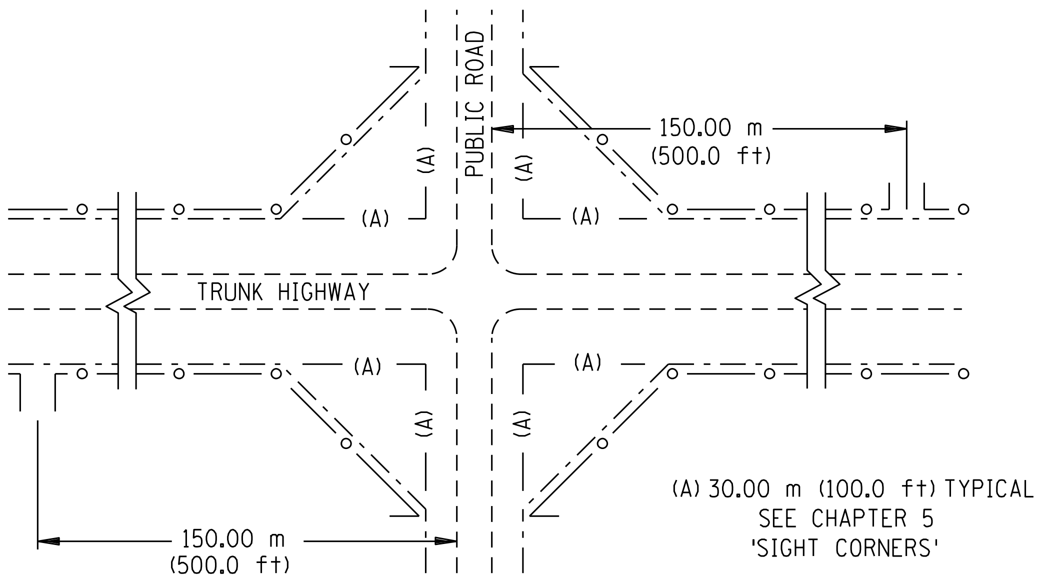
TYPICAL ACCESS CONTROL
FULL DIAMOND AND LOOP RAMP
SEPARATION OF FREEWAY WITH TRUNK HIGHWAY AND PUBLIC ROAD
Figure 2-3.06B (Dual Units)



TYPICAL ACCESS CONTROL
HALF DIAMOND
SEPARATION OF FREEWAY WITH PUBLIC ROAD (TURN LANE ONTO FREEWAY)
Figure 2-3.06C (Dual Units)

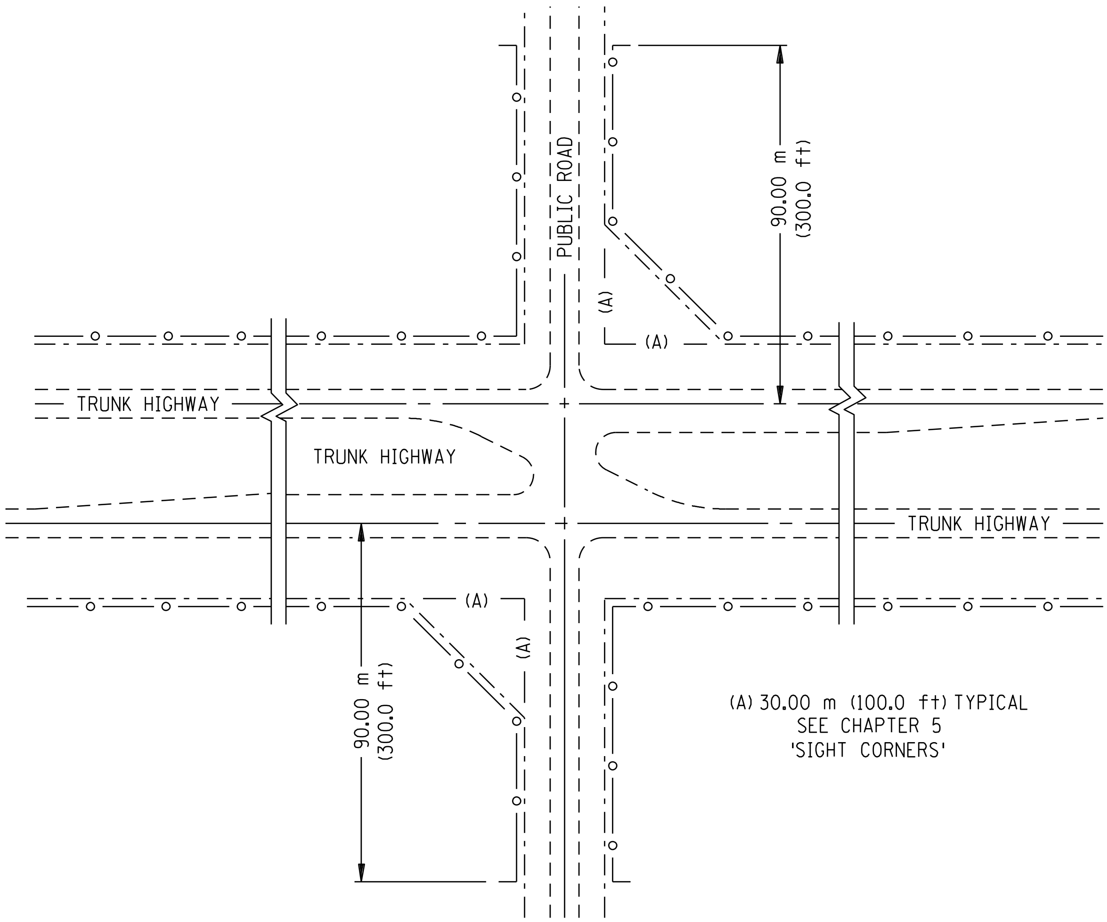


TYPICAL ACCESS CONTROL
HALF DIAMOND
SEPARATION OF FREEWAY WITH PUBLIC ROAD (TURN LANE ONTO PUBLIC ROAD)
Figure 2-3.06D (Dual Units)



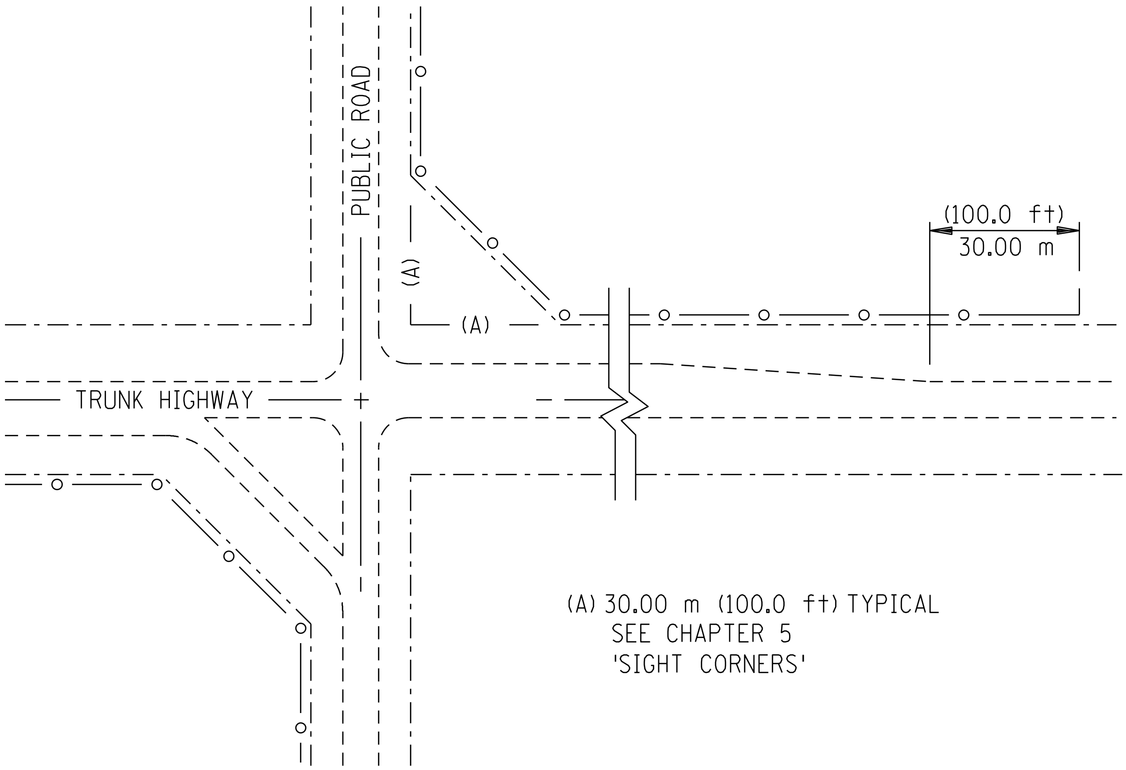
Rural Section with No Anticipated Land Development at the Intersection
Random Access Openings along the Highway as needed
(Triangle Corners Optional)

TYPICAL ACCESS CONTROL
2-LANE HIGHWAY AND PUBLIC ROAD AT-GRADE INTERSECTION
Figure 2-3.06E (Dual Units)



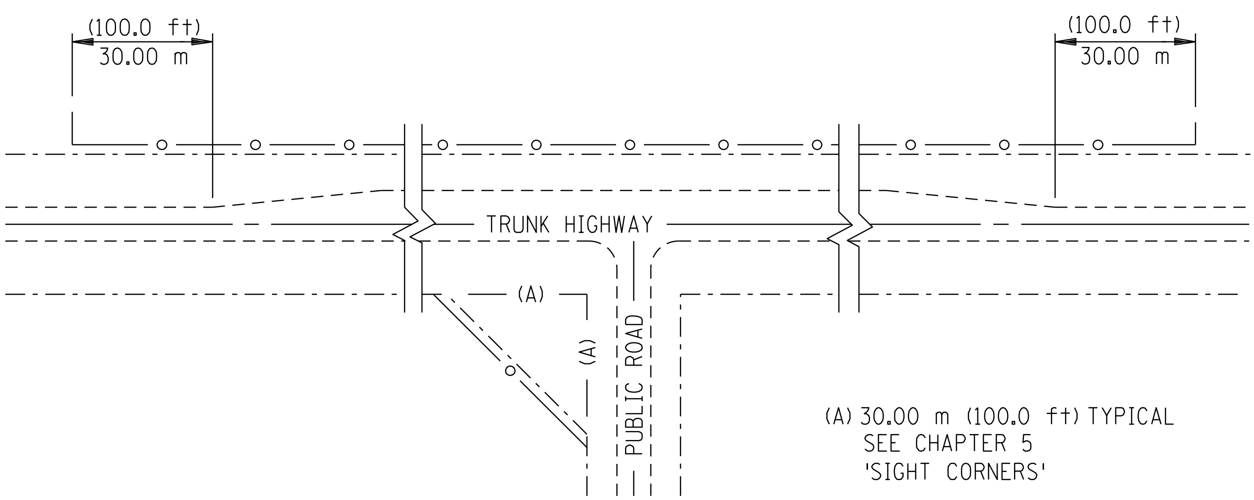
Sight Corners Are Desirable In Approach Quadrants

TYPICAL ACCESS CONTROL
4-LANE DIVIDED HIGHWAY AND PUBLIC ROAD AT-GRADE INTERSECTION
Figure 2-3.06F (Dual Units)



Access Variable Length to Protect Right Turn Movement (Triangle Corners Optional)

TYPICAL ACCESS CONTROL
2-LANE HIGHWAY AND PUBLIC ROAD, AT-GRADE INTERSECTION WITH RIGHT-TURN LANES
Figure 2-3.06G (Dual Units)



Access Variable Length to Protect Right Turn Movement (Triangle Corners Optional)

TYPICAL ACCESS CONTROL
2-LANE HIGHWAY AND PUBLIC ROAD, AT-GRADE INTERSECTION WITH BY-PASS LANES
Figure 2-3.06H (Dual Units)

2-3.06.04 Statute and Zoning

Statutory control with no compensation can only be used to control access where a reasonable alternate access is available or to close a highway median opening. Zoning may effectively control the adjacent property development to prevent traffic generators from arising; however, zoning is only advisory and is at the discretion of the local government. As required by state statute, MnDOT reviews all plats adjacent to trunk highways. Driveway regulations are used to control the geometric design of entrances, driveway spacing, and driveway proximity to public road intersections.

2-4.0 PROJECT SCOPE DETERMINATION

2-4.01 Project Scoping

The purpose of this section is to outline the general process used to identify project scope, the inclusion of the project in the program, and the selection of appropriate design standards.

Each District has a planning process to identify regional priorities, future needs, and broad-based investment directions for a given area or corridor. The planning process incorporates direction from the State, region, metropolitan planning organization (MPO), and local planning efforts. Potential design concepts may be identified for consideration during further scoping and project development.

Deficiencies and needs of the existing highway system are identified through many sources including system operation monitoring, data from management systems (bridge, pavement, safety, etc.), maintenance problems, and public comments.

Based on planning direction and identified deficiencies, scoping defines the appropriate type, cost, limits, impacts, funding sources, and other major aspects of potential project concepts. The ultimate level of investment desired for a given corridor may not be achievable for every project. Often preservation, management, or safety improvements will retain most of the existing features within a corridor to serve immediate needs while longer-range planning identifies a need for future reconstruction or expansion of the facility. The ultimate design and desired operation for a given corridor must be carefully balanced with immediate needs and available resources to provide the appropriate scope for proposed projects.

The level of scoping required will vary according to the scale of the project concepts being evaluated. For example, scoping of preservation projects may only require involvement with other MnDOT functional groups, while scoping of new construction/reconstruction project concepts may involve significant agency and public involvement. Scoping should allow involvement of appropriate MnDOT functional groups, other agencies, and the public as necessary to arrive at the preferred project concept.

The scoping process is intended to minimize the potential for later opposition to a proposed project concept, changes in project type or size, cost escalation, and lack of available funds. Scoping should identify the preferred project concept or range of concepts for further evaluation through the appropriate project development activities.

2-4.02 Project Programming

Projects identified through the scoping process are selected for inclusion in the District Transportation Improvement Program (TIP) in various ways depending on the scope of the project and District Area Transportation Partnership (ATP) procedures. Although preservation projects may be included without a lot of project development, major projects may need to have significant project development work completed prior to inclusion in the program.

Project development includes all preconstruction activities necessary to prepare a project for letting. Design standards and other elements included in the project depend upon the type of project (preservation or new construction/reconstruction) as identified in Section 2-5.0. Design standards should be identified early in the project development process.

The scope of work, concepts, cost, or schedule of a project may change during the project development process. If these changes are significant, the project may need to undergo the scoping process again and be revised accordingly in the TIP according to District and ATP policies.

2-4.03 Cost-Effectiveness Policy

The Minnesota Statewide Transportation Plan established the Department's policy on cost-effectiveness (see the latest Cost-Effectiveness Framework, Minnesota Statewide Transportation Plan). The intent of the Cost-Effectiveness Policy is to make the best overall investment decisions based upon a balanced consideration of both quantitative cost-effectiveness goals and qualitative goals. Any MnDOT project requiring an Environmental Impact Statement (EIS), an Environmental Assessment (EA), or an Environmental Assessment Worksheet (EAW) is subject to the provisions of this policy which is available in MnDOT's Highway Project Development Process (HPDP) Handbook section on Cost-Effectiveness Policy.

2-4.04 Value Engineering

Value Engineering (VE) is defined as "The systematic application of recognized techniques by a multi-disciplined team to identify the function of a product or service, establish a worth for that function, generate alternatives through the use of creative thinking, and provide the needed functions to accomplish the original purpose of the project, reliably, and at the lowest life-cycle cost without sacrificing safety, quality, and environmental attributes of the project."

Federal Regulation 23 CFR Part 627 requires that States apply Value Engineering to all Federal-aid highway projects on the National Highway System (NHS) with an estimated cost (i.e. environmental studies, preliminary engineering, final design, ROW, construction, and state and local participation) of $25 million or more. Projects are defined as "…a portion of a highway that a State proposes to construct, reconstruct, or improve as described in the preliminary design report or applicable environmental document. A project may consist of several contracts or phases over several years" and applies to Design-Build projects as well. A VE study is also required for a contract or phase with an estimated cost of $25 million or more.

The goal of a VE study is to optimize quality and achieve excellence at the lowest costs. However, some VE recommendations may add cost. Its basic objectives are to assure reliability, improve maintainability, eliminate redundancy, and minimize total ownership costs. Although it incorporates the principles of cost-effectiveness, VE in its fullest sense also establishes a formal process and review team that identifies product functions, explores and identifies alternatives, and eliminates unnecessary costs. The VE process should incorporate the following characteristics:

1. A multi-disciplinary team approach.
2. Identification and evaluation of function or service, cost, and worth.
3. The use of creative thinking to speculate on alternatives that can provide the required functions.
4. The evaluation of the best and lowest life-cycle cost alternatives.
5. The development of acceptable alternatives into fully supported recommendations.
6. The presentation/formal reporting of all VE recommendations to management for review, approval, and implementation.

It is essential that the VE study process begin as soon as the preferred alternative layout has been selected. VE studies take a considerable amount of time to arrange; therefore, early notification and coordination are essential so that sound VE recommendations can be implemented without delaying the progress of the project.

VE studies provide a benefit to the highway design process in that the actual dollars spent on highway design are comparatively small in contrast to the contribution of construction and maintenance operations in terms of the total life-cycle costs. However, the decisions made in planning and design have a greater impact on total life-cycle costs than those decisions made in construction and maintenance, therefore a relatively small investment in time and money can lead to substantial savings over the project life.

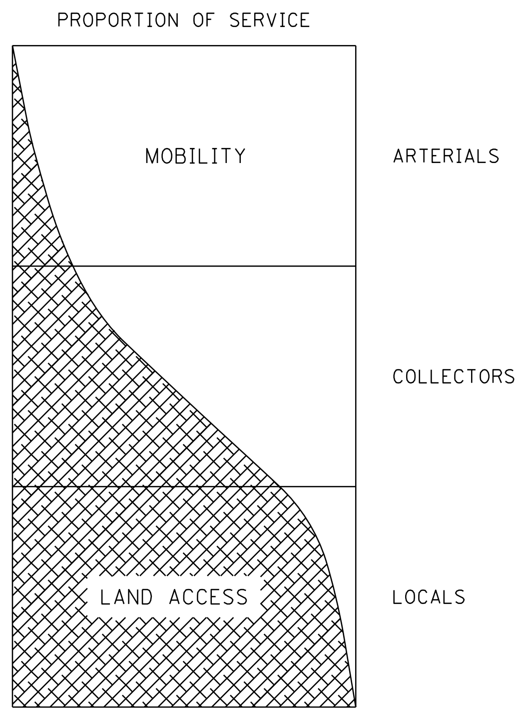
The Office of Technical Support has a Departmental VE Coordinator who provides VE support and annual agency reporting as required by the FHWA. The designer must insure that a VE study is performed on required projects, or any project that will significantly benefit from a VE study. VE studies can be either contracted or developed in-house. Each method has advantages and disadvantages, so contact the VE Coordinator to determine the best method for a candidate project.

2-5.0 DESIGN PARAMETERS

2-5.01 Functional Classification

The intended function of a highway segment will determine its functional classification, and therefore the design values needed to serve that function. The two characteristics that determine a highway's functional classification are access and mobility. These two functions conflict with each other as the highway network attempts to serve two basic purposes: the safe and expedient movement of traffic and the provision of access to residences, businesses**,** and places of recreation. As access increases, mobility decreases. It is important to vary the level of access and mobility provided among different highway segments so that the entire highway network will achieve these two goals. Figure 2-5.01A illustrates the variation of service.

Functional classifications group streets and highways according to the character of service they provide. This classification recognizes that most travel involves movement through a network of roads. The highway network is made up of roads that are categorized by their functional relationships and hierarchy of movement. For more detailed descriptions, see AASHTO's "A Policy on Geometric Design of Highways and Streets," Chapter 1, "Highway Functions."



ACCESS AND MOBILITY
Figure 2-5.01A

2-5.01.01 Arterials

Arterial highways have a capacity to move relatively large volumes of traffic in an expedient manner. In rural areas, arterials provide connections between the major urban areas and provide levels of service suitable for statewide or interstate travel. The rural arterial system provides integrated, continuous movements. In urban areas, the arterial system:

1. Serves the major centers of activity within the urban area,
2. Carries the highest traffic volumes and the longest trip movements, and
3. Serves both major intra-city and through-city trips.

The rural and urban arterial systems provide continuous through movements at approximately the same level of service.

Arterial roads are subdivided into principal and minor categories, based upon their relative distribution of providing access and mobility, the relative importance of the areas and activities they serve, the lengths of trips they accommodate, and the traffic volumes they carry.

2-5.01.02 Collectors

Collector routes place approximately equal importance on access and mobility. Traffic volumes and speeds are somewhat lower on collector roads than on arterials. In rural areas, collectors connect all cities and towns within a county and typically serve intra-county travel needs and provide connections to the arterial systems. In urban areas, collectors act as an intermediate link between the arterial system and other points of access. Urban collectors typically penetrate residential neighborhoods and commercial/industrial areas.

2-5.01.03 Local Roads and Streets

Local roads and streets normally have many points of access and place relatively little value on mobility. Speeds and volumes are low, trip distances are short, and through traffic is often deliberately discouraged.

2-5.02 Investment Categories

The project objectives and available funding must be carefully balanced early in the scoping process. Once the project scope has been identified, the designer can determine the appropriate investment category. Design standards are different for the three investment categories: new construction/reconstruction, preservation, and preventive maintenance, to allow for differing levels of investment to address the most critical deficiencies within the project area. Project scoping and programming are explained in Sections 2-4.01 and 2-4.02.

2-5.02.01 New Construction/Reconstruction

The new construction/reconstruction investment category includes the most intensive types of work, which typically cost the greatest amount of dollars per kilometer (**mile**). This investment category includes projects that will result in a new roadway or bridge on new alignment or reconstruction or replacement on existing alignment.

These types of projects provide the highest degree of safety and traffic-carrying capability for each functional classification. The design of new construction or reconstruction projects should meet all current design standards as identified in Section 2-6.0.

This category includes the investment priority goals of expansion, replacement, and large management and operations projects. Major construction, reconstruction, bridge replacement, reconditioning, safety capacity, and safety hazard elimination are some of the program projects included in this category.

2-5.02.02 Preservation

The primary objective of the preservation investment category is to extend the life of a highway, bridge, or other transportation facility. For bridge projects**,** see the MnDOT Bridge Preservation, Improvement, and Replacement Guidelines. In some cases, preservation projects are projects that safely manage and operate existing systems efficiently while effectively addressing critical safety and operations needs through minor and moderate cost improvements to the existing facility.

Preservation projects, which generally utilize the majority of the existing pavement or structure, may entail minor widening or geometric improvements, and normally require little or no additional right of way. These projects should either retain the existing design features of the roadway or meet new construction/ reconstruction standards, whichever is less. Safety must also be considered in the design of all preservation projects, including cost-effective safety improvements where warranted.

The preservation investment category includes the investment priority goals of preservation and small management and operations projects. Road repair, surface treatment, resurfacing, and bridge repair, along with smaller reconditioning and cooperative agreements, junkyard screening, planning rest area beautification, safety capacity, safety hazard elimination, rail safety, and traffic management projects are some examples of preservation projects.

2-5.02.03 Preventive Maintenance

According to 1997 AASHTO Standing Committee on Highways, preventive maintenance is "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity)." The preventive maintenance investment category includes projects whose goal is to maintain existing pavement and structures. It requires no additional right of way.

Preventive maintenance is typically applied to pavements in good condition having significant remaining service life. Examples of preventive treatments include asphalt crack sealing, chip sealing, diamond grinding, dowel-bar retrofit, and isolated, partial and/or full-depth concrete repairs to restore functionality of the slab (e.g., edge spalls, or corner breaks).

2-5.03 Types of Highways

Highways are further categorized according to their number of lanes.

2-5.03.01 Two-Lane Highways

The majority of Minnesota's highways are two-lane roads. Truck climbing lanes and passing lane sections may be provided on two-lane highways. The design speed of a high-speed two-lane highway is greater than 70 km/h (**45 mph**). Urban arterials, rural arterials, urban collectors, rural collectors, urban local streets, and rural local roads can all be two-lane highways.

2-5.03.02 Multi-Lane Highways

Multi-lane highways make up the remainder of the state's highways. Freeways, arterials, and collectors can all be multi-lane highways. Multi-lane highways are divided into three categories: freeways, high-speed multi-lane highways (expressways), and low-speed multi-lane highways.

2-5.03.02.01 Freeways

Freeways, defined as expressways with full access control, are principal arterials for both urban and rural regions. Freeways provide high-speed travel, improve safety, preserve the as-built capacity, and are intended for motor vehicle travel only.

All roads that intersect freeways are separated by grade or connected by interchanges, and all rail crossings are separated by grade. Major freeway elements include medians, grade separations, ramp connections, and frontage roads.

2-5.03.02.02 High-Speed Multi-Lane Highways (Expressways)

High-speed multi-lane highways (expressways) are generally arterial roads with design speeds equal to or greater than 70 km/h (**45 mph**). Expressways can be divided or undivided, and can be located in both urban and rural sections. Most intersections are at grade, although grade separation and interchanges may be used in cases where high volume roads or rail crossings exist, or terrain conditions favor the grade separation. To maintain the desirable level of service, partial access control is desired along the entire length of the expressway. Where high traffic volumes are present, and/or land development is required adjacent to an expressway, full access control may be necessary. These short segments resemble freeways in their design, and are usually in close proximity to urban areas. Access control can be maintained by zoning, driveway regulations, or geometric design. Area terrain, intersection treatment, and economics dictate median width. Left-turn lanes are often provided at all significant at-grade intersections.

Although undivided expressways exist, they are highly discouraged due to their propensity for rear-end and head-on collisions. In special situations, such as in areas where right-of-way is restricted, a designer may consider this option. The standards for these sections will be developed on a case-by-case basis.

2-5.03.02.03 Low-Speed Multi-Lane Highways

Low-speed multi-lane highways are generally arterials or collectors with design speeds less than 70 km/h (**45 mph**).

Low-speed highways can be divided or undivided. Divided low-speed multi-lane highways typically have four or more lanes with opposing traffic on two or more of those lanes, separated by a median. To maintain the desirable level of service, partial access control may be necessary along some sections. Access control can be achieved through zoning, driveway regulations, or geometric design. Median width is dictated by area, terrain, intersection treatment, and economics.

Undivided low-speed multi-lane highways typically have four or more lanes with opposing traffic on two or more of those lanes, separated by striping. Undivided sections are usually developed where right of way is limited or development restrictions dictate.

2-5.03.03 Scenic Byways

Scenic byways are designated roadway corridors that highlight our outstanding scenic roads, featuring natural, cultural, historic, archeological, recreational, and scenic qualities. Most byways are represented by a local grassroots organization representing a coalition of local governments, chambers of commerce, tourism associations, and other interests. These organizations are often engaged in tourism marketing, interpretation, and resource management initiatives and may be able to provide useful local contacts for construction or maintenance operations.

The National Scenic Byways Program was established by ISTEA and operates under FHWA policy as documented in the Federal Register. The Minnesota Scenic Byway Program was established with a 1992 Memorandum of Understanding between MnDOT, the Minnesota Department of Natural Resources, the Minnesota Historical Society, and Explore Minnesota Tourism. A Scenic Byways Commission representing these agencies makes the principal decisions on the state scenic byway designations and on funding priorities for National Scenic Byway Discretionary Grant projects.

For detailed information and procedures regarding scenic byway programs, the designer should contact the Office of Environmental Services.

2-5.04 Interregional Corridors

An interregional corridor (IRC) is a corridor that provides safe and efficient transportation between Minnesota's regional trade centers and will ensure competitive access to markets and services and easy connections to tourist and recreational areas. Mapping of Minnesota's IRC network is available on the MnDOT Office of Investment Management website.

2-5.05 Traffic Characteristics

Traffic operational characteristics have a large impact on the applicable geometric and structural design criteria of a highway. The designer must provide a facility that will reasonably accommodate all anticipated traffic characteristics in the selected design period, (i.e., 20 years from the completion date of the project). The designer should refer to the current Transportation Research Board (TRB) "Highway Capacity Manual" (HCM) for a more detailed description of the operational factors of highways. The MnDOT Traffic Engineering Manual also contains information concerning how to make field measurements of traffic data and how to interpret and apply the data. For bicycle traffic characteristics, see the planning section of the MnDOT Bikeway Facility Design Manual.

2-5.05.01 Volume

Forecasted traffic volumes and their projected equivalent single axle loads (ESALs) approximate the total load that a highway facility must accommodate during its design life.

Certain important definitions are listed below:

1. **Annual Average Daily Traffic (AADT)**
   The AADT is the total yearly volume divided by the number of days in the year.
2. **Average Daily Traffic (ADT)**
   The ADT is the total traffic volume during a given time period (in days) greater than one day and less than one year, divided by the number of days in that time period. ADT is often used interchangeably with AADT.
3. **Heavy Commercial Average Daily Traffic (HCADT)**
   The HCADT is the ADT of commercial traffic having two or more axles and six or more tires.
4. **Design Hourly Volume (DHV)**
   The DHV is the one-hour volume selected from the design year to determine the highway design.
5. **Peak-Hour Traffic**
   The peak-hour traffic is the highest number of vehicles found to be passing over a section of highway during 60 minutes.
6. **Peak-Hour Factor (PHF)**
   The PHF is a ratio of the total hourly volume occurring during the peak hour and the maximum rate of flow during a given time within the peak hour. Typically, this time is 5 minutes for freeways and 15 minutes for intersections. For example:
   Peak hour = 500 VPH
   15 Minute Maximum = 145
   PHF = 500 / (4 x 145) = 0.86
7. **Equivalent Single Axle Load (ESAL)**
   ESALs estimate the design loads that a pavement must accommodate during its design life by equating the various axle loads of projected vehicle types to the damage done by an equivalent number of 8,165 kg (**18,000 lb**) single axles with dual tires.

Although the AADT or ADT is useful in making design decisions related to the total user benefit of a proposed improvement, many other characteristics are necessary to indicate the variations in traffic during months of the year, days of the week, or hours of the day.

Peak traffic volumes are more appropriate for use in some design criteria and reflect normal operating conditions. The 30th highest hourly volume (30 HV) of the selected design year is generally a reasonable design control, but there are some exceptions. Some roads in large metropolitan areas may use the AM and PM peak hour volumes**,** and some recreational routes might even use another high hourly volume entirely. The DHV will affect many design elements including the number of travel lanes, lane and shoulder width, and intersection layout. The DHV will directly determine the standards for each project.

A highway should be designed to accommodate the traffic that is expected to occur during its useful life under reasonable maintenance. Although long-range forecasts are uncertain, projecting traffic volumes 20 years into the future from a project's programmed completion date is reasonable. For some reconstruction or rehabilitation projects, a 20-year forecast may not be appropriate due to planned changes in the regional economy, population, or land development. In those cases, a five to ten-year forecast may be prudent.

Traffic forecasts for DHV are generally prepared by the District Traffic Engineering Section. A simple analysis would be predicting the 30th highest hourly volume in 20 years by applying current area traffic growth factors to present volumes. The forecaster must also incorporate the impact of any anticipated land development or traffic diversions onto or away from the facility. In addition, traffic characteristics of directional distribution, composition of flow, and level of service must be addressed. For intersections and interchanges, a DHV forecast must be made for every possible through and turning movement.

Heavy Commercial Average Daily Traffic (HCADT) volume must be considered in all designs. The cumulative ESALs for the project design period are required for pavement design and determination purposes. Refer to the TRB “Highway Capacity Manual” (HCM) and the MnDOT Geotechnical and Pavement Manual for more information on ESALs.

2-5.05.02 Directional Distribution

AADT and DHV are expressed as two-way volumes, but without the knowledge and application of the percentage of volume in each direction during the design hour, the inherent assumption of a 50-50 split could lead to a serious under-design of the facility. Typically, the distribution in the predominant direction during the peak hour, will vary from 55 to 70 percent, but occasionally may be as high as 80 percent. At intersections and interchanges, it is necessary to know the volumes of all movements to design the facility properly.

2-5.05.03 Composition

The impact of large vehicles on traffic operation will have the effect of several cars. The percentage of truck traffic must therefore be determined. For highway capacity purposes, trucks are defined as all buses, single-unit trucks, truck tractor-trailer combinations, and truck tractors with semitrailers in combination with full trailers. Normally, trucks have a gross vehicle weight greater than 4100 kg **(9,000 lb)**. It is also important to determine the specific truck percentage during the peak hour, which is usually less than the truck percentage for a 24-hour period. For highway capacity analysis, the impact of buses must be considered separately because of their stop-and-go operation.

2-5.05.04 Traffic Flow

Traffic flow can be characterized by volume (vph), speed (km/h (**mph**)), and density (v/km (**vpm**)). Traffic density, the number of vehicles per unit length of roadway, is a function of volume and speed. Because vehicles can comfortably follow other vehicles somewhat closely at low speeds, the greatest motor vehicle densities, or capacity, typically occur at speeds of 50 to 60 km/h (**30 to 40 mph**). Weather and roadside interference also affect vehicle densities. Vehicle queues will develop when a slower vehicle interferes with the desired operating speed of other vehicles. The frequency and length of a queue are dependent upon the prevalence of slower vehicles and the traffic volume on the highway. Passing opportunities on two-lane highways are dependent upon the traffic flow characteristics of the oncoming traffic.

Intersection operations are subject to traffic flow characteristics. The level of disruption a left-turning vehicle will cause is a function of headway or gaps between oncoming vehicles. This is dependent on their speed and volume.

The maximum discharge rate of a standing queue of vehicles governs the capacity of an intersection. Intersection capacity is approximately 25 percent less than that of a free-flowing section of highway. Arrivals at many urban intersections are rather predictable, aiding the capacity analysis. Often, the random nature of arrivals at low-volume intersections will affect the desired traffic control.

2-5.06 Speed

The speed at which highway users are able to travel is one of the most important measures of a facility's serviceability. The measures of speed for design and operating characteristics are defined below:

1. **Design Speed**
   Design speed is the selected speed used to determine the various geometric design features of the roadway.
2. **Average Highway Speed**
   Average highway speed is the weighted average of the design speeds within a highway section based on each subsection's proportional contribution to total mileage.
3. **Running Speed**
   Running speed is the speed over a specified section of highway equal to the distance divided by the running time, or the total time required to travel over the highway section.

4. **Operating Speed**
   Operating speed is the speed at which drivers are operating their vehicles during free-flow conditions under typically good weather and surface conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.
5. **Average Running Speed**
   Average running speed is the sum of the distances traveled by vehicles on a highway section during a specified time period, divided by the sum of their running times.
6. **Legal Speed**
   The legal speed is the value prescribed by Minnesota Statute 169.14 or the posted limit as set by Commissioner's authorization. All the Commissioner's authorizations are on file in the Traffic Engineering Office. See the MnDOT Traffic Engineering Manual for accepted procedures to perform an engineering and traffic investigation for determining a speed limit. Legal speed is approximately the 85th percentile speed, often determined by observation of a sizable sample of vehicles' average running speeds.
7. **Posted Speed**
   The posted speed is the numeric value displayed on an approved "Manual on Uniform Traffic Control Devices" (MUTCD) regulatory sign indicating the legal speed as set by the commissioner or categorical compliance to statutory provisions.

The MnDOT Traffic Engineering Manual describes the accepted means to collect field data to determine the desired speed information.

2-5.06.01 Design Speed

The design speed, perhaps more so than any other design control on a highway, will have a major impact on all facets of geometric design, and other design elements. The project segment's appropriate design speed depends upon the functional classification and use, average daily traffic ADT, anticipated and desirable operating speed, terrain, and adjacent land use of the highway. Advantages of a higher vehicle operating speed attained by the use of a higher design speed must be evaluated against the design flexibility that is lost. The most appropriate design speed may be a lower value that recognizes the importance of attaining maximum design flexibility and a context sensitive roadway that fits community needs and environmental constraints. Design speed values above the minimums are usually most appropriate and desirable, but the designer should not be averse to adopting lower values where significant constraints or opportunities exist. The designer must carefully document all of the considerations and analyses important to the determination of the most appropriate design speed and weigh the benefits of a desired degree of safety, access, mobility, design consistency, and efficiency against the community, environmental, right of way, and cost impacts. Design speeds usually fall between 50 and 120 km/h **(30 and 75 mph)**, at 10 km/h **(5 mph)** increments. High-speed facilities have design speeds that are 70 km/h **(45 mph)** or greater, and low-speed facilities have design speeds that are less than 70 km/h **(45 mph)**.

The element of driver expectation must be considered when selecting the design speed. Drivers expect to be able to drive at certain maximum speeds based on the functional classification and rural or urban character of the highway. The design speed should fit the travel desires and habits of the majority of drivers. Table 2-5.06A provides the allowable ranges of design speeds for varying conditions. For design work, it is typically desirable to choose a design speed that equals or exceeds the anticipated posted speed, and complements the highway type, setting, functional classification, traffic volume, and terrain.

Terrain is typically classified as level, rolling, or mountainous for the purposes of highway design. Section 2-5.09 provides further definitions.

Table 2-5.06A (Dual Unit)
DESIGN SPEED

<table>
<tr><th colspan="4">Conditions</th><th colspan="3">Design Speed, km/h (mph)</th></tr>
<tr><th rowspan="2">Type of Highway</th><th rowspan="2">Setting</th><th rowspan="2">Functional Class</th><th rowspan="2">Terrain</th><th colspan="3">ADT</th></tr>
<tr><th><1500</th><th>1500-3000</th><th>>3000</th></tr>
<tr><td rowspan="13">2-Lane Highway</td><td rowspan="9">Rural</td><td rowspan="3">Principal Arterial</td><td>Level</td><td colspan="3">100-120 (60-75)</td></tr>
<tr><td>Rolling</td><td colspan="3">90-110 (55-70)</td></tr>
<tr><td>Mountainous</td><td>60-100 (40-60)</td><td colspan="2">80-100 (50-60)</td></tr>
<tr><td rowspan="3">Minor Arterial</td><td>Level</td><td colspan="3">100-110 (60-70)</td></tr>
<tr><td>Rolling</td><td colspan="3">80-110 (50-70)</td></tr>
<tr><td>Mountainous</td><td colspan="2">60-100 (40-60)</td><td>80-100 (50-60)</td></tr>
<tr><td rowspan="3">Collector</td><td>Level</td><td>80-100 (50-60)</td><td colspan="2">100 (60)</td></tr>
<tr><td>Rolling</td><td>60-100 (40-60)</td><td colspan="2">80-100 (50-60)</td></tr>
<tr><td>Mountainous</td><td>50-100 (30-60)</td><td colspan="2">60-100 (40-60)</td></tr>
<tr><td rowspan="2">Urban High-Speed</td><td>Arterial</td><td rowspan="2">All</td><td rowspan="2" colspan="3">70-100 (45-60)</td></tr>
<tr><td>Collector</td></tr>
<tr><td rowspan="2">Urban Low- Speed</td><td>Arterial</td><td rowspan="2">All</td><td rowspan="2" colspan="3">50-60 (30-40)</td></tr>
<tr><td>Collector</td></tr>
<tr><td rowspan="4">Freeway</td><td rowspan="3">Rural</td><td rowspan="3">Arterial</td><td>Level</td><td colspan="3">110-120 (70-75)</td></tr>
<tr><td>Rolling</td><td colspan="3">110 (70)</td></tr>
<tr><td>Mountainous</td><td colspan="3">80-110 (50-70)</td></tr>
<tr><td>Urban</td><td>Arterial</td><td>All</td><td colspan="3">80-110 (50-70)</td></tr>
<tr><td rowspan="6">Multi-Lane Highway</td><td rowspan="3">Rural</td><td rowspan="3">Arterial</td><td>Level</td><td colspan="3">100-120 (60-75)</td></tr>
<tr><td>Rolling</td><td colspan="3">100-110 (60-70)</td></tr>
<tr><td>Mountainous</td><td colspan="3">80-110 (50-70)</td></tr>
<tr><td>Urban High-Speed</td><td>Arterial</td><td>All</td><td colspan="3">70-110 (45-70)</td></tr>
<tr><td rowspan="2">Urban Low-Speed</td><td>Arterial</td><td rowspan="2">All</td><td rowspan="2" colspan="3">50-60 (30-40)</td></tr>
<tr><td>Collector</td></tr>
</table>

2-5.06.02 Average Running Speed

The average running speed offers a meaningful measure of highway service and allows a means of evaluating highway user costs and benefits. The relationship between design speed and average running speed varies. At low volumes and low design speeds, average running speed may be very close to the design speed. As volumes and design speeds increase the difference between the design speed and the average running speed increases.

On urban streets, the average running speed is more important than the design speed. Urban streets should be designed and control devices regulated to permit running speeds of 30 to 70 km/h **(20 to 45 mph)**. The lower range is appropriate for local and collector streets and arterials in the central business district (CBD), residential areas, and parks while the higher range should be achieved on arterials away from the CBD. A general approximation is that running speeds of 30 to 100 km/h **(20 to 60 mph)** require design speeds of 50 to 120 km/h **(30 to 75 mph)**. If the average running speed will be used for design, a speed study should be conducted.

2-5.07 Capacity

Highways and intersections need to accommodate the design hourly volume (DHV). The detailed calculation factors and methodology used to determine the DHV are in the TRB "Highway Capacity Manual" (HCM). The design service volume is the maximum volume of traffic that a highway would be able to serve without congestion becoming greater than a predetermined value. It needs to be calculated for each segment. Although capacity assumes a level of service E, a highway is usually designed to exceed level of service E.

Design normally conducts an initial capacity analysis to determine if a proposed design will roughly accommodate the DHV. The District Traffic Offices conduct the detailed capacity analyses of signalized intersections to finalize the design details of the project.

2-5.07.01 Highway Mainline

Many of the factors that affect the capacity of a highway segment are listed below:

1. **Traffic composition**
   As the percentage of trucks and/or buses increases, the capacity decreases. Standard procedure converts the heavy vehicle volumes to passenger car equivalents.
2. **Lane and shoulder width**
   Capacity has a tendency to decrease as lane and shoulder width decrease. Corresponding factors are used to incorporate the influence of narrower pavement widths.
3. **Lateral clearance**
   If roadside interferences are within a certain distance of the edge of the travel lane, capacity decreases. This "shy distance" varies with design speed and one-way or two-way operation.
4. **Auxiliary lanes**
   The presence or absence of auxiliary lanes, such as parking or turn storage lanes, affects capacity. Because universal factors cannot be used to calculate their impact on capacity, individual analyses are necessary.
5. **Alignment**
   Horizontal and vertical alignment significantly affect capacity. For traffic operations on relatively long sections of highway, the frequency and sharpness of curves and grades affect the "average highway speed" (a weighted average design speed), stopping sight distances, and passing opportunities. Based on these three characteristics, adjustment factors can be applied to calculate their impact on capacity. At specific sites, grades can have significant and measurable impacts on highway capacity. Trucks lose speed when ascending grades. Chapter 3 provides details on the impact of grades on truck speeds and discusses warrants for climbing lanes.
6. **At-grade intersections**
   Intersections including driveways have a major impact on the capacity of a highway. Intersection capacity analysis must be treated separately because its influence on service volumes can be so great that it governs the capacity of an entire segment.
7. **Freeway interchanges**
   Weaving sections and exit and entrance ramp junctions at interchanges are usually the most important adjustments to freeway capacity. Operating conditions within weaving sections are affected by traffic volumes and the length and width of the section. Chapter 6 discusses the required design details to properly allow for weaving maneuvers.

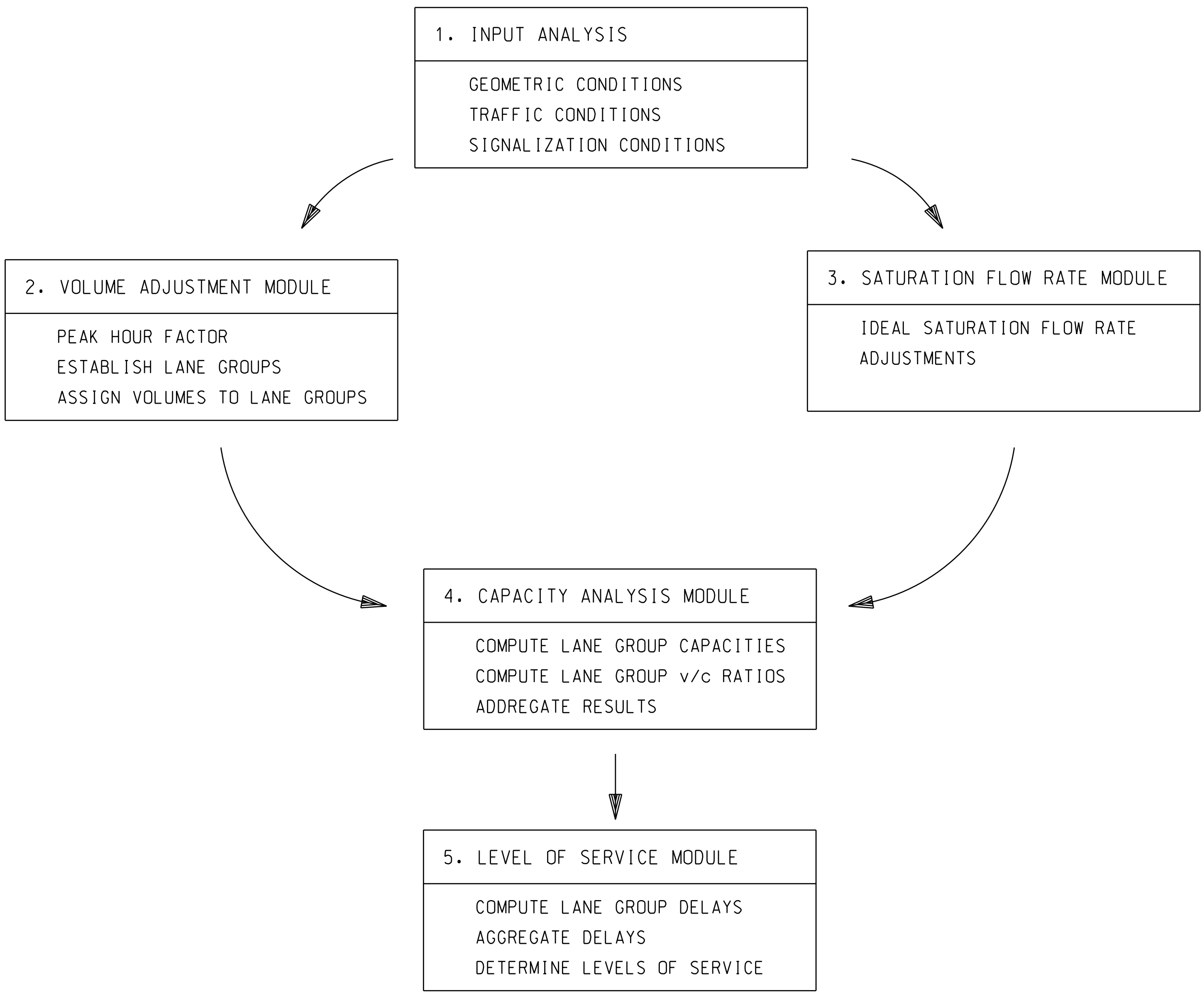
The HCM should be referenced when calculating the capacity or design service volume of the highway mainline and freeways.

2-5.07.02 Signalized Intersections

Chapter 18, “Signalized Intersections,” in the HCM explains how to calculate the capacity of a signalized intersection. The operational analysis method addresses the capacity and level of service of intersecting approaches and the level of service of the intersection as a whole. Capacity is evaluated in terms of the ratio of demand flow rate to capacity (v/c ratio), while level of service is evaluated on the basis of average stopped delay per vehicle (s/veh). The HCM does not address the capacity of an intersection as a whole because the design and signalization of intersections focus on the accommodation of the intersection’s major movements and approaches. The methodology can be used for pre-timed signals, vehicle-actuated signals, or multiphase signals.

Operational analysis requires detailed information concerning geometric, traffic, and signalization conditions at an intersection. These data may be known for existing cases or projected for future situations. Because this analysis is complex, it is divided into five separate modules: input, volume adjustment, saturation flow rate, capacity analysis, and level of service. The HCM provides the detailed steps of intersection analysis. Figure 2-5.07A illustrates the basic procedure.

The basic unit of capacity for signalized intersections is 1900 passenger cars per hour of green per lane under ideal conditions (12 ft (3.6 m) lanes and no trucks, buses, turns, or pedestrian movements), which reflects the time lost due to queue start up and signal change intervals.



OPERATIONAL ANALYSIS FOR SIGNALIZED INTERSECTIONS
Figure 2-5.07A

2-5.07.03 Unsignalized Intersections

Chapters 19 and 20 in the HCM demonstrates how to calculate capacity for two-way and all-way stop-controlled intersections. The two-way stop-control analysis calculates the available capacity of the minor road primarily based upon the traffic operating characteristics of the major road by assuming that major street traffic is not affected by minor street movements.

Most at-grade junctions are unsignalized intersections. In most of these cases, stop and yield signs are used to assign the right of way to one street of the junction. This designation forces the drivers of the controlled approaches to select gaps in the major street to complete their maneuvers. The capacity of the controlled maneuver is based on:

1. The distribution of gaps in the major street traffic stream, and
2. Driver judgment in selecting gaps to execute their maneuvers.

This methodology adjusts for conflicting movements of minor street flows on each other and accounts for shared use of lanes by two or three minor street movements. The HCM further explains the basic procedures and detailed analyses of unsignalized intersections.

2-5.07.04 Level of Service

The average highway user will tolerate a certain level of congestion and delay before becoming frustrated or attempting unsafe driving maneuvers. This level will vary according to the type of facility. For instance, a user expects a relatively free-flow condition on a rural freeway but will accept a certain number of stops and delays and heavier traffic volumes on a signalized urban arterial.

The level of service concept addresses the issue of acceptable degrees of congestion. The various levels have been subjectively determined and qualitatively described. From these descriptions, quantitative measures have been developed, such as volume to capacity ratio (v/c), density, average travel speeds, percent-time-following, and control delay.

Level of service is designated by a letter grade ranging from A to F, with A representing free-flow conditions and F designating breakdown flow. The designer should strive to provide the highest level of service feasible for the design year by weighing the desires and tolerances of road users against the resources available for satisfying those road users.

2-5.08 Sight Distance

The driver must be able to see ahead a sufficient distance to conduct a variety of possible maneuvers. The type of sight distance that should be provided will depend upon the type of highway and the nature of the potential hazard. This section discusses the definitions and derivations of the various sight distances, including stopping, passing, and decision sight distances. Intersection sight distance is discussed in Chapter 5.

Stopping sight distance, the distance required for a vehicle traveling at the design speed to stop before reaching a stationary object in its path, is the minimum sight distance that should be provided at any point on any highway. Passing sight distance, the distance that drivers must be able to see along the road ahead to initiate and complete passing maneuvers, is applicable only on two-lane roadways. Decision sight distance, the distance required for a driver to detect an unexpected or obscure condition or source of information, decide on a course of action, and react accordingly, should be considered at each individual location.

Applications are discussed under the appropriate topics in other chapters. All sight distance calculations are based on the passenger car as the design vehicle.

2-5.08.01 Stopping Sight Distance

The available stopping sight distance on any roadway should be long enough to enable a vehicle traveling at the design speed to stop before reaching a stationary object in its path. Stopping sight distance is the minimum length that should be provided at any point on any roadway.

Stopping sight distance (SSD) is the sum of two distances; the distance (d_1) traveled during driver perception/reaction time, and the braking distance (d_2) traveled during brake application. Based on the results of many studies, 2.5 seconds has been chosen for a perception/reaction time. This time will accommodate approximately 90 percent of all drivers when confronted with simple to moderately complex highway situations. Greater reaction time should be allowed in situations that are more complex. For more information, see Section 2-5.08.03 Decision Sight Distance.

Driver perception/reaction distance is calculated by:

$d_1 = 1.47\ Vt$ (U.S. Customary)

$d_1 = 0.278\ Vt$ (Metric)

where:
d_1 = perception/reaction distance, ft (m)
V = design speed, mph (km/h)
t = perception/reaction time, 2.5 s

Braking distance is calculated by:

$d_2 = 1.075\ \frac{V^2}{a}$ (U.S. Customary)

$d_2 = 0.039\ \frac{V^2}{a}$ (Metric)

where:
d_2 = braking distance, ft (m)
V = design speed, mph (km/h)
a = deceleration rate, ft /s^2 (m/$\mathbf{s^2}$)

Stopping Sight Distance (SSD) is calculated by:

SSD = d1 + d2

Stopping sight distance represents a near worst-case situation. Approximately 90 percent of all drivers decelerate at rates greater than 11.2 ft/s^2 (3.4 m/s^2). These values are within a driver’s ability to stay within his or her lane and maintain steering control. A threshold of 11.2 ft/s^2 (3.4 m/s^2) is used to determine stopping sight distance. Implicit in the choice of this deceleration threshold is the assessment that most vehicle braking systems and the tire-pavement friction levels of most roadways are capable of providing a deceleration of at least 11.2 ft/s^2 (3.4 m/s^2). The friction available on most wet pavement surfaces and most vehicle braking systems are capable of providing braking friction that exceeds this deceleration rate.

In computing and measuring stopping sight distances, the height of the driver’s eye is defined as 3.5 ft (1080 mm) above the pavement, and the height of the object the driver needs to see is 2.0 ft (600 mm), which is representative of automobile headlights and taillights.

Table 2-5.08A summarizes the stopping sight distance data for wet pavement on level terrain.

Table 2-5.08A
STOPPING SIGHT DISTANCES ON LEVEL TERRAIN

U.S. Customary				
Design speed (mph)	Perception / reaction distance (ft)	Braking distance (ft)	Stopping sight distance	
			Calculated (ft)	Design (ft)
30	110.3	86.4	196.7	200
35	128.6	117.6	246.2	250
40	147.0	153.6	300.6	305
45	164.4	194.6	359.8	360
50	183.8	240.0	423.8	425
55	202.1	290.3	492.4	495
60	220.5	345.5	566.0	570
65	238.9	405.5	644.4	645
70	257.3	470.3	727.6	730
75	275.6	539.9	815.5	820

Metric				
Design speed (km/h)	Perception / reaction distance (m)	Braking distance (m)	Stopping sight distance	
			Calculated (m)	Design (m)
50	34.8	28.7	63.5	65
60	41.7	41.3	83.0	85
70	48.7	56.2	104.9	105
80	55.6	73.4	129.0	130
90	62.6	92.9	155.5	160
100	69.5	114.7	184.2	185
110	76.5	138.8	215.3	220
120	83.4	165.2	248.6	250

Note: Perception/reaction distance predicated on a time of 2.5 s; deceleration rate of 11.2 ft/s^2 (3.4 m/s^2) used to determine calculated sight distance.

2-5.08.01.01 Stopping Sight Distances on Grades

Increases or decreases in the level braking distances in Table 2-5.08A are warranted for grades of 3 percent or more. The braking distance formula(d_2) should be modified as follows:

$$d_2 = \frac{V^2}{30\left(\frac{a}{32.2} + G\right)} \text{ (U.S. Customary)}$$

$$d_2 = \frac{V^2}{254\left(\frac{a}{9.81} + G\right)} \text{ (Metric)}$$

where:

G = the grade expressed as a decimal (e.g. 6 percent is 0.06). Downgrades are negative and upgrades are positive.

All other terms are as stated in the stopping sight distance equation.

Table 2-5.08B provides the adjusted stopping sight distances due to grade assuming wet pavement conditions.

Table 2-5.08B
STOPPING SIGHT DISTANCES ON GRADES

U.S. Customary						
Design speed (mph)	Stopping sight distance (ft)					
	Downgrades			Upgrades		
	3%	6%	9%	3%	6%	9%
30	205	215	227	200	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375
55	520	553	593	469	450	433
60	598	638	686	538	515	495
65	682	728	785	612	584	561
70	771	825	891	690	658	631
75	866	927	1003	772	736	704

Metric						
Design speed (km/h)	Stopping sight distance (m)					
	Downgrades			Upgrades		
	3%	6%	9%	3%	6%	9%
50	66	70	74	61	59	58
60	87	92	97	80	77	75
70	110	116	124	100	97	93
80	136	144	154	123	118	114
90	164	174	187	148	141	136
100	194	207	223	174	167	160
110	227	243	262	203	194	186
120	263	281	304	234	223	214

2-5.08.02 Passing Sight Distance

On two-lane highways, passing maneuvers – in which faster vehicles overtake slower vehicles – must be accomplished on lanes used by opposing traffic. Passing sight distance (PSD) is that distance needed for drivers to assess whether to initiate, continue and complete or abort such a passing maneuver.

If passing is to be accomplished without interfering with an opposing vehicle, the passing driver should be able to see a sufficient distance ahead, clear of traffic, so the passing driver can decide whether to initiate and to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle that appears during the maneuver. When appropriate, the driver can return to the right lane without completing the pass if he or she sees opposing traffic is too close when the maneuver is only partially completed.

Minimum passing sight distances for use in design are based on the minimum sight distances presented in the MUTCD as warrants for no-passing zones on two-lane highways. Design practice should be most effective when it anticipates the traffic controls (i.e., passing and no-passing zone markings) that will be placed on the highways. The potential for conflicts in passing operations on two-lane highways is ultimately determined by the judgments of drivers that initiate and complete passing maneuvers in response to (1) the driver's view of the road ahead as provided by available passing sight distance and (2) the passing and no-passing zone markings.

The design values for passing sight distance are presented in Table 2-5.08C. For this application, an eye height of 3.5 ft (1080 mm) and object height of 3.5 ft (1080 mm) are used.

Table 2-5.08C
PASSING SIGHT DISTANCES FOR THE DESIGN OF TWO-LANE HIGHWAYS

U.S. Customary				**Metric**			
Design speed (mph)	Assumed speeds (mph)		Passing sight distance (ft)	Design speed (km/h)	Assumed speeds (km/h)		Passing sight distance (m)
	Passed vehicle	Passing vehicle			Passed vehicle	Passing vehicle	
30	18	30	500	50	31	50	160
35	23	35	550	60	41	60	180
40	28	40	600	70	51	70	210
45	33	45	700	80	61	80	245
50	38	50	800	90	71	90	280
55	43	55	900	100	81	100	320
60	48	60	1000	110	91	110	355
65	53	65	1100	120	101	120	395
70	58	70	1200				
75	63	75	1300				

Passing sight distance applied in design should be based on a single passenger vehicle passing a single passenger vehicle. While there may be occasions to consider multiple passings – where two or more vehicles pass or are passed – it is not practical to assume such conditions under typical circumstances.

Vertical alignment needs to be coordinated with horizontal alignment and cross section design so that, where passing sight distance is intended to be provided, it is available in all three dimensions. Conversely, where horizontal obstructions limit sight distances, providing a vertical alignment based on attaining passing sight distance may not be beneficial.

The frequency and length of passing opportunities have an important influence on the level of service of two-lane highways. Passing opportunities should be provided frequently and be as long as practical, though subject to physical and cost limitations. In challenging terrain, it may be more economical to construct intermittent four-lane passing sections with stopping sight distance instead of two-lane sections with passing sight distance. See Provisions For Passing in Chapter 3. Analytical procedures are available in the *Highway Capacity Manual* (HCM) to determine level of service considering the passing sight distance profile of a design alternative. These procedures can be used to assess the benefit of providing various extents of passing sight distance or 4-lane passing sections. It should be noted that passing sections shorter than 400 to 800 feet have been found to contribute little to operational performance of 2-lane highways and should be excluded in these analyses.

2-5.08.03 Decision Sight Distance

Although providing stopping sight distance is usually sufficient under ordinary circumstances, it can be inadequate when drivers must make complex decisions, when information is difficult to perceive or when unexpected or unusual maneuvers are required. In these circumstances, providing longer sight distances can allow drivers to make evasive maneuvers rather than a full stop, often involving less risk and being otherwise preferable to stopping.

Decision sight distance is the distance needed for a driver to detect an unexpected or difficult-to-perceive condition, recognize the condition and its potential threat, select an appropriate speed and path, and perform the maneuver safely and efficiently. Drivers need decision sight distances whenever there is likelihood for error in information reception, decision-making, or control actions. Examples of situations where these kinds of errors are prone to occur include interchange and intersection locations where unusual or unexpected maneuvers are required, changes in cross section (such as lane drops), and areas of concentrated demand where there is visual noise from competing sources of information (e.g. roadway elements, traffic control devices or extra-roadway distractions).

The application of decision sight distance to highway design should be individually assessed at each location and subject to engineering judgment, feasibility, site constraints, and cost-effectiveness. For most practical purposes, providing a 10-second decision time – from the initial detection point to the location of the critical feature, based on design speed – is adequate. Use of values more than or less than 10 seconds may be judged appropriate as circumstances dictate.

For design purposes, the height of eye is 3.5 ft (1080 mm); the height of object is considered a variable, depending on the nature of the condition. Possible applications for decision sight distance and the corresponding object height are shown by the following examples:

1. For deceleration lanes at freeway interchanges, decision sight distance should desirably be provided to the beginning of the striped gore area; the height of object should be 0 ft (0 mm).
2. For conditions where decision sight distance is to be applied and taillights would be the critical feature or source of information to the driver – as may be the case at an intersection – the height of object should be 2 ft (600 mm).
3. For a driveway or minor road where intersection sight distance criteria is not deemed fully applicable, decision sight distance can be applied as an alternative criterion; in these cases, the height of object should be 4.25 ft (1300 mm).

In cases where providing 10-second decision sight distance is desired but not practical, special geometric, signing and/or delineation measures should be considered to aid in drivers' perception and decision making.

2-5.09 Terrain

Topography has great influence on the alignment and design speed of roads and streets. Although it affects horizontal alignment, its effects are more evident on vertical alignment. To characterize variations, topography is broken into three classifications for the purposes of highway design: level, rolling, and mountainous.

Level terrain generally permits the construction of a highway grade that fits the existing topography with minimal vertical departure from adjacent ground elevation. Sight distances are generally long or can be made long without construction difficulty or major expense.

Rolling terrain is characterized by highway grades requiring substantial soil excavation and fill operations to satisfy design criteria. In rolling terrain, natural slopes alternately rise and fall above and below the roadway grade. Occasional steep slopes may offer restrictions on vertical and horizontal alignments.

Mountainous terrain describes dramatic landforms with abrupt vertical relief, usually predominated by exposed bedrock. Mountainous topography poses significant challenges to highway construction, often necessitating benching and terraced rock cuts to obtain adequate alignments. Natural ground elevations with respect to the highway grade will be greatly variable and sometimes precipitous. Steep grades and sight distance restrictions are common.

Terrain classifications should pertain to the general character of the specific route corridor, not the geographic area. For example, a road constructed in a mountainous area but traversing a level stretch of topography should be designed using controls for level terrain.

2-5.10 Crash Data

A review of the crash history within project limits is an integral part of the design of any project. In particular, the designer should review high crash clusters, highway segment crash listings**,** and intersection crash listings provided by the Transportation Information System (TIS). The crash data is an important tool available to identify hazardous locations that may warrant corrections within the project limits. The TIS will provide data such as crash clusters, intersection or interchange crashes, roadway segment crashes, and crash characteristic listing reports. These data can then be used to develop intersection collision diagrams and strip collision diagrams, which are excellent analytical tools to identify safety deficiencies within the proposed project limits. The District Traffic Office also has information that can estimate the likely crash reduction of a proposed countermeasure and the benefit-cost ratio of the improvement.

The MnDOT Office of Traffic Engineering can prepare crash report summations for many data elements on the crash form. These data are disseminated to the districts, cities, counties, and individuals upon request. The Districts are responsible for maintaining trunk highway crash records in their area and to identify and analyze all locations with high crash history. Some cities maintain up-to-date crash spot maps, by either the police department or the engineering department.

The MnDOT Traffic Engineering Manual (TEM) Chapter 11, Traffic Crash Surveillance, provides a more thorough discussion of crash data availability and analysis.

2-6.0 DESIGN STANDARDS

Highway design standards are divided into two categories: critical design elements and general design elements. The following sections define these two categories and explain how they are applied to projects. Design elements are also listed with references to specific areas of the Road Design Manual and other sources for further information.

2-6.01 Critical Design Elements

The Federal Highway Administration (FHWA) designates ten critical design elements of primary importance to geometric design due to their effects on roadway safety and traffic operation. MnDOT designates one additional critical element—Ramp Length—due to its operational effect on mainline highways. Except as noted, they are applicable only on facilities with design speeds of 50 mph [80 km/h] or higher. They are as follows:

1. **Design Speed**
   This criterion applies to the full range of design speeds.
   Refer to 2-5.06.01 for general information and requirements.
   This is a fundamental design control, upon which standard values for all design speed-dependent elements are based. For this reason, FHWA states that design exceptions for Design Speed "should be extremely rare." Normally, a design speed value within the specified allowable range is selected, and individual design elements not meeting the associated criteria are cited as design exceptions. There are cases, however, where classification of an entire highway corridor or segment using a nonstandard design speed value is most representative of the road, its attributes and context, and is therefore appropriate.
2. **Lane Width**
   Refer to Technical Memorandum No. 18-08-TS-06 for design requirements and general information.
3. **Shoulder Width**
   Refer to Technical Memorandum No. 17-12-TS-05 for design requirements and general information.
4. **Horizontal Curve Radius**
   Refer to Chapter 3 for general information and requirements.
5. **Superelevation Rate**
   Superelevation exceeding the maximum rates designated in Chapter 3 requires a design exception.
6. **Stopping Sight Distance**
   Refer to 2-5.08.01 for general information and requirements.
7. **Maximum Grade**
   Refer to Chapter 3 for general information and requirements.
8. **Cross Slope**
   Refer to Chapter 4 for general information and requirements.
9. **Vertical Clearance**
   Refer to MnDOT LRFD Bridge Design Manual for design requirements and general information.
10. **Design Loading Structural Capacity**
    This criterion applies to the full range of design speeds.
    For new construction/reconstruction projects, any new or existing bridge that does not meet the standard loading requires a design exception. As with Design Speed, FHWA states that exceptions to this criterion should be extremely rare. For preservation projects, any existing bridge that fits the horizontal and vertical alignment of the roadway may remain in place without any requirements for structural capacity. For improvement projects, bridges should meet the minimum inventory load requirements of the MnDOT Bridge Preservation, Improvement and Replacement Guidelines. A design exception is required if the bridge does not meet these guidelines.
11. **Ramp Length**
    This criterion applies to the full range of ramp, loop and mainline design speeds. Chapter 6 as amended by Technical Memorandum No. 19-01-TS-01 provides standard acceleration and deceleration lengths for ramps and loops.

For preservation projects, the design standards for the critical elements are the existing conditions or the new construction / reconstruction standards, whichever is less. Preservation standards are not applicable on freeways; in other words, the design standard for preservation-type projects on freeways is the new construction / reconstruction standard. The MnDOT Bridge Preservation, Improvement and Replacement Guidelines document contains the bridge preservation design standards.

Where the new construction / reconstruction or preservation standards for the critical design elements cannot be attained, a formal design exception is required. The consideration given to safety, maintenance, or other improvements as part of preservation projects should be addressed in the appropriate project documents.

2-6.02 General Design Elements

There are many general design elements that are common to most projects. These elements and the typical design values, policies, and practices that have been developed for them are referenced below.

General design elements included in new construction/reconstruction projects should normally meet the standard value for that element. Preservation projects may modify these elements as warranted to correct performance deficiencies. Although designers do not have to document design exceptions if these standards cannot be met, they must discuss any judgments and decisions in the project documents.

The following list includes some of the general design elements that are often encountered:

Alleys
For information, refer to AASHTO guidelines.
Backslopes
Refer to Chapter 4 for design guidance, requirements, and ditch traversability guidelines.
Bikeways
Refer to Chapter 11, the MnDOT Bicycle Facility Design Manual, and the Minnesota GO Statewide Bicycle System Plan for design assistance, requirements, and route designations.
Clear Zone
Refer to Chapters 4 and 10 and AASHTO's "Roadside Design Guide" for design information, guidance, and requirements.
Climbing Lanes
Refer to Chapter 3 for design guidelines and requirements.
Continuous Rumble Strips
Refer to Chapter 4 for design guidance and general information.
Curbs
Refer to Chapter 4 for design guidance and requirements.
Curb Ramps
Refer to Chapter 11 and Standard Plans .200 series for design guidance and requirements.
Drainage
Refer to Chapter 8 for design guidance.
Entrances and Driveways
Refer to Chapter 5 for design guidance and requirements.
Erosion Control
Refer to Chapter 8 for design guidance on current practices.
Frontage Roads
Refer to Chapters 4 and 6 for proper design and location of frontage roads.
Roadside Slopes
Refer to Chapter 4 for design requirements and general guidance.
Interchanges
Refer to Chapter 6 for design guidance and information.
Intersections
Refer to Chapter 5 for design criteria and general information.
Lighting
Refer to Chapter 10 and the MnDOT Traffic Engineering Manual for design information.

Mailbox Supports
Refer to Chapter 11 for design guidance and requirements.
Medians
Refer to Chapter 4 for information on medians. Refer to Chapter 5 for information on median openings.
Noise Abatements
Refer to Chapter 11 for design guidance and information.
Operational Improvements to Two-Lane Highways (Passing Lane Sections)
Refer to Chapter 3 for design guidance and general information.
Park and Ride Facilities
Refer to Chapter 11 for design information. Park and ride facilities are desirable at locations where it is beneficial for commuters to park and use public transit or ride share.
Parking Lanes
Refer to Technical Memorandum No. 17-12-TS-05 for design information. Parking lanes may be provided on low-speed urban and suburban facilities.
Pedestrian Traffic and Crossings
Refer to Chapter 11 and the MnDOT Traffic Engineering Manual for design guidance and information.
Rail Crossings
Refer to Chapter 11 for design guidance and information.
Rest Areas
Refer to Chapter 11 for design information. Rest areas are desirable on facilities with long distances between towns. Rest areas provide a safe area to recover from the effects of fatigue.
Retaining Walls
Refer to Chapter 9 for design guidance and information.
Sidewalk
Refer to Chapter 11 for widths, location, and general information.
Sight Distances
Refer to Section 2-5.08 for definitions. Refer to Chapter 3 for application to horizontal and vertical curves.
Signals
Refer to the MnDOT Traffic Engineering Manual for design guidance and general information.
Signing and Marking
Refer to the MnDOT Traffic Engineering Manual for guidance and general information.
Special Freeway Designs
Several examples exist in the AASHTO publication "A Policy on Geometric Design of Highways and Streets" including reverse-flow freeways, dual-divided freeways, collector/distributor roads, and exclusive bus and high-occupancy vehicle (HOV) lanes.
Terminals (Turn Arounds, Cul-de-Sacs, etc.)
Refer to Chapter 4 of the Road Design Manual and Chapter 5 of AASHTO's "A Policy on Geometric Design of Highway and Streets" for design guidance and general information.
Traffic Barriers
Refer to Chapter 10 for current design guidance and requirements.
Traffic Control Devices
Refer to the MnDOT Traffic Engineering Manual for guidance and standards.
Tunnels
Refer to Chapter 9 of the Road Design Manual and Chapter 4 of AASHTO's "A Policy on Geometric Design of Highway and Streets."
Turf Establishment and Landscape
Refer to Chapters 8 and 11 for design guidance and requirements. Turf establishment is provided where ground cover is disturbed.
Turn Lanes
Refer to Chapter 5 for design information and requirements.
Utilities
Refer to the MnDOT Utility Accommodation & Coordination Manual.

2-6.03 Geometric Design Exceptions

When a project design includes geometric elements that fail to satisfy minimum criteria as set forth by MnDOT policy, a design exception is required. Failure of a design to meet the standard for any of the critical design elements requires approval of a *Formal Design Exception.* If the standard for any general design element is not met, an *Informal Design Exception* should be documented.

2-6.03.01 Formal Design Exceptions

MnDOT's general practice is to right-size project designs, which usually satisfies standard criteria for the critical design elements (a.k.a. controlling criteria, as defined by FHWA). However, standard values for these elements should not be strived for at all costs. On occasion, the judicious application of good design practice and engineering judgment—including balanced consideration of functional, modal, safety, economic, environmental and context-related factors—involves the use of sub-standard critical design elements to fashion an appropriate solution and achieve project goals. In these cases, formal documentation and processing of the design exceptions and their justification is required.

U.S. Federal policy on application of design standards—as well as evaluation and approval procedure for design exceptions—on the National Highway System is provided in rulemaking dated November 1, 2018 to the Code of Federal Regulations (CFR), Title 23. It states, "For most situations, there is sufficient flexibility within the range of acceptable values to achieve a balanced design. However, when this is not possible, a design exception may be appropriate. State and local agencies may consider designs that deviate from the design standards when warranted based on the conditions, context, and consequences of the proposed projects."

Design documentation requirements for projects with or without design exceptions are provided in the MnDOT Highway Project Development Process (HPDP) Handbook. Pertinent information such as functional classification, traffic volume and project description are recorded, as are tabular existing and proposed values for the critical design elements and a written justification for the exception(s).

The design exception justification should address the stated evaluation components outlined in Federal guidance on the subject. It states, "All proposed design exceptions should be thoroughly analyzed and the potential impacts understood before approval. The process to evaluate and justify design exceptions must be based on an evaluation of the context of the facility (e.g., community values), needs of all the various project users, safety, mobility (i.e., traffic performance), human and environmental impacts, project costs, and other impacts." It goes on to outline recommended documentation elements: specific design criteria that will not be met; existing roadway characteristics; alternatives considered; comparison of the performance of the roadway against various contextual and environmental factors; proposed mitigation measures; and compatibility with adjacent sections of roadway. The assembled components and supporting data should represent a compelling basis for proposed solution. A rule of thumb for successful design exception justification is that two conditions are successfully asserted:

1. No reasonable, feasible, and practical solution can be devised to provide standard values for the critical design elements in question, OR the selection of a non-standard value or values for these elements is advantageous in some way or ways and results in an overall superior design.
2. Use of non-standard values for the elements in question will not be expected to unduly degrade the safety or operational performance of the proposed facility for any users.

2-6.03.02 Informal Design Exceptions

As with critical design elements, the Department's policy for general design elements is to adhere to standard design criteria where practical, reasonable, and beneficial. In cases where substandard values for general elements are applied, some documentation of these informal design exceptions should be included in the project file. Although the level of formality and degree of justification in documenting informal exceptions will generally be less than for formal exceptions, compelling reasoning for the variance and considerations taken into account in the decision-making process should always be provided.

It is understood that not every piece of design information presented in this manual or in AASHTO publications is considered a "design standard" but would more appropriately be described as good engineering practice. The designer should exercise judgment in discerning which general elements and design attributes are deserving of documentation when compromised.

2-7.0 DESIGN PROCEDURES

2-7.01 Design Memorandums

Design Memorandums document project design concepts, standards and exceptions, and indicate whether a project will meet or exceed the minimum standards of the thirteen critical design elements. MnDOT's Highway Project Development Process Handbook contains further clarification on the use of Design Memorandums.

2-7.02 Coordination With Functional Groups

The designer is responsible for properly coordinating with functional groups by contacting them and providing and/or receiving information and guidance concerning specific areas of a project. The functional groups that need to be involved will vary from project to project. Some of the common ones are:

1. Materials;
2. Hydraulics;
3. Bridge;
4. Municipal Agreements;
5. Utilities Agreements and Utility Permits;
6. Special Provisions;
7. Engineering Cost Data and Estimating;
8. Surveying and Mapping;
9. Traffic, Security and Operations;
10. Maintenance;
11. Construction and Innovative Contracting;
12. Environmental Services;
13. Cultural Resources;
14. Right of Way or Land Management; and
15. State Aid.

2-7.03 Intermodal Coordination

The designer is responsible for properly coordinating with intermodal groups inside and outside the Department by contacting each group that the project may affect in the present or the future. Proper coordination with intermodal groups reduces costly mistakes and may save dollars by combining projects. The intermodal groups are able to determine proper procedures, directions**,** and time frames needed to complete reviews of each project. The intermodal offices to consider contacting for each project are:

1. Freight and Commercial Vehicle Operations;
2. Transit, including the Bicycle and Pedestrian Sections; and
3. Aeronautics.

2-7.04 Agency/Department Coordination

The designer is responsible for coordinating with the different agencies and/or departments that a project may affect. Some of them are:

1. Federal agencies
    a. United States Department of Transportation
    b. U.S. Coast Guard
    c. U.S. Department of Agriculture, Natural Resources Conservation Services
    d. U.S. Army Corps of Engineers
    e. U.S. Environmental Protection Agency
    f. U.S. Fish and Wildlife Service
2. State agencies
    a. Minnesota Historical Society
    b. Minnesota Department of Natural Resources (DNR)
    c. Minnesota Department of Public Safety (DPS)
    d. Minnesota Pollution Control Agency (MPCA)
    e. Minnesota Environmental Quality Board (MEQB)
    f. Minnesota Board of Water and Soil Resources

3. Counties
4. Municipalities
5. Metro and other regional groups
    a. Metropolitan Council of the Twin Cities
    b. Metropolitan Airports Commission (MAC)
    c. Local planning agencies
    d. Watershed districts
6. National Transportation service groups
    a. American Association of State Highway and Transportation Officials (AASHTO)
    b. Transportation Research Board (TRB)

2-8.0 REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2018

2. *Highway Capacity Manual*, Transportation Research Board, 2016

3. *Design Standards for Highways—Final Rule*, Federal Register, Vol. 83, No. 212, November 1, 2018

4. *Memo: Revisions to the Controlling Criteria for Design and Documentation for Design Exceptions*, U.S. Department of Transportation, Federal Highway Administration, May 5, 2016

5. *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements*, AASHTO, 1977

6. *Economic Analysis for Highways*, Robley Winfrey, International Textbook Company, 1969

7. *A Guide for Achieving Flexibility in Highway Design*, AASHTO, May 2004

8. *Older Driver Highway Design Handbook*, FHWA, January 1998

9. *Application of Design Standards, Uniform Federal Accessibility Standards, and Bridges*, FHWA

10. *Highway Design and Operational Practices Related to Highway Safety*, AASHTO, 2nd Edition, June 1974

11. *Roadside Design Guide*, AASHTO, 2011

12. *Passing Sight Distance Criteria*, NCHRP Report 605, Transportation Research Board, 2008

13. *Bridge Preservation, Improvement and Replacement Guidelines*, MnDOT, 2006

14. *Geotechnical and Pavement Manual*, MnDOT

15. *LRFD Bridge Design Manual*, MnDOT

16. *Traffic Engineering Manual*, MnDOT

17. *State Aid Manual*, MnDOT

18. *Right of Way Manual*, MnDOT

19. *Bicycle Facility Design Manual*, MnDOT, February 2020