FDM 11-1-1 General Design Introduction

November 15, 2022

1.1 Originator

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1.2 General Introduction

This Chapter includes the established policies, design criteria and guidelines for application on all highways and streets being designed by or for WisDOT. The design information presented is based primarily on policies, design criteria, and specifications adopted by the American Association of State Highway and Transportation Officials (AASHTO). AASHTO publications are frequently referred to throughout this Chapter and are intended to supplement the design information presented. The letters GDHS will be used to represent various editions of the AASHTO publication "A Policy on Geometric Design of Highways and Streets."

The basic criteria that govern the design and selection of traffic control devices are found in the latest edition of the U.S. DOT publication, "Manual on Uniform Traffic Control Devices for Streets and Highways" (MUTCD). This publication defines national design criteria and provides the necessary uniformity in application of control devices. The provisions of the MUTCD are further interpreted or modified by the Wisconsin DOT supplement to the MUTCD, and by specific provisions of this Facilities Development Manual. The purpose of traffic control devices and the warrants for their use, as stated in the MUTCD, is to help ensure highway safety by providing for the orderly and predictable movement of all traffic.

Safety is a prime consideration in the development of all designs. A performance-based safety engineering analysis and economic appraisal must be used to determine cost and safety effectiveness. See FDM 11-38.

Regarding Wisconsin State Statutes, design criteria are design standards.

FDM 11-1-5 Asset Management by a Practical Design System Preservation Approach May 17, 2022

5.1 Federal Highway Administration (FHWA) Perspective on Performance-Based Practical Design[1]

State Departments of Transportation (DOT) are increasingly challenged with addressing their system performance, mobility, and safety needs in the current era of financial limitations.

The Federal Highway Administration (FHWA) conducted an in-depth review of the Practical Design concept, including interviewing several States about their practices.

Though the name, definition, and approach of Practical Design vary from state to state, most states with a Practical Design program emphasize a renewed focus on scoping projects to stay within the core purpose and need. By exercising a greater level of discipline, agencies may eliminate nonessential project design elements resulting in lower cost and improved value. This approach enables states to deliver a greater number of projects than otherwise possible under their previous project development approaches. By implementing Practical Design, states realized cost savings by utilizing flexibility that exists in current design guidance and regulations.

Some states implementing Practical Design, as well as FHWA, have expressed concern that there may have been an overemphasis on short-term cost savings without a clear understanding of how such decisions could impact other objectives (such as; safety performance, context sensitivity, life-cycle costs, long-range corridor goals, livability, and sustainability).

To address this concern, agencies can make more informed decisions by evolving towards a Performance Based Practical Design (PBPD) approach grounded in a performance management framework. PBPD can be articulated as modifying the traditional design approach to meet both project and system objectives. PBPD uses appropriate performance-analysis tools and considers both short and long-term project and system goals while addressing project purpose and need.

The key to addressing geometric design and safety elements of a projects purpose and need is knowledge of the past safety performance of the location. This is essential for evaluating risk. Designers need a full knowledge of the expected substantive safety performance of the project locations. A project location exhibiting acceptable, long-term safety performance relative to expectation, despite having design features that do not meet current criteria, may indicate a lower level of risk.

See FDM 3-5-1 for asset management information and guidance.

5.2 WisDOT Perspective on Performance-Based Practical Design

The term Performance-Based Practical Design consists of two components:

- Performance-based means that any engineering changes to a highway are based on the actual performance benefits to that highway, rather than whether it is built to a certain standard or criteria.
- Practical design is an approach that starts with addressing only those issues that have been identified as being needed to meet the project specific purpose and need.

Substandard is not the same as deficient. If no discernable safety issues exist in a roadway segment, then the existing configuration can be maintained.

Upgrading to a certain standard may not be the most cost-effective solution. If discernable safety issues are present, project level engineering, standardized safety screening, and appropriate economic analysis is required to ensure the potential design elements will provide the appropriate performance and most reasonable financial cost benefit.

The Department utilizes a PBPD tool for pavement treatments and safety-driven geometric alterations. It includes safety screening to identify safety flags, but also applies a safety certification process that uses performance-based engineering and system-based economic analysis to ensure the right solutions are implemented at the right time, in the right locations.

The flexibility in design guidance and regulations provided in PBPD as described by FHWA is founded in having the appropriate analysis of past and expected future safety performance. PBPD considers individual project investment decisions within the broader context of overall system-wide performance. The engineering methods and documentation that correlates that safety analysis to appropriate design is the key to successfully executing

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[1] Federal Highway Administration; “Performance-Based Practical Design”;

https://www.fhwa.dot.gov/design/pbpd/general_information/index.cfm; 1200 New Jersey Avenue, SE; Washington, DC 20590; 2017

PBPD.

Frequently asked questions related to PBPD are answered at the Wisconsin DOT Public Webpage.

FDM 11-1-10 Application of Design Criteria *May 17, 2022*

Application of geometric design criteria to a project will depend upon the type of facility and the nature of the project. The design criteria in this chapter apply to state-funded and Federal-Aid projects. FHWA also accepts the values given in the following documents that can be applied when the criteria are not addressed in this chapter:

1. Interstate Highways - A Policy on Design Standards - Interstate System, 2016, AASHTO (see FHWA website, “Interstate System”, https://www.fhwa.dot.gov/programadmin/interstate.cfm, under “Interstate Design Standards”)
2. Non-Interstate Highways - A Policy on Geometric Design of Highways and Streets, 7th edition, AASHTO 2018 (see FHWA website, “Geometric Design”, https://www.fhwa.dot.gov/programadmin/standards.cfm, under “Information”)
3. Off System Roads - Refer to Chapter 5, 6, and 7 of 2018 GDHS.

10.1 S-1 Application

S-1 application involves the retention and restoration of the roadways existing geometric and cross-sectional features to satisfy the purpose and need of the project.

S-1 will be applied if no discernable safety issues are present as determined by the Safety Certification Document (SCD). Restore existing highway features to satisfy project purpose and need. S-1 will also be applied where safety issues will be mitigated by the addition of low-cost counter measures.

Projects using S-1 applications include Perpetuation and portions of some Rehabilitation Improvement Strategies as defined in FDM 3-5-1.

FDM 11-1 Attachment 10.1 shows the relationship between Improvement Strategies, Improvement Concepts and Application of Design Criteria.

10.2 S-2 Application

Use S-1 application on the project corridor except for specific areas with corrective actions as identified and justified through safety, operation, environmental or ancillary factor evaluations.

S-2 application will involve use of the lower end of the design criteria ranges (where a range exists) as a starting point for the corrective actions. Apply PBPD principles to satisfy project purpose and need.

Projects using S-2 application are Rehabilitation Improvement Strategies as defined in FDM 3-5-1.

FDM 11-1 Attachment 10.1 shows the relationship between Improvement Strategies, Improvement Concepts and Application of Design Criteria.

10.3 S-3 Application

Use upper end of the design criteria ranges (where a range exists) as a starting point. Apply PBPD principles to satisfy project purpose and need.

Projects using S-3 applications include Modernization Improvement Strategies as defined in FDM 3-5-1.

FDM 11-1 Attachment 10.1 shows the relationship between Improvement Strategies, Improvement Concepts and Application Criteria.

10.4 Ancillary Factors

During scoping and design, potential needs may be identified that require further analysis and possible design alterations or additions. These are referred to as Ancillary Factors. Identification of these factors likely are or may be independent of safety analysis. These factors will require additional analysis to determine their validity. If they are found valid, they may require alterations or additions to the current design. They include:

- Remaining Pavement Life-cycle service life (Assessed by Pavement Design)
- System continuity considerations and user expectancy considerations
- Existing or proposed bicycle or pedestrian routes
- Existing or proposed oversize-overweight (OSOW) routes
- Traffic calming measures, traffic stratification measures or corridor classification changes

- Regional or municipal planning documents showing:
  - Intended future development needs, especially if imminent
  - Land use zoning changes
- County or local government concern
- Concern by other agencies or governmental entities, safety commission comments made
- Public input and/or concern
- Known detour or work zone traffic staging/operations issues
- Environmental impact or commitments
- Sociological or societal factors
- Consistency of intersection/interchange types in the area (driver expectancy)
- Ripple effects (i.e. when addressing one issue inadvertently creates another issue; unintended consequences)

Presence of one or more of these factors may require addition of alignment, profile, cross-sectional or other feature changes or additions to a highway project.

Presence of a given factor or factors does not *require* the designer to address them by including changes or additions. Careful consideration should be given to the magnitude and immediacy of the need balanced against the purpose and need for the current project. For example: a given factor may not be addressed with a current project if a more substantial subsequent project is expected.

Ultimately all potential additions to a design should ensure theme compliance and consistency with program effectiveness. Coordination and consultation should occur between the region, BPD and DTIM Office of Asset and Performance Management (OAPM) to ensure program effectiveness and theme compliance. Where possible project staff should develop a numerically quantifiable evaluation to demonstrate a cost benefit to a proposed improvement based on safety, operation, or quality improvement.

Absence of these factors should indicate that no further consideration of project feature or geometric and cross-sectional changes are required.

Discussion of Ancillary Factors analysis should be included in the Final Scope Certification if identified during scoping (preferred), otherwise discuss in the Design Study Report. Any action taken to address these, or decisions taken to eliminate their consideration should be included as part of this discussion.

LIST OF ATTACHMENTS

Attachment 10.1	Improvement Strategies, Improvement Concepts, and Design Criteria Applications

FDM 11-1-15 Programmatic Exception to Standards — *November 30, 2018*

Programmatic Exception to Standards (PES) process has been superseded with the Safety Certification Process (SCP) (FDM 11-38). During the implementation of the SCP, projects that are at LC11 or higher which have a completed Safety Screening Analysis (SSA) and been determined to meet PES based on the former SSA/PES procedures, do not need an SCD. The applicability of the PES should be documented in the Design Study Report (DSR) and the SSA should be attached to the DSR.

FDM 11-1-20 Design Justifications (Formerly Exceptions to Standards) — *May 17, 2022*

20.1 General

Design Justifications are required for engineering decisions which fall outside design criteria and are not recommended by the Safety Certification Document (SCD). SCD decisions which fall outside the criteria do not require additional documentation as design justifications.

For any project that does not use the Safety Certification Process (SCP), Design Justifications are required for all engineering decisions which fall outside of ranges.

20.1.1 Justification (Exception) Process

A Design Justification (exception to standards) is a documented decision to design a highway element or a segment of highway to design criteria that fall outside design criteria established for that highway or project.

From “FHWA-SA-07-011: Mitigation Strategies for Design Exceptions.”[2], page 3:

- “Designers and engineers are faced with many complex tradeoffs when designing highways and streets. A good design balances cost, safety, mobility, social and environmental impacts, and the needs of a wide variety of roadway users. Good design is also context-sensitive - resulting in streets and highways that are in harmony with the natural and social environments through which they pass.
- Highway design criteria that have been established through years of practice and research form the basis by which roadway designers achieve this balance. These criteria are expressed as minimum dimensional values or ranges of values for various elements of the three-dimensional design features of the highway. The criteria are intended to deliver an acceptable, generally cost-effective level of performance (traffic operations, safety, maintainability, and constructability). The criteria are updated and refined as research and experience increase knowledge in the field of highway engineering, traffic operations, and safety.
- Designers are trained to use accepted design criteria throughout the project development process. Striving to meet design criteria is important because it is the primary means by which a resultant high-quality roadway will be produced. A highway or roadway that reflects full compliance with accepted design criteria decreases the probability that safety problems will develop. Using design values that lie within typical ranges thus provides a high degree of quality control and reduced risk.
- It must be recognized, however, that to achieve the balance described above, it is not always possible to meet design criteria. There is a wide variety of site-specific conditions and constraints that designers encounter. Roadways have a multitude of contexts. Establishing design criteria that cover every possible situation, each with a unique set of constraints and objectives, is not possible. On occasion, designers encounter situations in which the appropriate solution may suggest that using a design value or dimension outside the normal range of practice is necessary. Arriving at this conclusion requires the designer to understand how design criteria affect safety and operations. For many situations, there is sufficient flexibility within the design criteria to achieve a balanced design and still meet minimum values. However, when this is not possible, that is when a design exception may be considered.”

Despite the range of flexibility that exists with respect to virtually all the major road design features, there are situations in which the application of even the lowest end of the design criteria would result in unacceptably high costs or major impacts to the human or natural environment. In these situations, Design Justification allows for the use of criteria below those specified as lowest values in Chapter 11 of the FDM for the controlling criteria listed in Table 20.1a. Projects on the National Highway System (NHS) must conform to the FHWA prescribed standards (as specified in 23 C.F.R. 625) regardless of the source of funding.

The determination to approve a project design that does not conform to the lowest criteria is to be made only after due consideration is given to all project conditions such as:

- Maximum service and safety benefits for the dollar invested,
- Compatibility with adjacent sections of roadway, and
- The probable time before reconstruction of the section due to increased traffic demands or changed conditions.

Design Justifications may be given on a project basis to designs that do not conform to the lowest criteria, as set forth in the FDM or other applicable design manual, for:

- Experimental features on projects; and
- Projects where conditions warrant that exceptions be made.

The FHWA and WisDOT Stewardship & Oversight Agreement, and its amendments, specify project responsibilities, including approval authority for Design Justification (exceptions to standards) (see FDM 5-2-1 and its Exhibits).

[2] Stein, W.J. and T. R. Neuman. FHWA-SA-07-011: Mitigation Strategies for Design Exceptions. Federal Highway Administration, Office of Safety, Washington, DC, 2007. https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/fhwa_sa_07011.pdf

20.2 Applicability

The provisions of this procedure apply to improvements[3] on the following roads, regardless of who is designing, constructing, or administering the improvement, including improvements resulting from permits, Traffic Impact Analysis Reports, etc.:

- National Highway System (NHS) routes[4]., regardless of system, regardless of funding source; (https://www.fhwa.dot.gov/planning/national_highway_system/nhs_maps/wisconsin/index.cfm)
- STH, USH and Interstate routes, regardless of funding source;
- Connecting Highways[5], regardless of funding source;
- Business Routes[6], regardless of funding source;
- CTH routes, regardless of funding source;
- Town Roads, regardless of funding source;
- City or Village roads for improvements that have state or federal funding. (NOTE: City or Village roads that are not part of one of the above listed systems do not require WisDOT or FHWA approval for Design Justifications on improvements that are 100% locally funded (i.e., no state or federal funding)).

20.3 Controlling Criteria

On May 5, 2016, FHWA issued a memo, https://www.fhwa.dot.gov/design/standards/160505.cfm, revising and reducing the number of Controlling Criteria.

Design Justifications shall be processed whenever the controlling criteria shown in Table 20.1a and Table 20.1b cannot be met. For those criteria that are related to speed, the Design Justification shall be based on the design criteria for the design speed for the appropriate segment of the project.

Table 20.1a Controlling Criteria for Freeway / Expressway Projects regardless of Design Speed, and for Non-Freeway / Non-Expressway Projects with a Design Speed of 50 mph or Greater

Controlling Criteria	Speed Related
Design Speed	*
Lane Width	
Shoulder Width	

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[3] Section 84.06, Wis. Statutes Highway construction. (1) DEFINITIONS. In this section: (a) Subject to par. (b), “improvement” or “highway improvement” includes all of the following: 1. Construction, reconstruction, rehabilitation, and processes incidental to building, fabricating, or bettering a highway or street. 2. Highway operations or activities that are life−cycle or investment driven and that are based on an asset management philosophy in which taking action adds service life by preventing or delaying deterioration of highway system functionality. (b) “Improvement” or “highway improvement” does not include any of the following: 1. Maintenance activities described in s. 84.07 (1). 2. The installation, replacement, rehabilitation, or maintenance of highway signs, highway lighting, or pavement markings or the maintenance of traffic control signals or intelligent transportation systems, unless incidental to building, fabricating, or bettering a highway or street.

[4] FDM 5-2 Project Action Responsibility Matrix (Appendix A of FHWA and WisDOT Stewardship & Oversight Agreement, September 2015).

[5] Section 84.03(10), Wis. Statutes “Federal aid; state and local funds. IMPROVEMENT OF CONNECTING HIGHWAYS. All connecting highways shall be constructed or reconstructed by the state in the same manner as portions of the state trunk highway system. It shall not be compulsory for the state to construct or reconstruct any such highway to a greater width than those portions of the state trunk system connecting therewith.”

[6] Section 84.02 (6), Wis. Stats “State trunk highway system. ALTERNATE ROUTES THROUGH CITIES, VILLAGES AND TOWNS. In cases where any state trunk highway passes near but not through the central or business portion of any city, village or town, the department may upon petition of any city, village or town designate an alternate route through such central or business portion, and shall install suitable marking to guide travelers over such alternate route. No such designation shall be made unless the department finds that public travel will be benefited. Any such designation may be revoked on 30 days’ notice to the city, village or town if the department finds that public travel is not benefited. Such designation shall impose no responsibility on the state, except the cost of marking in the first instance. Such alternate routes shall be constructed and maintained and kept clear of snow, in a condition satisfactory to the department without expense to the state, and the department may require assurances to that effect before making such designation.”

Horizontal Curve Radius	*
Superelevation Rate	*
Stopping Sight Distance	*
Maximum Grade	*
Cross Slope	
Vertical Clearance	
Design Loading Structural Capacity	

***Table 20.1b* Controlling Criteria for Non-Freeway / Non-Expressway Projects with a Design Speed of Less than 50 mph**

Controlling Criteria	Speed Related
Design Speed	*
Design Loading Structural Capacity	

See chapter 3 of FHWA SA-07-011(1) for additional technical information on the controlling criteria, including clarifications on when Design Justification (formal design exceptions) are required and the potential impacts to traffic operations or substantive safety that a designer should consider when evaluating Design Justifications (design exceptions) and mitigation strategies. Also, see NCHRP Report 783[7] for information on Design Criteria, Traffic Operational and Safety Effects, and Mitigation Strategies for the Controlling Criteria.

20.4 Approval Authority

Table 20.2 illustrates the level of approval that must be obtained for Design Justifications. These levels of approval are determined based on the highway system on which the project is located.

The Federal-Aid Oversight Agreement that is included as Attachment A of the FHWA and WisDOT Stewardship Agreement specifies that FHWA has approval authority for all Design Justifications on the NHS. An amendment to this agreement delegates additional approval actions to WisDOT, including approval authority for some Design Justification on the NHS. FHWA has not delegated approval authority on projects defined as either “Projects of Corporate Interest” (PoCI), or “Projects of Division Interest” (PoDI). A PoDI could be either a Mega-PoDI or a non-Mega PoDI. All other projects, including those on the NHS, are defined as “Delegated Projects” on which WisDOT has final approval of Design Justifications[8].

NOTE: FHWA's approval of design justifications (formerly exceptions) for all highway improvement projects on the NHS or Interstate System is considered to be a Federal Administrative Action (as specified in 23 CFR 771.107). The approval of design justifications (formerly exceptions) by FHWA is a Federal Administrative Action even if:

- The project does not utilize Federal-Aid highway funding, and
- FHWA is not involved in the review and approval of project level environmental documentation for the purposes of complying with the National Environmental Policy Act (NEPA) requirements.

[7] Harwood, D.W., J. M. Hutton, C. Fees, K. M. Bauer, A. Glen, H. Ouren, MRIGlobal, Quincy Engineering, and HQE, Inc. NCHRP Report 783: Evaluation of the 13 Controlling Criteria for Geometric Design. Transportation Research Board of the National Academies, Washington, DC, 2014. https://www.trb.org/Publications/Blurbs/171358.aspx

[8] FDM 5-2 Exhibit 1.1, FH*WA and WisDOT Stewardship & Oversight of Projects through Implementation of a Risk-Based Approach,* Attachment 2, “Project Approval Responsibilities List” under Detailed/Final Design: Design Exceptions (13 controlling criteria) (23 CFR 625.3), page 14

Table 20.2 Approvals for Design Justifications

Highway or Road		Funding Source	Project Defined As: Delegated – Approval(s) – Initial	Delegated – Approval(s) – Final	non-Mega-PoDI – Approval(s) – Initial	non-Mega-PoDI – Approval(s) – Final	PoCI or Mega-PoDI – Approval(s)
NHS route	STH, USH, Interstate [A]	ANY [B]	Region [C]	BPD [D]	Region [C]	(1) BPD [D] (2) FHWA [E]	Per Project Agreement
	Connecting Highway	ANY [B]	(1) City or Village (2) Region [C]		(1) City or Village (2) Region [C]		
	Business Route on City, Village or Town road	ANY [B]	(1) City, Village or Town (2) Region [C]		(1) City, Village or Town (2) Region [C]		
	City or Village Road, non-Business Route, non- Connecting Highway	ANY [B]	(1) City or Village (2) Region [C]		(1) City or Village (2) Region [C]		
	CTH	ANY [B]	(1) County (2) Region [C]		(1) County (2) Region [C]		
	Town Road, non-Business Route	ANY [B]	(1) Town (2) Region [C]		(1) Town (2) Region [C]		
Non-NHS route	STH, USH	ANY [B]	Region [C]	BPD [D]	Region [C]	(1) BPD [D] (2) FHWA [E]	
	Connecting Highway	ANY [B]	(1) City or Village (2) Region [C]		(1) City or Village (2) Region [C]		
	Business Route on City, Village or Town road	ANY [B]	(1) City, Village or Town (2) Region [C]		(1) City, Village or Town (2) Region [C]		
	City or Village Road, non-Business Route, non- Connecting Highway	State or Federal	(1) City or Village (2) Region [C]		(1) City or Village (2) Region [C]		
	CTH	State or Federal	(1) County (2) Region [C]		(1) County (2) Region [C]		
	Town Road, non-Business Route	State or Federal	(1) Town (2) Region [C]		(1) Town (2) Region [C]		
	City or Village Road, non-Business Route, non- Connecting Highway	City, Village, or Private	City or Village	City or Village	(1) City or Village (2) Region [C]	(1) BPD [D] (2) FHWA [E]	
	CTH	County or Private	County	Region [D]	(1) County (2) Region [C]		
	Town Road, non-Business Route	Town or Private	Town	Region [D]	(1) Town (2) Region [C]		

(1) First Signature

(2) Second Signature

(A) The National Highway System (NHS) includes the Interstate Highway System.

(B) This includes funding from any source whatsoever, for example, the federal government, state government, local government(s), grants, private citizens and businesses.

(C) The Region Project Development Section (PDS) Chief is the Department's initial approval authority for projects that are not administered by the Local Program Unit.

The Region Local Project Manager is the Department's initial approval authority for projects that are administered by the Local Program Unit.

The Region Director is the Department's initial approval authority for Design Justifications on non-Mega PoDI Projects on County Trunk Highways financed totally by a County (in accord with Administrative Code TRANS 205.04); and for Design Justifications on non-Mega PoDI Projects on non-Business Route Town Roads financed totally by a Town (in accord with Section 82.50(2) Wis. Stats.)

(D) The DTSD BPD Project Services Section Chief is the Department's final approval authority, except that the Region Director is the Department's final approval authority for Design Justifications on Delegated Projects on County Trunk Highways financed totally by a County (in accord with Administrative Code TRANS 205.04); and for Design Justifications on Delegated Projects on non-Business Route Town Roads financed totally by a Town (in accord with Section 82.50(2) Wis. Stats.)

(E) FHWA is the final approval authority for Design Justifications on non-Mega PoDI projects, regardless of funding source.

20.5 Procedure

Requests for Design Justification shall be documented as part of the Design Study Report (DSR). See FDM 11-4-10.

FDM 11-1-25 Metric to US

November 30, 2018

WisDOT no longer uses metric units for highway design. However, there are numerous Metric as built plans because many projects were designed using metric design criteria. WisDOT used metric units for highway design during the1990's and early 2000's.

WisDOT used the International System of Units (SI). An international standard, called "ASTM E380," provides guidelines for the proper use of SI metrics. WisDOT used that standard, except that the American spelling of liter and meter were used, rather than the French litre and metre.

25.1 Metric Units

25.1.1 Basic Units

All units are based on decimal mathematics. Basic units that apply to highway design are:

1. **Meter** (m): The basic measure of distance in the metric system.
2. **Liter** (L): The metric system's basic measure of liquid.
3. **Gram** (g): For weighing small quantities.
4. **Time** (s): The second, the basic measure of time, remains the same as in the U.S. system.
5. **Temperature** (°C): The basic unit of temperature is the degree Celsius. This scale defines the freezing point of water as 0°C and the boiling point as 100°C.
6. **Angles**: Although the radian is the metric unit of angular measure, WisDOT continued to measure plane angles using degrees (°), minutes (‘) and seconds (“).

25.1.2 Special Units

These basic metric units have been used to develop special units of measure to describe other measurable attributes as listed in Table 25.1.

Table 25.1 Special Metric Units

Measurable Attribute	Unit	Symbol	Expression
Frequency of periodic phenomena	hertz	Hz	$Hz = s^{-1}$
Force	newton	N	$N = kg{\cdot}m/s^2$
Energy or work	joule	J	$J = N{\cdot}m$
Power	watt	W	W = J/s
Pressure or stress	pascal	Pa	$Pa = N/m^2$

25.1.3 Derived Units

Other measurable attributes were expressed as combinations of the metric units listed above rather than creating more special units. Some of these are shown in Table 25.2.

Table 25.2 Derived Units

Measurable Attribute	Unit	Expression
Acceleration	Meters per second squared	m/s^2
Area	square meter	m^2
Density	kilogram per cubic meter	kg/m^3
Velocity	meters per second	m/s
Volume	cubic meter	m^3

25.1.4 Multiplication Factors

Sometimes, the units shown above are too large or too small to be practical for use in engineering calculations. To remedy this, metrics uses a series of prefixes to adjust the order of magnitude of its units. Some of the more common prefixes are listed in Table 25.3.

Table 25.3 Common Metric Prefixes

Prefix	Symbol	Order of Magnitude	Examples
mega	M	1000000	megapascal (MPa), megagram (Mg)
kilo	k	1000	kilogram (kg), kilometer (km)
milli	m	0.001	millimeter (mm), milliliter (mL)

25.2 Conversion Guidelines

Conversion from metric to US can be either exact ("soft"), or a suitable approximation ("hard"). A soft conversion transforms a metric value to an exact US equivalent (e.g., 3.6m X 39.37/12 = 11.8’). A hard conversion transforms the metric value to a rounded, rationalized US value that is convenient to work with (e.g., AASHTO has hard converted the 3.6 m to a 12-ft lane lane).

25.2.1 Conversion Factors

The factors listed in Table 25.4 allow the conversion of metric values to US. Note that the metric unit centimeter does not appear in the conversion factor tables. The SI system does not recognize this as a standard unit of measure. Therefore, the unit centimeter was not used in WisDOT projects.

Table 25.4 Conversion Factors (based on US Survey Foot*)

Class	Multiply	By	To Get
Length	in	25.4	mm
	U.S. survey ft.	12/39.37**	m
	yd.	36/39.37	m
	mi	1.609 347	km
Area	ft2	(12/39.37)2	m2
	yd2	(36/39.37)2	m2
	acre	4046.873	m2
	acre	0.404 687 3	hectares (ha)
	mi2	2.590 00	km2
Volume	ft3	(12/39.37)3	m3
	yd3	(36/39.37)3	m3
	gal	3.785 412	L
	acre ft.	1233.489	m3
Mass	lb	0.453 592 4	kg
	ton	0.907 184 7	Mg
Mass/unit length	lb/ft	1.488 161	kg/m
Mass/unit area	lb/ft2	4.882 408	kg/m2
Density	lb/ft3	16.018 37	kg/m3
	lb/yd3	0.593 272 9	kg/m3
Force	lb	4.448 222	N
Pressure	psi	6894.730	Pa
Velocity	mph	0.447 040 9	m/s
Temperature	°F	(°F - 32) x 5/9	°C

* State Statute designates the U.S. Survey Foot (not the International Foot) as the recognized measure for length in Wisconsin. The U.S. survey foot is, by definition, exactly 12/39.37 of a meter.

** When used to convert U.S. coordinates (x, y, and z) or stationing to metric, this factor shall be carried to ten decimal places or 0.3048006096.

25.3 Metric Drafting Standards

WisDOT plans were prepared on the following metric-size sheets:

Full size: Metric sheet A1 (594 mm X 841 mm)

Reduced size: Metric sheet A3 (297 mm X 420 mm)

Stationing was based on 1000 meters per station with each station subdivided into twenty-five increments of 40 m each (rural) and 50 increments of 20 m each (urban).

Table 25.5 presents metric scales which were used in lieu of the corresponding U.S. scales shown.

Table 25.5 Equivalent English and Metric Scales

Metric Scale	Engineer's Scale	% enlargement or reduction using metric scale
1:20	1"= 2'	+20
1:50	1" = 5'	+20
1:100	1" = 10'	+20
1:250	1" = 20'	- 4
1:500	1" = 30'	-28
	1" = 40'	- 4
	1" = 50'	+20
1:1000	1" = 60'	-28
	1" = 100'	+20
	Architect Scale	
1:2	1:2	-
1:5	3" = 1'0"	-20
1:10	1 1/2 " = 1'-0	-20
	1" = 1'-0	+20
1:20	3/4" = 1'-0	-20
	1/2" = 1'-0	+20
1:50	3/8" = 1'-0	-36
	1/4" = 1'-0	- 4
	3/16" = 1'-0	+28
1:100	1/8" = 1'-0	- 4

Cross sections were provided at 40 m intervals in rural areas and 20 m intervals in urban areas. Cross sections were also provided for special situations such as the locations of side roads, driveways or culverts.

Pavement cross slope and superelevation were shown as percentages.

Side slopes were expressed in non-dimensional ratios with the vertical component shown first.

For slopes <45°, the ratio was expressed as 1:X.

For slopes >45°, the ratio was expressed as Y:1 because the metric system does not use fractions.

Angular measurements were shown in degrees, minutes and seconds.

Curves were defined in terms of radius rather than degree of curvature.

Curves originally defined by degree had their radius specified to the nearest millimeter.

Curves to be based on metrics initially had their radii established in 5 m increments.

The normal contour interval for aerial-based topographic maps is 500 mm.

Construction plans showed only metric units.

Right-of-way plats were dual dimensioned with metric values shown first followed by U.S. values in parentheses.