TRAFFIC DESIGN MANUAL

Traffic Operations Division
Traffic Engineering Office

August 2018

[This page intentionally left blank.]

TABLE OF CONTENTS

Table of Contents iii
List of Figures xii
List of Tables xv
List of Equations xvii
Appendices xvii

Chapter 1: Introduction 1-1
1.1 About this Manual 1-1
1.2 Standard Abbreviations 1-2
1.3 Standard References 1-4
1.4 Traffic Control Devices 1-5
1.5 Design of Traffic Control Devices 1-6
1.6 TDOT Traffic Operations Division, Traffic Engineering Office 1-6
1.7 Governing Laws, Rules and Regulations 1-6

Chapter 2: Traffic Impact Studies 2-1
2.1 General Information 2-1
2.1.1 Purpose 2-2
2.1.2 Applicability 2-2
2.1.3 Prequalified Engineering Firms and Preparer Qualifications 2-2
2.2 Traffic Impact Study Parameters 2-2
2.2.1 Proposed Development Trip Calculations 2-2
2.2.2 Traffic Impact Study Screening Evaluation Form 2-3
2.2.3 Minimum Threshold Levels 2-3
2.2.4 Traffic Impact Study Levels 2-4
2.2.5 Waiver 2-4
2.2.6 Target / Horizon Year 2-4
2.2.7 Time Periods 2-4
2.2.8 Traffic Impact Study Scoping Meeting 2-5
2.3 Development of Traffic Conditions 2-6
2.3.1 Existing Traffic Conditions 2-6
2.3.2 Background Traffic Development and Growth Calculations 2-6

TABLE OF CONTENTS (CONT.)

2.3.3 Future Traffic Conditions without Project....2-6
2.3.4 Site Traffic Conditions....2-7
2.3.5 Future Traffic Conditions with Project....2-7
2.4 Traffic Impact Study Analyses and Mitigation Measures....2-8
2.4.1 Capacity Analyses....2-8
2.4.2 Level of Service (LOS) Goals....2-10
2.4.3 Queuing Analyses....2-11
2.4.4 Mitigation Measures....2-11
2.5 Traffic Impact Study Report Format....2-13
2.5.1 General Information....2-13
2.5.2 Title Page....2-13
2.5.3 Table of Contents....2-13
2.5.4 Executive Summary....2-13
2.5.5 Introduction....2-14
2.5.6 Study Analysis Considerations....2-14
2.5.7 Existing Traffic Conditions....2-14
2.5.8 Background Traffic Development and Growth Calculations....2-15
2.5.9 Future Traffic Conditions without Project....2-15
2.5.10 Site Traffic Conditions....2-15
2.5.11 Future Traffic Conditions with Project....2-15
2.5.12 Summary of Findings....2-16
2.5.13 Recommendations....2-16
2.5.14 Submittal Requirements....2-16

Chapter 3: TDOT Project Development....3-1

3.1 Project Schedule....3-1
3.2 Plans Development Responsibilities....3-1
3.2.1 TDOT Design Manager....3-1
3.2.2 Local Agency....3-1
3.2.3 Design Engineer....3-1
3.3 Plan Development Stages....3-2
3.4 Support Projects....3-5
3.5 Conformance to TDOT Plans Format....3-5

TABLE OF CONTENTS (CONT.)

Chapter 4: Justifying the Need for Traffic Signals 4-1

4.1 Justification for Traffic Signal Control..4-1

4.1.1 Engineering Study Data Collection...4-1

4.1.2 Traffic Signal Warrants..4-11

4.2 Authorization for Installation and Ownership of Traffic Signal Control 4-13

4.2.1 Additional Requirements 4-14

Chapter 5: Traffic Signal Design – General Information 5-1

5.1 General Information 5-1

5.2 Site Reviews...5-2

5.3 Proprietary Equipment for Traffic Signal Systems...5-3

5.3.1 Necessary for Synchronization with Existing Facilities 5-3

5.3.2 Unique Product for which there is No Equally Suitable Alternative 5-3

5.3.3 Experimental Products 5-4

Chapter 6: Traffic Signal Design – Cabinets and Equipment 6-1

6.1 Traffic Signal Cabinet..6-1

6.2 Traffic Signal Controllers 6-2

6.3 Traffic Signal Detector Cards 6-2

6.4 Traffic Signal Load Switches and Flasher 6-2

6.5 Traffic Signal Monitor 6-2

6.6 Traffic Signal Power Supply 6-3

Chapter 7: Traffic Signal Design – Operations and Coordination......7-1

7.1 Traffic Signal Operation Basic Concepts...7-1

7.1.1 Traffic Signal Movements...7-1

7.1.2 Traffic Signal Phases 7-1

7.1.3 Ring-and-Barrier Diagrams 7-5

7.2 Traffic Signal Modes of Operation...7-5

7.2.1 Pre-timed (Fixed Time) Operation 7-5

7.2.2 Actuated Operation 7-8

7.2.3 Coordinated Operation...7-8

TABLE OF CONTENTS (CONT.)

7.2.4 Volume-Density Operation 7-9
7.2.5 Traffic Responsive Operation 7-9
7.2.6 Adaptive Signal Control Technology Operation 7-9
7.2.7 Traffic Signal Preemption 7-9
7.2.8 Traffic Signal Priority 7-9
7.2.9 Flashing Mode Operation 7-10
7.3 Traffic Signal Phasing 7-10
7.3.1 Need for Left-Turn Phasing 7-10
7.3.2 Types of Left-Turn Phasing 7-13
7.3.3 Guidelines for Selecting Left-Turn Phasing 7-16
7.3.4 Sequence of Left-Turn Phasing 7-18
7.3.5 Flashing Yellow Arrow for Left-Turn Movement Phasing 7-23
7.3.6 Right-Turn Treatments 7-26
7.4 Pedestrian Signal Phasing 7-31
7.4.1 Pedestrian Warrants and Signal Heads 7-31
7.4.2 Pedestrian Signal Phasing Alternatives 7-31
7.5 Traffic Signal Timing 7-33
7.5.1 TDOT's Role 7-33
7.5.2 Traffic Signal Timing Considerations 7-33
7.5.3 Data Collection 7-34
7.5.4 Operational Objectives 7-35
7.5.5 Yellow Change Interval and Red Clearance Interval 7-36
7.5.6 Pedestrian Signal Timing Parameters 7-41
7.5.7 Pre-timed (Fixed Time) Operation Signal Timing Parameters 7-44
7.5.8 Actuated Operation Signal Timing Parameters 7-47
7.6 Traffic Signal Coordination 7-53
7.6.1 Traffic Signal Coordination Objectives 7-53
7.6.2 Fundamentals of Traffic Signal Coordination 7-53
7.6.3 Traffic Signal Coordination Parameters Guidelines 7-56
7.6.4 Traffic Signal Coordination Complexities 7-60

TABLE OF CONTENTS (CONT.)

7.7 Traffic Signal Timing Plans 7-62
7.7.1 Timing Software 7-62
7.8 Advanced Traffic Signal Operations....7-63
7.8.1 Volume Density....7-63
7.8.2 Traffic Responsive Plan Selection Systems 7-69
7.8.3 Adaptive Signal Control Technology Systems....7-69
7.9 Traffic Signal Priority 7-70
7.10 Traffic Signal Preemption 7-71
7.10.1 Emergency Vehicle Preemption 7-71
7.10.2 Railroad Preemption 7-75
7.10.3 Multiple Preemption 7-80
7.11 Flashing Operations....7-80
7.11.1 Types of Flashing Operation 7-80
7.11.2 Flashing Operation Signal Display 7-81

Chapter 8: Traffic Signal Design – Detection....8-1

8.1 Detection 8-1
8.1.1 Detection Objectives 8-1
8.1.2 Detection Location 8-1
8.2 Detection Parameters....8-2
8.2.1 Detection Operating Modes....8-2
8.2.2 Detection Memory Modes 8-2
8.2.3 Detection Modifiers 8-3
8.3 Phase Recalls 8-5
8.3.1 Minimum Recall 8-5
8.3.2 Maximum Recall 8-5
8.3.3 Soft Recall 8-5
8.3.4 Pedestrian Recall....8-5
8.4 Detection Design for Approaches Below 35 MPH....8-7

TABLE OF CONTENTS (CONT.)

8.5 Detection Design for Approaches 35 MPH or Above 8-9
8.5.1 Timing of the Yellow Change Interval 8-9
8.5.2 Driver Behavior 8-9
8.6 Detection Design for Coordinated Systems 8-12
8.7 Pedestrian Detection 8-12
8.7.1 Accessible Pedestrian Signals 8-12
8.8 Types of Detection 8-13
8.8.1 Inductive Loop Detection 8-13
8.8.2 Video Detection 8-16
8.8.3 Radar Detection 8-16

Chapter 9: Traffic Signal Design – Supports and Signal Heads 9-1

9.1 Traffic Signal Supports 9-1
9.1.1 Traffic Signal Strain Poles 9-1
9.1.2 Traffic Signal Mast Arm Poles 9-5
9.2 Traffic Signal Indications 9-9
9.2.1 Lens Size, Illumination and Shielding 9-9
9.2.2 Traffic Signal Housing 9-9
9.2.3 Traffic Signal Backplates 9-9
9.2.4 Strobe Lights 9-9
9.2.5 Countdown Displays 9-9
9.2.6 Number of Signal Faces and Arrangement on an Approach 9-10
9.2.7 Visibility of Signal Faces on an Approach 9-10
9.2.8 Mounting Height of Signal Faces 9-11
9.2.9 Lateral and Longitudinal Positioning of Signal Faces 9-12
9.2.10 Shared and Separate Signal Faces 9-12
9.2.11 Signal Head Visors 9-14
9.2.12 Visibility-Limited Traffic Signal Devices 9-16
9.2.13 Use of Signs at Signalized Intersections 9-18
9.2.14 Use of Stop Signs at Signalized Intersections 9-18
9.2.15 Pedestrian Signal Indications 9-19

TABLE OF CONTENTS (CONT.)

Chapter 10: Traffic Signal Design – Pull Boxes, Conduits, and Wiring 10-1

10.1 Pull Boxes 10-1
10.1.1 Type/Size/Use of Pull Boxes 10-1
10.1.2 Spacing of Pull Boxes 10-1
10.1.3 Pull Box Material 10-1
10.2 Traffic Signal Conduits 10-2
10.2.1 Conduit Material Type 10-2
10.2.2 Conduit Installation Methods 10-2
10.2.3 Depth Installed Underground 10-3
10.2.4 Conduit Sizing 10-3
10.2.5 Communications Cable Conduit 10-4
10.2.6 Power Cable Conduit 10-4
10.2.7 Jacked and Bored Conduit 10-4
10.2.8 Conduit Radii 10-4
10.2.9 Spare Conduit 10-4
10.2.10 Conduit for Road Widening Projects 10-4
10.3 Traffic Signal Wiring 10-5
10.3.1 Signal Control Cable 10-5
10.3.2 Inductive Loop Wire 10-5
10.3.3 Loop Detector Lead-In Cable Wire 10-5
10.3.4 Preformed Loop Detector Wire 10-5
10.3.5 Coordinated Systems Communications 10-5
10.3.6 Cable Lashing 10-6
10.3.7 Cable/Wire Sizing and Measurements 10-6

TABLE OF CONTENTS (CONT.)

Chapter 11: Traffic Signal Design – Miscellaneous Information 11-1

11.1 Signal Control for Driveways within Signalized Intersections 11-1

11.2 Utilities 11-1

11.3 Street Lighting on Traffic Signal Supports at Intersections 11-3

11.3.1 Street Light Support Design 11-3

11.3.2 Luminaire Mounting Height 11-3

11.3.3 Wiring Requirements 11-3

11.4 Traffic Signal Installation Inspection Guidelines 11-4

11.4.1 Responsibilities of the Inspector 11-4

11.4.2 Preconstruction Activities 11-4

11.4.3 Sampling and Testing of Materials 11-5

11.4.4 General Principles 11-5

11.4.5 Inspection Activities 11-5

11.4.6 Final Acceptance and Notification 11-6

11.5 Traffic Signal Activation Procedures 11-7

Chapter 12: Traffic Signal Design – Post-Installation 12-1

12.1 Traffic Signal Maintenance Guidelines 12-1

12.1.1 Reducing Agency Exposure to Liability 12-1

12.1.2 Preventive Maintenance 12-2

12.1.3 Response Maintenance 12-5

12.2 Automated Traffic Signal Performance Measures 12-6

12.3 Removal of Traffic Signals 12-10

Chapter 13: Other Types of Traffic Signals 13-1

13.1 Highway Traffic Signals 13-1

13.2 Pedestrian Hybrid Beacons 13-2

13.3 Emergency-Vehicle Traffic Control Signals 13-3

13.3.1 Displays 13-3

13.3.2 Control 13-3

13.3.3 Signing 13-3

TABLE OF CONTENTS (CONT.)

13.4 Flashing Beacons 13-5
13.4.1 Intersection Control Beacons 13-5
13.4.2 Stop Sign Beacons....................13-5
13.4.3 Speed Limit Sign Beacons 13-5
13.4.4 School Zone Speed Limit Sign Beacons 13-7
13.4.5 Warning Sign Beacons....................13-7
13.4.6 Traffic Signal Ahead Beacons 13-7

Chapter 14: Signing and Pavement Markings....................14-1

14.1 General Information....................14-1
14.2 Signing 14-1
14.2.1 MUTCD....................14-2
14.2.2 Application 14-2
14.2.3 Sign Layouts 14-2
14.2.4 Conventional Highways (Non-Access Controlled) Signs 14-2
14.2.5 Freeway and Expressway Signs (Access Controlled)....................14-29
14.2.6 Sign Vertical Clearances....................14-31
14.2.7 Traffic Signal Signs 14-32
14.2.8 Other Traffic Control Signs....................14-37
14.2.9 Proposed Overhead Street Name Sign Layouts....................14-38
14.3 Pavement Markings....................14-39
14.3.1 Stop Lines....................14-39
14.3.2 Yield Lines 14-42
14.3.3 Crosswalks 14-43
14.3.4 Turn Arrows 14-44
14.3.5 Materials 14-44

TABLE OF CONTENTS (CONT.)

Chapter 15: Roadway and Intersection Lighting 15-1

15.1 General Information 15-1

15.1.1 Need for Engineering Expertise 15-1

15.1.2 Priorities and Funding Guidelines 15-2

15.2 Analyzing Highway Lighting Needs 15-4

15.2.1 Freeways 15-4

15.2.2 Streets and Highways Other Than Freeways 15-8

15.2.3 Other Locations 15-13

15.3 New Lighting Projects 15-15

15.3.1 Lighting Design Process 15-15

15.3.2 Lighting Design Process Overview 15-16

15.3.3 Design Considerations 15-18

15.3.4 Determine Classifications 15-18

15.3.5 Roadside Safety Considerations 15-30

15.3.6 Other Design Considerations 15-30

15.4 Lighting Design Criteria, Policies, and Procedures 15-33

15.4.1 Methodologies 15-33

15.4.2 Computerized Design 15-38

15.4.3 Electrical Design 15-38

15.4.4 Foundation, Pole Mounting, and Structural Considerations 15-42

15.4.5 TDOT Foundation Design 15-44

15.4.6 High-Mast Lighting Design 15-45

15.4.7 Underpass Lighting 15-46

15.4.8 TDOT Bridge Lighting Plan 15-47

15.5 Materials and Equipment 15-53

15.5.1 Foundations and Mounting 15-54

15.5.2 Pole Bases 15-54

15.5.3 Poles 15-55

15.5.4 Luminaires 15-55

15.5.5 Other Materials and Equipment 15-56

TABLE OF CONTENTS (CONT.)

15.6 TDOT Lighting Plans Layouts 15-57
15.6.1 Plans Preparation 15-57
15.6.2 Photometric/Preliminary Plans Preparation 15-59
15.6.3 Photometric/Preliminary Plan Review...15-60
15.6.4 Lighting Computer-Aided Design Drafting Standards 15-60
15.6.5 Site and Field Reviews..15-60
15.6.6 Photometric Plans and Work Files Submittal..15-61
15.6.7 Lighting Design Checklists 15-62

LIST OF FIGURES

Figure 4.1 – Vehicular, Pedestrian, and Bicycle Counts Example 4-3
Figure 4.2 – Condition Diagram Example 4-9
Figure 4.3 – Collision Diagram Example 4-10
Figure 7.1 – Movement and Phase Numbering (East-West as Major Street) 7-2
Figure 7.2 – Movement and Phase Numbering (North-South as Major Street) 7-3
Figure 7.3 – Movement and Phase Numbering (Permissive Left-Turns) 7-4
Figure 7.4 – Standard NEMA Dual Ring-and-Barrier Diagram 7-6
Figure 7.5 – Pre-timed and Actuated Operation 7-7
Figure 7.6 – Horizontal Intersection Sight Distance for Left-Turns 7-12
Figure 7.7 – Offset Left-Turn Lanes 7-13
Figure 7.8 – Ring-and-Barrier Diagram and Left-Turn Phasing 7-14
Figure 7.9 – Guidelines for Selecting Left-Turn Phasing 7-17
Figure 7.10 – Sequence of Left-Turn Phasing 7-19
Figure 7.11 – Left-Turn Yellow Trap 7-22
Figure 7.12 – Flashing Yellow Arrow (Permissive Left-Turn Movement Display) 7-25
Figure 7.13 – Right-Turn Overlap 7-28
Figure 7.14 – Right-Turn Overlap Phase Lettering Scheme 7-29
Figure 7.15 – Right-Turn On Red (RTOR) Signal Displays 7-30
Figure 7.16 – Exclusive Pedestrian Phasing 7-32
Figure 7.17 – Leading Pedestrian Interval 7-32
Figure 7.18 – Pedestrian Intervals 7-43
Figure 7.19 – Webster's Minimum Delay Cycle 7-45
Figure 7.20 – Actuated Phase Operation Parameters 7-48
Figure 7.21 – Time-Space Diagram 7-55
Figure 7.22 – Cycle, Split, and Offset Relationships 7-59
Figure 7.23 – Rest-in-Walk Parameter 7-61
Figure 7.24 – Volume Density (Variable Initial) 7-64
Figure 7.25 – Volume Density (Gap Reduction) 7-66
Figure 7.26 – Emergency Vehicle Preemption Sequence 7-73
Figure 7.27 – Emergency Vehicle Preemption Design Example 7-74
Figure 7.28 – Railroad Preemption Sequence (2 or 3 Phase Operation) 7-76
Figure 7.29 – Railroad Preemption Sequence (8 Phase Operation) 7-77
Figure 7.30 – Railroad Preemption Sequence 7-79

LIST OF FIGURES (CONT.)

Figure 8.1 – Typical Detection Design Schematics (< 35 MPH) 8-7
Figure 8.2 – Inductive Loop Detection (< 35 MPH) 8-8
Figure 8.3 – Typical Detection Design Schematics (≥ 35 MPH) 8-10
Figure 8.4 – Inductive Loop Detection (≥ 35 MPH) 8-11
Figure 8.5 – Preformed Inductive Loop 8-15
Figure 9.1 – Typical Strain Pole Span Wire Layouts 9-4
Figure 9.2 – Typical Mast Arm Pole Layouts 9-8
Figure 9.3 – Positioning of Signal Faces 9-13
Figure 9.4 – Types of Signal Head Visors 9-14
Figure 9.5 – Line of Sight Angle Measurements 9-15
Figure 9.6 – Recommended Signal Head Screening Types 9-16
Figure 9.7 – Types of Visibility-Limited Screening Devices 9-17
Figure 11.1 – Uniform Color Codes for Underground Utilities 11-2
Figure 12.1 – Automated Traffic Signal Performance Measure Before Example 12-8
Figure 12.2 – Automated Traffic Signal Performance Measure After Example 12-9
Figure 13.1 – Pedestrian Hybrid Beacon Sequence Display 13-2
Figure 13.2 – Emergency Vehicle Traffic Signals 13-4
Figure 13.3 – Intersection Control Beacons and Stop Beacons (Red) 13-6
Figure 13.4 – School Zone Speed Limit Sign Beacons 13-8
Figure 13.5 – Warning Beacons (Yellow) and Traffic Signal Ahead Beacons 13-9
Figure 14.1 – Intersection of Two Major Routes (4-Way Intersection) 14-4
Figure 14.2 – Intersection of Two Major Routes (3-Way Intersection) 14-5
Figure 14.3 – Intersection of Two Major Routes with Overlapping Route Numbers 14-6
Figure 14.4 – 4-Way Intersection Route Signing with Scenic (Bird) Route 14-7
Figure 14.5 – 3-Way Intersection Route Signing with Scenic (Bird) Route 14-8
Figure 14.6 – 3-Way Intersection Route Signing with Scenic (Bird) Route with Overlapping Route Numbers 14-9
Figure 14.7 – Crossroad Signing, Medians less than 30 feet, One-Way and Wrong-Way Signing 14-10
Figure 14.8 – Signalized Intersection, Medians less than 30 feet, One-Way and Wrong-Way Signing 14-11
Figure 14.9 – “T” Intersection Right, Medians less than 30 feet, One-Way and Wrong-Way Signing 14-12

LIST OF FIGURES (CONT.)

Figure 14.10 – "T" Intersection Left, Medians less than 30 feet, One-Way and Wrong-Way Signing......14-13

Figure 14.11 – Median Crossover, Medians less than 30 feet, One-Way and Wrong-Way Signing......14-14

Figure 14.12 – Crossroad Signing, Medians 30 feet or greater, One-Way and Wrong-Way Signing......14-15

Figure 14.13 – Signalized Intersection, Medians 30 feet or greater, One-Way and Wrong-Way Signing......14-16

Figure 14.14 – "T" Intersection Right, Medians 30 feet or greater, One-Way and Wrong-Way Signing......14-17

Figure 14.15 – "T" Intersection Left, Medians 30 feet or greater, One-Way and Wrong-Way Signing......14-18

Figure 14.16 – Median Crossover, Medians 30 feet or greater, One-Way and Wrong-Way Signing......14-19

Figure 14.17 – Estimating Length of Sign Support......14-26

Figure 14.18 – Strain Pole Foundation and Cable Connection Details......14-28

Figure 14.19 – Strain Pole Foundation and Cable Connection Details......14-30

Figure 14.20 – Sign Vertical Clearances......14-33

Figure 14.21 – Typical Signal Related Signs......14-34

Figure 14.22 – Stop Line Placement......14-40

Figure 14.23 – Stop Line Locations......14-41

Figure 15.1 – Partial Interchange Lighting (Crossing Types A and B)......15-7

Figure 15.2 – Partial Interchange Lighting (Crossing Types C and D)......15-7

Figure 15.3 – Lighting Design Process Flow Chart......15-15

Figure 15.4 – Plan View of Roadway Coverage from IES Luminaires......15-25

Figure 15.5 – Sample Utilization Curve......15-26

Figure 15.6 – Roadway Luminaire Dirt Depreciation Curve......15-28

Figure 15.7 – Typical Luminaire Arrangements for Conventional Highway Lighting Design......15-29

Figure 15.8 – Calculation Points for Luminance and Illuminance Design Methods......15-35

Figure 15.9 – Detail of Overpass Bridge Lighting for Submittal to Structures......15-49

Figure 15.10 – Detail of Underpass Bridge Lighting for Submittal to Structures......15-50

Figure 15.11 – Detail of Proposed Lighting Layout at Bridge Overpass (NTS)......15-51

Figure 15.12 – Detail of Proposed Lighting Layout at Bridge Underpass (NTS)......15-52

Figure 15.13 – Typical Highway Lighting Structure......15-53

LIST OF TABLES

Table 2.1 – Traffic Impact Study Minimum Threshold Levels 2-2
Table 2.2 – Minimum LOS Goals 2-2
Table 2.3 – Examples of Possible Mitigation Measures...2-3
Table 3.1 – Plan Sheet Numbering Example...3-6
Table 4.1 – Tennessee Statewide Average Traffic Volumes Hourly Percentages.................4-4
Table 4.2 – TDOT Region 1 Average Traffic Volumes Hourly Percentages...........................4-5
Table 4.3 – TDOT Region 2 Average Traffic Volumes Hourly Percentages...........................4-6
Table 4.4 – TDOT Region 3 Average Traffic Volumes Hourly Percentages...........................4-7
Table 4.5 – TDOT Region 4 Average Traffic Volumes Hourly Percentages...........................4-8
Table 7.1 – Minimum Critical Left-Turn Related Crashes 7-11
Table 7.2 – Minimum Critical Left-Turn Related Crashes for Left-Turn Phasing (Single Left Turn Lanes)...7-16
Table 7.3 – Left-Turn Phase Sequence Advantages and Disadvantages 7-20
Table 7.4 – Calculated Yellow Change Intervals 7-37
Table 7.5 – Recommended Yellow Change Intervals 7-38
Table 7.6 – Calculated 85th Percentile Speed Red Clearance Intervals 7-39
Table 7.7 – Recommended 85th Percentile Red Clearance Intervals..................................7-39
Table 7.8 – Calculated Posted Speed + 7 MPH Red Clearance Intervals...........................7-40
Table 7.9 – Recommended Posted Speed + 7 MPH Red Clearance Intervals 7-40
Table 7.10 – Minimum Values for Phase Green Intervals for Pre-timed Operation.............7-46
Table 7.11 – Typical Minimum Green Values Needed to Satisfy Driver Expectancy............7-47
Table 7.12 – Typical Minimum Green Values Needed to Satisfy Queue Clearance.............7-49
Table 7.13 – Typical Values for Maximum Green...7-50
Table 7.14 – Typical Values for Passage Time for Stop Line Detection..............................7-52
Table 7.15 – Volume Density Typical Values for Minimum Initial Settings 7-64
Table 7.16 – Volume Density Typical Values for Added Initial Settings 7-65
Table 7.17 – Volume Density Typical Values for Maximum Initial Settings 7-65
Table 7.18 – Volume Density Gap Reduction Settings for Passage Time 7-67
Table 7.19 – Volume Density Gap Reduction Settings for Time Before Reduction..............7-67
Table 7.20 – Volume Density Gap Reduction Settings for Time to Reduce 7-68
Table 7.21 – Volume Density Gap Reduction Settings for Minimum Gap 7-68

LIST OF TABLES (CONT.)

Table 8.1 – Typical Detector Switching Settings....................8-4
Table 8.2 – Typical Phase Recall Settings....................8-6
Table 8.3 – Typical Advance Detection Placement....................8-9
Table 9.1 – Minimum Sight Distance for Signal Visibility....................9-11
Table 9.2 – Mounting Height of Signal Faces....................9-11
Table 9.3 – Mounting Height to Top of Signal Housing (40-53 Feet)....................9-12
Table 10.1 – Conduit Size Requirements....................10-4
Table 10.2 – Typical Cable/Wire Sizes....................10-7
Table 12.1 – Types of ATSPMs and Controller/Detection Requirements....................12-7
Table 14.1 – Post Selection for Various Sign Assemblies (5 Pages)....................14-21
Table 14.2 – Determining Weight of Sign Supports....................14-27
Table 15.1 – Pavement Classification....................15-21
Table 15.2 – Typical TDOT Highway Lighting Design Parameters....................15-33
Table 15.3 – TDOT Illuminance Design Criteria....................15-36
Table 15.4 – TDOT Luminance Design Criteria....................15-37
Table 15.5 – Lamp Amperes (HPS Mag Regular Ballast)....................15-40
Table 15.6 – Conductor Properties....................15-41

LIST OF EQUATIONS

Equation 7.1 – Change Interval Formula 7-36
Equation 7.2 – Pedestrian Clearance Time 7-42
Equations 7.3 through 7.5 – Pedestrian Change Intervals 7-42
Equation 7.6 – Webster's Cycle Length Estimate 7-44
Equations 7.7 and 7.8 – Apportion All Phases' Green Intervals 7-46
Equations 7.9 and 7.10 – Minimum Green Duration for Queue Clearance 7-49
Equation 7.11 – Passage Time 7-51
Equation 7.12 – Coupling Index 7-53
Equation 9.1 – Pole Height 9-2
Equation 15.1 – Roadway Length for Transition Lighting 15-12
Equation 15.2 – Luminaire Spacing 15-17
Equation 15.3 – Uniformity Ratio 15-17
Equation 15.4 – Percentage Voltage Drop for One Luminaire 15-41
Equation 15.5 – Voltage Drop for Each Luminaire 15-41
Equation 15.6 – Branch Circuit Breaker Size 15-42
Equation 15.7 – Main Circuit Breaker Size 15-42
Equation 15.8 – Length of Foundation 15-44
Equation 15.9 – Lateral Movement of Foundation at Ground Line 15-44

APPENDICES

Appendix A – Traffic Impact Study Forms
Appendix B – Traffic Signal Forms
Appendix C – Traffic Inspection Forms
Appendix D – Traffic Maintenance Forms
Appendix E – Roadway and Intersection Lighting Forms/TDOT LED Specifications
Appendix F – Traffic Operations Standard Drawings List and Current Memorandums

[This page intentionally left blank.]

CHAPTER 1

INTRODUCTION

1.1 About this Manual

This manual is prepared in conjunction with the TDOT *Roadway Design Guidelines* to aid in the development of construction plans involving traffic signals, roadway lighting, signs, pavement markings, and minor intersection improvements. Where any conflict occurs between these manuals in the areas of project management or plans development, the TDOT *Roadway Design Guidelines* should be followed. Although this manual is not intended to provide the ultimate answers to all traffic engineering questions, the guidelines listed do represent the preferred procedures for developing traffic signal, roadway lighting, signing, and pavement marking construction plans.

The technical requirements of this manual should be used in the design of any traffic control devices that will be placed on a state highway, regardless of whether or not it is part of a TDOT construction project. Any devices installed on state highways by local forces or directly for a local agency shall adhere to this manual, unless otherwise noted in the construction plans.

The purpose of this manual is to present the concepts and standard practices related to the design of traffic control systems within the State of Tennessee. The following is a list of the chapters contained in this manual:

- Chapter 1: Introduction
- Chapter 2: Traffic Studies (Future Chapter)
- Chapter 3: TDOT Project Development
- Chapter 4: Justifying the Need for Traffic Signals
- Chapter 5: Traffic Signal Design – General Information
- Chapter 6: Traffic Signal Design – Cabinets and Equipment
- Chapter 7: Traffic Signal Design – Operation and Coordination
- Chapter 8: Traffic Signal Design – Detection
- Chapter 9: Traffic Signal Design – Supports and Signal Heads
- Chapter 10: Traffic Signal Design – Pull Boxes, Conduits, and Wiring
- Chapter 11: Traffic Signal Design – Miscellaneous Information
- Chapter 12: Traffic Signal Design – Post-Installation
- Chapter 13: Other Types of Traffic Signals
- Chapter 14: Signing and Pavement Markings
- Chapter 15: Roadway and Intersection Lighting

1.2 Standard Abbreviations

Standard abbreviations referred to within this Traffic Design Manual include, but are not limited to, the following sources:

- AADT – Annual Average Daily Traffic
- AASHTO – American Association of State Highway and Transportation Officials
- ADA – Americans with Disabilities Act
- ANSI – American National Standards Institute
- ASCT – Adaptive Signal Control Technology
- ATC – Advanced Transportation Controller
- ATSPM – Automated Traffic Signal Performance Measures
- ATSSA – American Traffic Safety Services Association
- AWG – American Wire Gauge
- BBS – Battery Backup System
- BIU – Bus Interface Unit
- C – Cutoff
- CADD – Computer-Aided Design Drafting
- CBD – Central Business District
- CFL – Continuous Freeway Lighting
- CFR – Code of Federal Regulations
- CIL – Complete Interchange Lighting
- CMB – Concrete Median Barrier
- CMU – Conflict Monitoring Unit
- COE – Corps of Engineers
- CU – Coefficient of Utilization
- EF – Equipment Factor
- FDW – Flashing Don’t Walk
- FHWA – Federal Highway Administration
- HCM – Highway Capacity Manual
- HCS – Highway Capacity Software
- HDPE – High-Density Polyethylene
- HID – High-Intensity Discharge
- HPS – High Pressure Sodium
- ID – Identification

- IES – Illuminating Engineering Society
- IMSA – International Municipal Signal Association
- ITE – Institute of Transportation Engineers
- ITS – Intelligent Transportation Systems
- LDDF – Luminaire Dirt Depreciation Factor
- LED – Light Emitting Diode
- LLDF – Lamp Lumen Depreciation Factor
- LLF – Light Loss Factor
- LOS – Level of Service
- LPS – Low Pressure Sodium
- LRT – Light Rail Transit
- LRTP – Long Range Transportation Plan
- MH – Metal Halide
- MMU – Malfunction Management Unit
- MOE – Measures of Effectiveness
- MOA – Memorandum of Agreement
- MOU – Memorandum of Understanding
- MUTCD – Manual on Uniform Traffic Control Devices
- MV – Mercury Vapor
- N/A – Not Applicable
- NC – Non-Cutoff
- NCHRP – National Cooperative Highway Research Program
- NEC – National Electrical Code
- NEMA – National Electrical Manufacturers Association
- NESC – National Electrical Safety Code
- NFPA – National Fire Protection Association
- PDF – Portable Document Format
- P.E. – Professional Engineer
- PIL – Partial Interchange Lighting
- PTOE – Professional Traffic Operations Engineer
- PVC – Polyvinyl Chloride
- RGS – Rigid Galvanized Steel
- RTOR – Right Turns On Red

- SC – Semi-Cutoff
- SEA – Systems Engineering Analysis
- SOP – Standard Operating Procedure
- STV – Small-Target-Visibility
- TAS – Traffic Access Study
- TCA – Tennessee Code Annotated
- TDEC – Tennessee Department of Environment and Conservation
- TDOT – Tennessee Department of Transportation
- TIP – Transportation Improvement Program
- TIS – Traffic Impact Study
- TMP – Transportation Management Plan
- TOD – Time-of-Day
- TRB – Transportation Research Board
- TRPS – Traffic Responsive Plan Selection
- TSP – Transit Signal Priority
- TVA – Tennessee Valley Authority
- TWRA – Tennessee Wildlife Resources Agency
- UPS – Uninterruptible Power Supply

1.3 Standard References

Standards, specifications, and references referred to within this Traffic Design Manual include, but are not limited to, the following sources (latest edition unless otherwise noted):

- TDOT – Roadway Design Guidelines
- TDOT – Intelligent Transportation Systems Design Guidelines
- TDOT – Standard Traffic Operations, Roadway, and Structures Drawings
- TDOT – Standard Specifications for Road and Bridge Construction
- TDOT – Tennessee Supplement to the Standard Highway Signs
- TDOT – Special Provisions
- TDOT – Survey Manual
- FHWA – Manual on Uniform Traffic Control Devices, 2009 Edition
- FHWA – Standard Highway Signs
- FHWA – Traffic Signal Timing Manual

- FHWA – Traffic Detector Handbook, Volumes 1 and 2
- FHWA – Performance Measurement Fundamentals
- FHWA – Lighting Handbook
- ITE – Traffic Control Devices Handbook
- ITE – Traffic Engineering Handbook
- ITE – Manual of Traffic Signal Design
- ITE – Traffic Signal Installation and Maintenance Manual
- ITE, IMSA – Traffic Signal Maintenance Handbook
- TRB – Highway Capacity Manual, 2010 Edition
- US Access Board – Proposed Right-of-Way Accessibility Guidelines (PROWAG)
- ITS America – Transit Signal Priority Handbook
- AASHTO – LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals
- AASHTO – A Policy on Geometric Design of Highways and Streets (i.e. Green Book), 2012 Edition
- AASHTO – An Informational Guide for Roadway Lighting, 2005 Edition
- AASHTO – Roadway Lighting Design Guide
- AASHTO, ITE, NEMA – Advanced Transportation Controller Standards
- NEC, NESC – Electrical Codes
- NEMA – Standards

1.4 Traffic Control Devices

Traffic control devices are defined by the *MUTCD* as all traffic signals, signs, pavement markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, private road open to public travel, pedestrian facility, or shared-use path by authority of a public agency or official having jurisdiction, or, in the case of a private road open to public travel, by authority of the private owner or private official having jurisdiction. Shared-use path is defined as a bikeway outside the traveled way and physically separated from motorized vehicular traffic by an open space or barrier and either within the highway right-of-way or within an independent alignment. Shared-use paths are also used by pedestrians (including skaters, users of manual and motorized wheelchairs, and joggers) and other authorized motorized and non-motorized users. The purpose of traffic control devices, as well as the principles for their use, is to promote highway safety and efficiency by providing for the orderly movement of all road users on streets and highways. Traffic control devices notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream.

1.5 Design of Traffic Control Devices

The design of traffic control devices must be carefully prepared by a qualified individual in the traffic engineering profession whose specialty is in traffic engineering. The qualified individual who is responsible for the traffic engineering construction plans of the project shall be a registered professional engineer in Tennessee and in good standing. The TDOT Traffic Engineering Office also recognizes the certification of a PTOE. The proper design and use of traffic control devices can result in an efficient and safe transportation system. However, improper or inadequate design can result in system inefficiency, decreased safety and potential liability. In addition to this TDOT Traffic Design Manual, other TDOT design information is available on TDOT's web site at www.tn.gov/tdot.

1.6 TDOT Traffic Operations Division, Traffic Engineering Office

The TDOT Traffic Operations Division, Traffic Engineering Office is responsible for the development of traffic signal, signing (overhead and street name signs), and roadway lighting construction plans, either as stand-alone projects or in support of larger roadway design projects administered by TDOT.

1.7 Governing Laws, Rules and Regulations

State laws, which govern the process of determining the need for and the installation of traffic control devices on all streets and highways in Tennessee, include:

- **T.C.A. 54-5-108. Cooperation by department with federal government in designating roads, and in erection of danger signals and safety devices;**

  .... (b) The department has full power, and it is made its duty, acting through its commissioner, to formulate and adopt a manual for the design and location of signs, signals, markings, and for posting of traffic regulations on or along all streets and highways in Tennessee, and no signs, signals, markings or postings of traffic regulations shall be located on any street or highway in Tennessee regardless of type or class of the governmental agency having jurisdiction thereof except in conformity with the provisions contained in said manual.

- **T.C.A. 54-5-601. Maintenance of signal light on state highway without commissioner's approval - Misdemeanor.**

  Any person who installs or maintains a signal light on a state highway without having secured prior written approval of the commissioner commits a Class C misdemeanor.

- **T. C.A. 54-5-602. Signal light declared public nuisance.**

  In addition, a signal light installed and maintained on a state highway without the authority of the commissioner is hereby declared a public nuisance which may be abated by the employees of the department at the direction of the commissioner or, upon the commissioners request, by any peace officer, or by civil actions or suits brought in the circuit or chancery courts as provided by the general law.

- **T C.A. 54-5-603. Inapplicable within boundaries of municipal corporation.**

  This part does not apply within the boundaries of municipal corporations.

  Under the Uniform Administrative Procedures Act, the Manual on Uniform Traffic Control Devices (MUTCD) and subsequent revisions are part of the Rules and Regulations of the State of Tennessee, Department of Transportation as certified by the Secretary of State (Tennessee Rule 1680-03-01). The MUTCD shall serve as the basis for the choice and installation of all traffic control devices installed in State of Tennessee, Department of Transportation roadway projects.

[This page intentionally left blank.]

CHAPTER 2

TRAFFIC IMPACT STUDIES

2.1 General Information

2.1.1 Purpose

The purpose of this section is to standardize Traffic Impact Study requirements and procedures in order to ensure consistency of information concerning the traffic impacts resulting from a proposed development. Generally, a traffic impact study will vary in detail and complexity depending on the type, size, and location of the proposed development. The submitted traffic impact study will assist TDOT in its evaluation of the impacts to traffic of a particular site and if necessary, identify appropriate mitigation measures to maintain the integrity of the surrounding transportation system.

2.1.2 Applicability

This document specifically applies to, but is not limited to, the following:

- All proposed new developments that meet minimum trip generation thresholds as defined in Table 2.1.
- All proposed redevelopment (i.e., proposed modifications to existing developments) that meet minimum trip generation thresholds as defined in Table 2.1.

Once a traffic impact study has been approved by TDOT, the approved traffic impact study shall be effective for a period of three years unless significant changes are made to the original proposed development and those changes result in additional impacts to the surrounding transportation system. Whether significant changes have occurred will be determined by the Regional Traffic Engineer. After the three-year period has elapsed, any proposed development seeking permits who have not demonstrated due diligence toward the completion of the project shall be re-evaluated by TDOT to determine the degree to which background traffic conditions have changed since the original traffic study was approved. Due diligence is generally defined as a project that has achieved at least 50% of the total proposed development’s build out (e.g. in square-footage, units) by the end of the three-year period. If necessary, at the sole discretion of TDOT, a new traffic study may be required in order to provide information to help determine if any additional mitigation measures are necessary.

2.1.3 Prequalified Engineering Firms and Preparer Qualifications

All traffic impact studies shall be prepared by a registered P.E., or an individual under the supervision of a registered P.E. The P.E. shall have specific training in traffic engineering and be in good standing with the State of Tennessee. All traffic impact studies submitted to TDOT for final review shall be signed and sealed by the P.E.

2.2 Traffic Impact Study Parameters

2.2.1 Proposed Development Trip Calculations

The number of trips generated by a proposed development shall be calculated using land use codes published in the latest edition of the *ITE Trip Generation Manual*. If the type of proposed development is not addressed in the *ITE Trip Generation Manual*, then other rates may be used as long as they are published documents and pre-approved by TDOT. A trip is defined as a single, one-way movement either to or from the proposed development. For the purposes of redevelopment (i.e., proposed modifications to existing developments), the estimated number of trips generated shall be measured as the net number of new trips generated by the proposed development as compared to trips generated by the existing use(s) on the site. In all cases, the total number of trips generated will be based on 100% occupancy of the proposed development, whether by a construction phase approach or full build-out. The utilization of a reduction in generated trips for internal capture trips and pass-by trips is allowed and shall be conducted in good faith based on ITE-approved data and methodologies.

Internal Capture Trips

The base number of trips generated by a proposed development may be reduced by rate of internal capture trips when two or more land uses are proposed using the methodology recommended in the latest edition of the *ITE Trip Generation Manual*. Internal capture reduction percentages greater than 10% require pre-approval by TDOT for use in the traffic study. The internal capture reduction percentage shall be applied before the pass-by trip percentages are applied.

Pass-by Trips

The base number of trips generated by a proposed development may be reduced by rate of pass-by trips using the methodology recommended in the latest edition of the *ITE Trip Generation Manual*. A pass-by trip is considered an intermediate trip between an origin and primary destination and is not diverted from another roadway. Pass-by trip reduction percentages of the existing adjacent public roads greater than 10% require pre-approval by TDOT for use in the traffic study.

2.2.2 Traffic Impact Study Screening Evaluation Form

The developer of a proposed development, as part of the application process, shall submit a *Traffic Impact Study Screening Evaluation Form* contained in Appendix A. When the form is submitted for review, TDOT will determine the appropriate next step in the traffic impact study process – either granting a waiver or determining the type of traffic impact study required for evaluation.

2.2.3 Minimum Threshold Levels

Table 2.1 presents the minimum threshold levels for a traffic study and the typical study area required, depending upon the number of new trips generated by a proposed development.

Table 2.1 – Traffic Impact Study Minimum Threshold Levels

Traffic Study Level	Minimum Thresholds	Typical Study Area
1	50 to 99 new peak hour trips or 250 to 499 new daily trips, whichever is greater	All site access intersections to existing adjacent public roads and the existing adjacent public roads to the first control point* from all site access intersections.
2	100 to 249 new peak hour trips or 500 to 2,999 new daily trips, whichever is greater	All site access intersections to existing adjacent public roads, existing major public roads, and study intersections (signalized and unsignalized) within ¼ mile of all site access intersections.
3	250 to 399 new peak hour trips or 3,000 to 5,999 new daily trips, whichever is greater	All site access intersections to existing adjacent public roads, existing major public roads, and study intersections (signalized and unsignalized) within ½ mile of all site access intersections.
4	≥400 new peak hour trips or ≥6,000 new daily trips, whichever is greater	All site access intersections to existing adjacent public roads, existing major public roads, and study intersections (signalized and unsignalized) within ¾ mile of all site access intersections.

*Control points are intersections controlled by traffic signal or stop signs. For cases where a traffic control device does not exist within a ¼ mile of a site access intersection, TDOT will determine the extent of the study area.

The above minimum thresholds are calculated for both new peak hour trips and new daily trips. The minimum threshold is satisfied if the calculated number of new trips satisfies either condition. If the new peak hour trip and new daily trip calculations satisfy different traffic study levels, then the higher study level is required. If necessary, the typical study area limits for each level of traffic study may also be extended or shortened at the sole discretion of TDOT and the Regional Traffic Engineer. An applicant of a proposed development shall not avoid the intent of these traffic study requirements by submitting piecemeal applications or approval requests for subdivision plats, site development plans, building permits, etc.

2.2.4 Traffic Study Levels

As shown in Table 2.1, there are four (4) levels of Traffic Impact Studies. Level 1 Traffic Impact Studies are typically required for smaller scale projects that are anticipated to have a smaller impact on the surrounding transportation system, mostly at the site access intersections. Level 2, 3, and 4 Traffic Impact Studies are typically required for larger scale projects that are anticipated to have a greater impact on the surrounding transportation system.

2.2.5 Waiver

Utilizing the *Traffic Impact Study Screening Evaluation Form*, TDOT may grant a waiver for a traffic impact study if the applicant shows that the trips generated by the proposed development on the surrounding transportation system is insignificant. Insignificant is typically defined as less than 50 new peak hour trips and 250 new daily trips generated by the proposed development. The waiver request shall be made in writing and shall include the traffic data analysis necessary to support the proposed development. If a waiver is granted, TDOT will notify the applicant in writing.

2.2.6 Target / Horizon Year

The traffic study shall be developed for all target and horizon years, as set by TDOT. Typically, the horizon year will be five years after build out of the proposed development. If a construction phase approach is being planned, then traffic conditions for multiple target years shall be developed for each construction phase year, as determined by the developer. Final target and horizon dates are to be determined by TDOT.

2.2.7 Time Periods

The time periods for analyzing traffic impacts are typically based on the type of proposed development when the highest traffic volumes from the proposed development are expected. Additional considerations to help determine the necessary time periods to analyze shall be the weekday a.m. and p.m. peak hours of adjacent street traffic that the proposed development is accessing. Depending upon the type of proposed development, additional weekend or midday (i.e., lunchtime) peak periods may be required to analyze traffic impacts.

2.2.8 Traffic Impact Study Scoping Meeting

Before beginning a Traffic Impact Study, the developer of a proposed development and/or his traffic consultant shall meet with the TDOT Region Traffic Engineering Office in the region where the property is located to verify the type of study that is to be conducted and to determine the scope of the traffic impact study. The traffic impact study scoping meeting shall be coordinated with TDOT for time and location. The following items may be discussed during the scoping meeting:

- Traffic Impact Study Screening Evaluation Form
- Level of traffic impact study required
- Extent of the study area limits, including the existing adjacent public roads and the major study intersections (signalized and unsignalized) to be analyzed
- Trip generation, distribution, and assignment methodology
- Assumptions for pass-by and internal capture trip reductions
- Assumptions for background growth rates
- Traffic analysis target and horizon years for the proposed development
- Traffic analysis time periods (a.m. peak hours, p.m. peak hours, weekend peak periods, etc.) for the proposed development
- Necessity of additional analyses, such as traffic signal warrant, safety, intersection sight distance, gap, and traffic simulation
- Other current and/or proposed transportation improvement projects within the vicinity of the proposed development site
- Consideration of pedestrian, bicycle, and ADA accommodations.
- Analysis software and reporting requirements

The minutes of the traffic study scoping meeting shall be prepared by the developer of a proposed development and/or his traffic consultant. Some meeting items may require follow up after the traffic study scoping meeting. When ready, the prepared minutes shall be submitted to TDOT for approval. Written approval from TDOT shall be obtained prior to initiating the traffic impact study.

2.3 Development of Traffic Conditions

2.3.1 Existing Traffic Conditions

Existing traffic conditions are considered the characterization, in the current year, of the surrounding transportation system within the study area limits and without the proposed development. If available, existing peak hour traffic volumes may be utilized if they are within two years from the date of the traffic study scoping meeting. If not available, the developer of a proposed development shall be responsible to collect the required traffic volume data at study intersections within the study area limits. Additional required geometric data to be collected include functional roadway classifications, traffic control devices at intersections including traffic signal phasing and timings, linear distance between intersections, posted speed limits, sight distance measurements from all site access intersections, identification of bicycle and pedestrian facilities, lane usage including lane width for roadways and intersections within the study area limits. Also, any driveways across from or adjacent to site access intersections shall be located. An analysis of the existing traffic conditions within the study area limits is important in order to determine existing deficiencies in the surrounding transportation system. The schedule for collecting new traffic volume data should consider area schools or seasonal peaks.

2.3.2 Background Traffic Development and Growth Calculations

For each target and horizon year, background traffic development and growth are defined as the increased traffic volumes of the surrounding transportation system within the study area limits without the proposed development. Projects that have an opening date at least one year out from the preparation of the traffic study will be impacted by natural background traffic volume growth (e.g. traffic from approved projects, population growth, etc.). The background traffic development and growth are developed by applying a background growth rate to the traffic volumes contained in the existing traffic conditions for each target/horizon year. The background growth rate is typically based on historical traffic count information from AADT counts located in the vicinity of the study area limits. Additional consideration shall be given to the likelihood for future growth in the study area and shall include traffic from other approved developments where applicable. In all cases, the background growth rate shall be pre-approved by TDOT.

2.3.3 Future Traffic Conditions without Project

Future traffic conditions without project are considered the characterization, for all target and horizon years, of the surrounding transportation system within the study area limits and without the proposed development. The future traffic conditions without project are simply developed by adding the traffic volumes contained in the existing traffic conditions together with the background traffic conditions for each horizon year. An analysis of the future traffic conditions without project within the study area limits is important in order to determine future deficiencies in the surrounding transportation system and to compare it against future traffic conditions with project.

2.3.4 Site Traffic Conditions

Site traffic conditions are considered the characterization, based on 100% occupancy of the construction phase or full build-out, of the total number of trips generated by the proposed development of the surrounding transportation system within the study area limits. The estimated number of trips generated by a proposed development shall be calculated in accordance with Table 2.1 of this document. During the analysis of the site traffic conditions, internal circulation shall be evaluated including the location of all site ingress/egress access intersections to existing adjacent public roads. The number of access points should be kept to a minimum and designed to be consistent with the type of existing adjacent public roadway facility. A directional trip distribution percentage model of the new trips generated by the proposed development should be based on an acceptable trip distribution methodology including, but not limited to, existing traffic patterns on adjacent public roads, population centers, and employment centers of the surrounding transportation system within the study area limits. If the proposed development is a mixed-use development, each land use shall justify a separate directional trip distribution percentage model. Typically, the same directional trip distribution percentage models are utilized for each construction phase or full build-out. Once a directional trip distribution percentage model is developed, the total number of trips generated by the proposed development is assigned throughout the surrounding transportation system within the study area limits by multiplying the total number of trips by each directional trip distribution percentage model. If multiple directional trip distribution percentage models are utilized to develop the site traffic conditions, then the trip assignment for each land use and/or construction phase shall be developed separately and an overall total trip assignment generated by the entire proposed development shall be prepared to summarize all of the directional trip distribution percentage models.

2.3.5 Future Traffic Conditions with Project

Future traffic conditions with project are considered the characterization, for all target and horizon years, of the surrounding transportation system within the study area limits and with the proposed development. The future traffic conditions with project are simply developed by adding the traffic volumes contained in the future traffic conditions without project together with the site traffic conditions for each target/horizon year. An analysis of the future traffic conditions with project within the study area limits is important in order to determine future deficiencies in the surrounding transportation system and to compare it against future traffic conditions without project.

2.4 Traffic Impact Study Analyses and Mitigation Measures

2.4.1 Capacity Analyses

Capacity analyses shall be conducted by using the most recent version, including updates, of HCS software for all study roadway segment and intersections as determined during the traffic impact study scoping meeting. Although other measurements may be considered, the primary measurement for determining traffic impacts of the surrounding transportation system within the study area limits is LOS, as defined in the latest edition of the HCM. Capacity analyses for each target/horizon year and time period shall be conducted for the following three traffic conditions:

- Existing Traffic Conditions + *Background Traffic Conditions* =
- Future Traffic Conditions Without Project + *Site Traffic Conditions* =
- Future Traffic Conditions with Project

Other traffic software packages such as Synchro, CorSim, and Sidra are not required, but may be utilized in the traffic impact study analyses. Results from any traffic software shall be reported in HCM/HCS, Synchro, or as approved by TDOT.

<u>Signalized Intersections**</u>

LOS for existing signalized intersections shall utilize existing traffic signal timing plans provided by signal owner as a base for evaluation. Additional traffic signal phases and adjustments in existing traffic signal timings may be evaluated as long as there is not a decrease in LOS for all lane group movements within an intersection. All signalized intersections that are part of a coordinated traffic signal system shall be analyzed as such under all traffic conditions. The analysis results shall be provided in the Full Report format, including the letter grade and delay (in seconds). Unless field data is collected otherwise, the following defaults are to be used in the HCS software:

- Analysis Type = Operational
- Analysis Period Duration = 0.25
- Multiple Period Analyses (in 15-minute increments beginning from an uncongested time period before the peak period to an uncongested time period after the peak period)
- Peak Hour Factor (PHF) = As provided by TDOT or 1.00
- Right-Turn of Red (RTOR) Reductions = As provided by traffic analysis software or as recommended by TDOT
- Cycle Length Range = 60 to 90 seconds for 2 phases, 70 to 120 seconds for 3 phases, 80 to 150 seconds for 4 or more phases (if the traffic signal

is located within a coordinated traffic signal system, then the actual coordinated cycle length shall be used)

- Base Saturation Flow Rate = 1,900 passenger cars/hour/lane
- Arrival Type = 3 for isolated traffic signals or 4 for coordinated traffic signals
- Lane Width = 12 feet
- Upstream Filtering Adjustment Factor = 1.0
- Percent Heavy Vehicles = As provided by TDOT or 3% (minimum). A *heavy vehicle* is defined as any vehicle with three or more axles.

***An Intersection Control Evaluation (ICE) may be required if signalized intersections are being considered for addition or improvements. As of 5/1/2018, TDOT has yet to finalize standards and guidance for ICE, however once these standards are implemented additional evaluation may be required.*

Unsignalized Intersections

LOS for unsignalized intersections evaluated with an overall LOS E or a lane group movement with LOS F shall also be evaluated to determine which control type may be best.

2.4.2 Level of Service (LOS) Goals

The minimum LOS goals for each study roadway segment and intersection evaluated shall be in accordance with Table 2.2.

Table 2.2: Minimum LOS Goals

		Future Traffic Conditions LOS (Without Project)[1,2]					
		A	B	C	D	E[2]	F[2]
Future Traffic Conditions LOS (With Project)[1,2]	A	-					
	B	B	-				
	C	B	C	-			
	D	B	C	C	-		
	E[3]	B	C	C	D	-	
	F[3]	B	C	C	D	E	-

[1]LOS values are for all lane group movements within a specific roadway segment and/or intersection.

[2]If the volume to capacity (v/c) ratio is equal to or greater than 1.0, then the LOS is F regardless of the calculated LOS value.

[3]Signalized or unsignalized intersections operating at LOS E or F in Future Traffic Conditions without Project shall not experience increased vehicular delay greater than 10% (measured in seconds/vehicle) when compared to the Future Traffic Conditions with Project.

A summary of Table 2.2 indicates that:

- When the LOS without the proposed development is LOS A, the minimum LOS goal shall be LOS B for all lane group movements within a specific roadway segment and/or intersection.
- When the LOS without the proposed development is LOS B, the minimum LOS goal shall be LOS C for all lane group movements within a specific roadway segment and/or intersection.
- When the LOS without the proposed development is LOS C, D, E, or F the minimum LOS goal shall be equal to the LOS without the proposed development for all lane group movements within a specific roadway segment and/or intersection.

The LOS values contained in Table 2.2 are considered goals and not regulatory requirements. Instead, these LOS goals shall be utilized primarily as a screening tool to assist in the determination of whether or not the traffic impacts resulting from a proposed development require mitigation. Proposed developments whose study roadway segments and intersections that satisfy the conditions in Table 2.2 may not be required to provide mitigation beyond their site ingress/egress access intersections to existing adjacent public roads and/or improve motorist's safety concerns adjacent to the proposed development.

2.4.3 Queuing Analyses

Queuing analyses shall be conducted at all signalized and unsignalized intersections for left turn and right turn lanes to determine the calculated storage length of the turn lanes in order to manage queue spillover. For proper queue evaluation, the queue storage ratio shall be less than 1.0. The HCS 95% percentile queue model shall be utilized to determine the appropriate vehicle queue length in feet and shall be rounded up and reported in 25-foot increments. If the 95th percentile queue model cannot be achieved due to physical and/or geometric constraints currently existing within the surrounding transportation system, then the reduced queue model percentage shall be reported along with an explanation why there is a need to reduce the queue model percentage. Any reduction from the 95% percentile queue model percentage shall require prior approval from TDOT.

2.4.4 Mitigation Measures

Mitigation measures are defined as modifications to the existing surrounding transportation system within the study area limits and may be required based on the comparison results of the Future Traffic Conditions without Project and the Future Traffic Conditions with Project. In the event that the LOS results are below the LOS goals presented in Table 2.2 (i.e., transportation system deficiencies), mitigation measures for the transportation system deficiencies shall be identified to determine necessary transportation system improvements necessary to satisfy the minimum LOS goals in order to maintain the future background traffic conditions at their current level before the construction of the proposed development. To be considered an adequate proposed solution, mitigation measures should be specific. Mitigation measures for proposed developments that result from alleviating traffic impacts directly caused by the proposed development shall be identified for which the developer would be 100% responsible for the implementation of the mitigation measure. Mitigation measures for proposed developments that result from alleviating traffic impacts indirectly caused by the proposed development shall be identified for which the developer would be responsible for an equitable share payment to TDOT. The proposed development's equitable share is defined as its highest percentage of the facility's total traffic volumes during any target/horizon year and time period included in the traffic analyses. Mitigation measures may also include a reduction of the proposed development's size in order to reduce the number of peak hour trips that are generated. For proposed developments with multiple construction phases, a construction phasing plan of the mitigation measures is acceptable. Unless a construction phasing plan is being proposed, all mitigation measures that are 100% responsible for by the developer shall be implemented prior to receipt of any certification of occupancy or final plat approval, whichever is appropriate. Examples of possible mitigation measures are presented in Table 2.3.

Table 2.3: Examples of Possible Mitigation Measures

Mitigation Category	Possible Mitigation Measure*
Roadway Improvements	• Improving sight distance • Repaving and/or re-striping • Realigning streets to eliminate offsets • Adding new travel lanes such as thru lanes and center two-way, left turn lanes • Constructing new roadways • Constructing acceleration/deceleration lanes • Improving pedestrian/bicycle access and/or circulation, including sidewalks and/or bike lanes
Intersection Improvements	• Extending or constructing left turn and/or right turn lanes • Modifications to control type based on intersection control evaluation • Modifying traffic control devices • Modifying traffic signal timing or phasing • Improving traffic signal progression • Improving pedestrian/bicycle access and/or circulation, including sidewalks and/or bike lanes
Access Management Improvements	• Increasing driveway spacing • Reducing the number of driveways • Relocating driveways or intersections • Constructing shared access driveways • Installing divided medians
Site Plan/Land Use Improvements	• Reducing the proposed development size • Adjusting construction phasing plan • Increasing driveway queue length • Improving internal circulation • Revising service vehicle/truck access and/or circulation • Improving pedestrian/bicycle access and/or circulation, including sidewalks and/or bike lanes • Improving way-finding to destinations through directional signs and pavement markings

*Including but not limited to.

2.5 Traffic Impact Study Report Format

2.5.1 General Information

The following traffic study report format is considered a recommended outline in preparing a traffic study for review by TDOT. A summary of this outline is contained in Appendix A. Most traffic studies can be documented using the sections in this outline, but additional sections may be required based on more complex proposed developments. In contrast, some of the following sections in this outline may be excluded if they are not applicable. The text contained in the traffic impact study shall be comprehensive and complete. All of the required data and information contained in the traffic impact study shall flow in an orderly manner and be clearly identified in the appropriate sections of the report including appendices.

2.5.2 Title Page

The title page is the first page of the traffic impact study and summarizes the name and location of the proposed development, name of the applicant, contact information for the applicant, and date of the study. If the traffic study was prepared by a consultant, their name and contact information is included on the title page. In addition, the professional engineer in responsible charge along with their Tennessee P.E. registration number, signature, and seal shall also appear on the title page.

2.5.3 Table of Contents

The table of contents shall provide a list of all sections, figures, and tables included in the traffic impact study report. Page numbers shall denote the location of all items listed in the table of contents. A list of all appendix headers shall also be provided in the table of contents.

2.5.4 Executive Summary

The executive summary represents a short, clear, concise description of the study findings and recommendations. The executive summary should include a general description of the proposed development scope, target and horizon years, time periods analyzed, existing and future conditions including a summary of the capacity analyses, identification of transportation system deficiencies including their mitigation measures, conclusions, and recommendations. Technical publications, calculations, documentation, data reporting, and detailed design should not be included in the executive summary.

2.5.5 Introduction

The introduction identifies the applicant's request including the need and purpose for the proposed development. The introduction provides a brief description of the proposed development's location including a figure showing a location map and a detailed description of the proposed development including the current zoning classification, the size of the parcel, anticipated completion year (or years if multiple construction phases are being planned), and the existing and proposed uses for the proposed development (e.g. square footage of each use, the number and size of dwelling units of each use, etc.). The introduction shall also identify other transportation improvement projects, other proposed roadway improvement projects, and other approved, but unconstructed, development projects in the vicinity of the proposed development site. The recommended manuals, software, and other tools used in the traffic impact study analyses shall be provided in the introduction. The traffic impact study scoping meeting shall be summarized in the introduction. The minutes from the traffic study scoping meeting including the *Traffic Study Screening Form* shall be contained in the appendix.

2.5.6 Study Analysis Considerations

The study analysis considerations shall describe the study area limits that were evaluated in the traffic impact study and identify the location of the proposed development including a figure showing the study area limits. The study analysis considerations shall also describe the surrounding transportation system within the study area limits and identify the horizon year (or years if multiple construction phases are being planned), peak hours, background growth rates, and transportation modes such as accommodations for pedestrians and bicycles.

2.5.7 Existing Traffic Conditions

The existing traffic conditions, as discussed in Section 2.3.1, shall consist of describing the existing geometric characteristics of the surrounding transportation system within the study area limits including figures showing the geometric characteristics. Such characteristics shall include acceleration, deceleration and weaving lanes. The existing traffic conditions shall also consist of developing existing year traffic volumes including figures showing the peak hour traffic volumes. The capacity and queuing analysis results of the existing year traffic volumes shall be included in this section. Any deviation from the HCS default values shall be documented. The existing traffic counts used to develop the existing year traffic volumes and the HCS computer printouts for the existing year analyses shall be contained in the appendix.

2.5.8 Background Traffic Development and Growth Calculations

The background traffic development and growth calculations, as discussed in Section 2.3.2, shall consist of documenting the development of background growth rate being applied to the current year traffic volumes for each horizon year of the proposed development.

2.5.9 Future Traffic Conditions without Project

The future traffic conditions without project, as discussed in Section 2.3.3, shall consist of developing the future traffic volumes resulting from the combination of existing year traffic volumes and the background traffic growth for each target/horizon year of the proposed development, including figures showing the peak hour traffic volumes. The capacity and queuing analysis results of the future year traffic volumes without project shall be included in this section. Any deviation from the HCS default values shall be documented. The HCS computer printouts for the future traffic conditions without project analysis shall be contained in the appendix.

2.5.10 Site Traffic Conditions

The site traffic conditions, as discussed in Section 2.3.4, shall consist of describing the proposed development, including internal circulation and the location of all site ingress/egress access intersections to existing adjacent public roads. The trip generation, distribution, and assignment methodologies shall be documented in the site traffic conditions, including tables and figures showing the development of the number of trips for the proposed development. If multiple construction phases are being planned, the trip generation, distribution, and assignment methodologies shall be documented separately for each construction phase. Support information for the proposed development shall be contained in the appendix.

2.5.11 Future Traffic Conditions with Project

The future traffic conditions with project, as discussed in Section 2.3.5 shall consist of developing the future traffic volumes resulting from the combination of future traffic conditions without project traffic volumes and the site traffic volumes for each target and horizon year of the proposed development, including figures showing the peak hour traffic volumes. The capacity and queuing analysis results of the future year traffic volumes with project shall be included in this section. Any deviation from the HCS default values shall be documented. The HCS computer printouts for the future traffic conditions with project analysis and any other related traffic analyses required in this study (e.g. multi-way stop control warrants, traffic signal warrants) shall be contained in the appendix.

2.5.12 Summary of Findings

The summary of findings shall document the comparison of the Future Traffic Conditions without Project and the Future Traffic Conditions with Project, including a table presenting the comparison results. The summary of findings shall consist of providing any transportation system deficiencies, including their proposed transportation improvement mitigation measures, as discussed in Section 2.4.4, required to maintain minimum acceptable LOS standards, as discussed in Section 2.4.2, for the surrounding transportation system within the study area limits.

2.5.13 Recommendations

The recommendations shall document in a clear, concise way any transportation improvements contained in the traffic impact study. These transportation improvements describe the mitigation measures, including the percentage of responsibility for the implementation of each mitigation measure between TDOT and the developer. The recommendations shall separate the mitigation measures into groups if multiple construction phases are being planned. The recommendation should end with a statement indicating whether or not the proposed development will meet minimum acceptable LOS standards described herein through the completion at horizon year. Proposed mitigation measures as well as road or signal improvements may also require completion target dates if the project is to be completed in a phased approach.

2.5.14 Submittal Requirements

For each traffic study review by TDOT, the consultant shall include an electronic copy of the traffic study, including data analysis files that match the data analysis presented in the traffic study. Submittal shall include two (2) signed and sealed printed copies along with the electronic final versions of the traffic study data in PDF format. Analysis files that match the data analysis presented in the approved traffic study shall also be included. Submittals shall be made to the Regional Traffic Engineering Office in the region where the property is located.

CHAPTER 3

TDOT PROJECT DEVELOPMENT

3.1 Project Schedule

Projects involving traffic signal, signing, and roadway lighting work are imperative to be kept on schedule, as projects of this type are quite often developed to improve an identified safety deficiency. Keeping projects on schedule is a shared responsibility between the designer and the assigned TDOT Design Manager. The designer should not hesitate to contact the TDOT Design Manager regarding any questions, difficulties or delays in receiving materials or information.

3.2 Plans Development Responsibilities

Local governing agencies often prefer to use local funds to contract with design firms or use in-house staff for the preparation of construction plans which will be let to contract by TDOT with state and/or federal funding. Various responsibilities are as follows:

3.2.1 TDOT Design Manager

The TDOT Design Manager will provide traffic projections, pavement design and other related data as needed. The TDOT Design Manager will also schedule field reviews and submit preliminary, right-of-way, and final construction plans for project coordination and letting. In most cases, because of the smaller nature of standalone traffic design projects, the preliminary and right-of-way phases will be combined into one phase, which is commonly referred to as the Right-of-Way Plans phase. The TDOT Design Manager will upload the plans and supporting files on FileNet at the completion of the right-of-way and construction phases and any subsequent plan revisions that occur.

3.2.2 Local Agency

The local agency will hire and approve the consultant or on-staff designer and assure that the plans development process is completed in a timely manner. The local agency will be responsible for contacting all parties to schedule and conduct a kick-off meeting to determine the scope of the project and assign various responsibilities.

3.2.3 Design Engineer

The design engineer (e.g. designer) will develop a set of construction plans and will contact the TDOT Design Manager as needed in a timely manner to settle design issues and answer questions. If the project is let by TDOT, then the construction plans shall adhere to TDOT's format (See Section 3.3).

3.3 Plan Development Stages

The various stages of plan development for traffic signal, roadway lighting, and signing projects follow the same procedures detailed in the Roadway Design Guidelines. The following is a summary outline of the plan development process:

- **Determination that a traffic signal, roadway lighting, and/or signing project is needed and funds are obligated.**
  - Determination of projects can be made from various sources including, but not limited to, the Roadway Design Division, the Traffic Operations Division, the Strategic Transportation Investments Division, and the Local Programs Office. In some cases, other sources can make the determination of a needed project.
- **Determination if the project can be surveyed and/or designed with in-house forces. If not, a consultant is selected and requested to provide a proposal for the services needed.**
  - If a consultant is utilized, then issue a work order and conduct a kick-off meeting or some understanding, in writing, of the various duties and responsibilities of the services needed.
  - The TDOT Design Manager will request traffic projections once a project commences.
- **Perform survey.**
  - Survey control points should be coordinated with the TDOT Regional Survey offices through the TDOT Design Manager.
  - Surveys completed by consultants will be sent to the TDOT Regional Survey offices for approval.
- **If the design project right-of-way plans are not combined with the preliminary plans, then follow the same process as right-of-way plans:**
  - Develop preliminary plans.
  - Conduct preliminary field review.
  - Finalize preliminary plans.
- **Develop right-of-way plans.**
  - Right-of-way plans consist of a nearly complete set of plans for either a utility only (if no right-of-way is required) or a right-of-way submittal and should include all sheets except for the quantity sheet and some detail sheets.
  - Where feasible, avoid design features requiring the acquisition of right-of-way, drainage structures, or conflicts with utilities to help expedite the project.
  - Six weeks are typically allowed for this stage.

- **Conduct site review.**
    - After the preliminary traffic signal layout and pole locations are determined, a site review should be scheduled prior to the right-of-way field review. In some cases, an in-person meeting can be scheduled at the end of the right-of-way field review near the project site.
    - One day including travel is typically allowed for this stage.
- **Conduct right-of-way field review.**
    - In most cases, because of the smaller nature of stand-alone traffic design projects, these field reviews consist of gathering comments from reviewers instead of an in-person meeting.
    - Three weeks are typically allowed for this stage.
- **Finalize right-of-way plans.**
    - Once all of the review comments are received, the consultant will provide the TDOT Design Manager with a disposition letter summarizing how they will proceed in addressing the right-of-way field review comments. The disposition letter should be submitted as soon as possible, but generally no later than two weeks from receiving the comments. The disposition letter shall include a statement that indicates whether or not there are impacts to the project limits, ROW, and/or utilities on the project and how they will be affected differently or changed due to the comments received.
    - Upon approval from the TDOT Design Manager, the design engineer will submit an electronically signed/sealed (title sheet only) right-of-way plan set in PDF format.
    - In addition to the signed and sealed right-of-way plan set, the design engineer will submit an info plan set (i.e. plan set not signed/sealed and marked not for construction), a right-of-way quantity estimate, and a ZIP file containing all of the design files that were created during the preparation of the design plans. This includes, but not limited to, Microstation DGN files and their associated reference files, Geopak files, survey files, cost estimates and their support data, pole designer software files, word documents such as correspondences and the field review comment disposition letters, spreadsheets such are earthwork grading sheets and support calculations, location maps and sketches, associated PDFs, and any other information or files that were used to develop and prepare the design project.
    - At the completion of the right-of-way plans phase, the TDOT Design Manager will request the pavement design (if mainline paving is needed) and the TMP.
    - Four weeks are typically allowed for this stage.

- **Post right-of-way plans turn-in.**
  - Requests for right-of-way revisions will occasionally come from the TDOT Design Manager and should be processed as soon as possible.
- **Develop construction plans.**
  - After receiving both the environmental document and right-of-way funding approval documents, the TDOT Design Manager will notify the consultant to proceed with the development of construction plans.
  - Construction plans consist of a complete set of plans including all index sheets, quantities sheets, general and special notes, tabulations and details as required.
  - Six weeks are typically allowed for this stage.
- **Conduct constructability field review.**
  - In most cases, because of the smaller nature of standalone traffic design projects, these field reviews consist of gathering comments from reviewers instead of an in-person meeting.
  - Three weeks are typically allowed for this stage.
- **Finalize construction plans.**
  - Once all of the review comments are received, the consultant will provide the TDOT Design Manager with a disposition letter summarizing how they will proceed in addressing the constructability field review comments. The disposition letter should be submitted as soon as possible, but generally no later than two weeks from receiving the comments. The disposition letter shall include a statement that indicates whether or not there are impacts to the project limits, ROW, and/or utilities on the project and how they will be affected differently or changed due to the comments received.
  - Upon approval from the TDOT Design Manager, the design engineer will submit an electronically signed/sealed (on every sheet) construction plan set in PDF format.
  - In addition to the signed/sealed construction plan set, the design engineer will submit an info plan set (i.e. plan set not signed/sealed and <u>marked not for construction</u>), a final quantity estimate, and a ZIP file containing all of the design files that were created during the preparation of the design plans. This includes, but not limited to, Microstation DGN files and their associated reference files, Geopak files, survey files, cost estimates and their support data, pole designer software files, word documents such as correspondences and the field review comment disposition letters, spreadsheets such are earthwork grading sheets and support calculations, location maps and sketches, associated PDFs, and any other information or files that were used to develop and prepare the design project.

  - When ready, the TDOT Design Manager will submit construction plans for turn-in.
  - Four weeks are typically allowed for this stage.

- **Post construction plans turn-in.**
  - Requests for letting and construction revisions will occasionally come from the TDOT Design Manager and should be processed as soon as possible.

3.4 Support Projects

Support projects, which are typically prepared as part of a larger roadway design project by a consultant or in-house staff, require only traffic signalization, roadway lighting, detail sheets, signing layouts, and sign schedules. Since support projects are often prepared by design engineers not under the direct supervision of the primary professional engineer responsible for signing/sealing the plans in general, the traffic engineering quantities and special notes should be included on a sheet separate from the roadway project quantities under the seal of the supporting signal design engineer. Coordination between the primary professional engineer, the supporting professional engineer, and the TDOT Design Manager should be maintained throughout the design process.

3.5 Conformance to TDOT Plans Format

TDOT requires all roadway plans let to contract in the State's bid process to be developed in the particular TDOT format described in the TDOT *Roadway Design Guidelines* and as adapted for traffic design in this manual. TDOT contracts for the design and construction of hundreds of millions of dollars and many miles of road construction projects and has developed a plans format that many designers, roadway observers (i.e. roadway inspectors), and road contractors have become familiar and comfortable with. Variations from this format could create some confusion and misunderstanding and should be avoided. The following are plans layout requirements:

- **Plan Sheet Numbering:** On support projects, consult with the TDOT Roadway Design Manager for sheet numbering. The example shown in Table 3.1 is an intersection widening project with a traffic signal.
- **Plan Scales:** The typical plan scale for traffic signal intersection layouts is 1 inch = 30 feet (1”=30’). However, a plan scale of 1 inch = 20 feet (1”=20’) is desired if the traffic signal intersection layout can fit on one plan sheet. No other scales for traffic signal intersection layouts are acceptable unless approved by the TDOT Design Manager. For traffic signal interconnect layouts, the minimum plan scale is 1 inch = 50 feet (1”=50’) unless another scale is approved by the TDOT Design Manager.

- **Aerial Photography:** This may be used as a base for signal layout plans where no utility relocation is involved and right-of-way is easily established. However, a survey may be required for control purposes. Contact the TDOT Design Manager before using aerial photography.
- **Details:** A signal detail sheet will be required for each signal installation and should display wiring diagrams, tabulations of signal phasing, detection tables, and signal timing requirements.
- **Notes:** Any notes not listed in the Roadway Design Guidelines as General Notes are to be labeled Special Notes and shown apart from the General Notes.
- **Quantities:** Keep items as specific as possible. If possible, avoid costs to be included in other items for items.

Table 3.1 – Plan Sheet Numbering Example

Sheet	Preliminary*	Right-of-Way	Construction
Title	1	1	1
Index	1 or 1A	1 or 1A	1 or 1A
General Notes	2	2	2
Roadway Quantities	N/A	N/A	2A
Property Map, Acquisition Table	N/A	3	3
Present Layout	3, 4, etc	4, 5, etc	4, 5, etc
Proposed Layouts	3A, 4A, etc.	4A, 5A, etc.	4A, 5A, etc.
ROW/Utility Details	3B, 4B, etc.	4B, 5B, etc.	4B, 5B, etc.
Signal Layout	5 (or next number), 6, etc.	6 (or next number), 7, etc.	6 (or next number), 7, etc.
Signal Details	5A, 6A, etc.	6A, 7A, etc.	6A, 7A, etc.
Erosion Control	7 (or next number)	8 (or next number)	8 (or next number)
Traffic Control	8 (or next number)	9 (or next number)	9 (or next number)
Cross-Sections	9 (or next number), 10, etc.	10 (or next number), 11, etc.	10 (or next number), 11, etc.

*Follow the Preliminary example if the project includes the separate preliminary phase. Otherwise, follow the Right-of-Way example.

CHAPTER 4

JUSTIFYING THE NEED FOR TRAFFIC SIGNALS

4.1 Justification for Traffic Signal Control

In order to determine whether or not the installation of a traffic signal control is justified an engineering study and a warrant analysis shall be performed as required by the *MUTCD*. The engineering study shall be signed and sealed by a registered professional engineer in Tennessee and in good standing. The engineering study shall be approved, in writing, by the TDOT Design Manager.

Generally, the installation of a traffic control signal is considered only after all of the following conditions are met:

- One or more of the *MUTCD* traffic signal warrants are met; and
- An engineering study shows that traffic signalization will improve the overall traffic operations and/or safety of an intersection and the resulting traffic signal will not seriously disrupt the progressive traffic flow from adjacent traffic signals.

The *MUTCD* cautions that "the satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal."

4.1.1 Engineering Study Data Collection

The following data should be included as a minimum in an engineering study:

- **Traffic Counts:** Traffic counts should be made on a typical weekday for the location, normally in the middle of the week (Tuesday through Thursday). Additionally, if the location is affected by school traffic, then the count should be made when school is in session. Counts should be avoided on holidays, and during special events or inclement weather. The practitioner should be aware that counts may be inaccurate due to data collection errors, and it is possible for traffic to vary significantly from day to day, week to week, and month to month.
    - **Vehicular 24-Hour Traffic Counts:** Twenty-four hour traffic counts should be conducted on each approach counting all vehicles entering the intersection. The 24-hour traffic volume profiles are an important element in the data collection effort of an engineering study and are used to identify the hours of the day during which total traffic entering the intersection is greatest. The 24-hour traffic volumes are usually collected using temporary road tubes.

- **Vehicular Turning Movement Counts:** Turning movement counts should be conducted on each approach of the intersection showing all vehicular movements classified by vehicle type (trucks, passenger cars, and public-transit vehicles) during each 15-minute interval for a minimum of two hours in each of the AM, midday, and PM peak periods. In any case, these hours should include the periods during which total traffic entering the intersection is greatest as revealed by the previously conducted 24-hour traffic counts.
- **Pedestrian Traffic Counts:** If pedestrians are a concern, pedestrian volume counts should be conducted on each approach for the same periods as the vehicular turning movement counts and during the periods of peak pedestrian volumes. The presence of nearby facilities that could generate young, elderly, or disabled pedestrian traffic should be noted. The traffic count data should be submitted in a format that shows hourly pedestrian volumes by approach.
- **Bicycle Traffic Counts:** If bicycles are a concern, bicycle volume counts should be conducted on each approach of the intersection showing all bicycle movements for the same periods as the traffic movement counts and during the periods of peak bicycle volumes. The count data should be submitted in a format that shows hourly bicycle volumes by approach. According to the *MUTCD*, bicycles may be counted as pedestrians when using pedestrian facilities.

Examples of vehicular, pedestrian, and bicycle counts are shown in Figure 4.1.

- **Traffic Volumes Hourly Percentages when using AADT Volumes:** In lieu of vehicular 24-hour traffic counts, Tennessee statewide average traffic volumes hourly percentages for arterial facilities (i.e. not interstate facilities) when using AADT Volumes are presented in Tables 4.1 to 4.5. In Table 4.1, the Tennessee statewide average traffic volumes hourly percentages shown include two lane facilities, multi-lane facilities, and overall for both facility types. Shaded areas indicate the eight highest hourly percentages for traffic signal warrant analysis purposes. In Tables 4.2 to 4.5, TDOT Region average traffic volumes hourly percentages shown include two lane facilities and multi-lane facilities. Further breakdown of the TDOT Region average traffic volumes hourly percentages include population tiers from larger cities (Tier A) to smaller cities/rural areas (Tier E).
- **Speed Data:** Information on the posted or statutory speed limit should be collected and a speed study showing the 85^{th} percentile speeds on the uncontrolled approach of the intersection should be conducted.
- **Condition Diagram:** A condition diagram of an intersection typically shows details of the physical layout, including such features as geometry, channelization, grades, sight-distance restrictions, pavement markings,

signs (traffic, business marquees, and billboards), driveways, utility poles, roadway lighting, parking conditions, transit stops, sidewalks and curb ramps, vegetation (if over three feet in height), adjacent land use, nearby railroad crossings, and the distance to the nearest traffic signal (if less than one mile). An example of a condition diagram is shown in Figure 4.2.

- **Collision Diagram:** A collision diagram or listing shows the crash record for the intersection covering as a minimum, the most recent 12-month period for which crash records are available. However, it is desirable to show the most recent 3-year period. Each crash symbol, or record, should show the crash type, travel direction of the vehicles, date, time of day, severity (injuries/fatalities), pavement condition, weather, and lighting conditions. An example of a collision diagram is shown in Figure 4.3.

Figure 4.1 – Vehicular, Pedestrian, and Bicycle Counts Example
Source: Traffic Signal Timing Manual

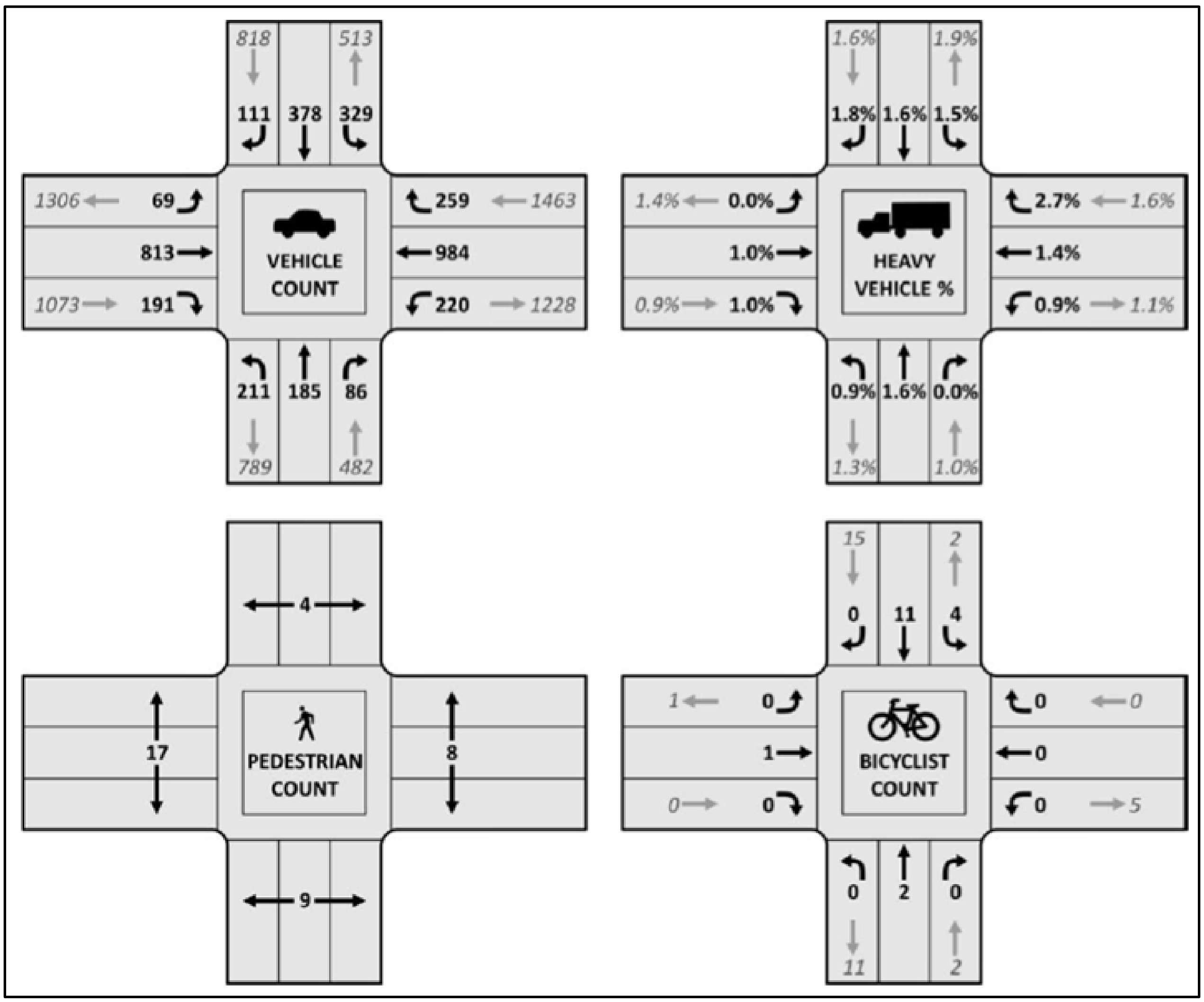


Table 4.1 – Tennessee Statewide Average Traffic Volumes Hourly Percentages

TRAFFIC OPERATIONS DIVISION - TRAFFIC ENGINEERING OFFICE

2017 TRAFFIC VOLUMES HOURLY PERCENTAGES

TENNESSEE STATEWIDE AVERAGE FOR ARTERIAL FACILITIES

Hour		TENNESSEE STATEWIDE AVERAGE FOR ARTERIAL FACILITIES		
From	To	Two Lane Facilities	Multi-Lane Facilities	Overall for Both Facility Types
12:00 M	1:00 AM	0.57	0.59	0.58
1:00 AM	2:00 AM	0.37	0.40	0.39
2:00 AM	3:00 AM	0.32	0.33	0.33
3:00 AM	4:00 AM	0.42	0.41	0.42
4:00 AM	5:00 AM	0.77	0.78	0.78
5:00 AM	6:00 AM	1.89	1.94	1.92
6:00 AM	7:00 AM	4.09	4.05	4.07
7:00 AM	8:00 AM	7.29	6.79	7.04
8:00 AM	9:00 AM	5.96	5.93	5.95
9:00 AM	10:00 AM	5.06	5.29	5.18
10:00 AM	11:00 AM	5.06	5.40	5.23
11:00 AM	12:00 N	5.62	6.05	5.84
12:00 N	1:00 PM	6.08	6.56	6.32
1:00 PM	2:00 PM	6.10	6.46	6.28
2:00 PM	3:00 PM	6.86	6.77	6.82
3:00 PM	4:00 PM	7.92	7.61	7.77
4:00 PM	5:00 PM	8.33	8.04	8.19
5:00 PM	6:00 PM	8.39	8.06	8.23
6:00 PM	7:00 PM	6.15	5.91	6.03
7:00 PM	8:00 PM	4.35	4.24	4.30
8:00 PM	9:00 PM	3.44	3.34	3.39
9:00 PM	10:00 PM	2.38	2.42	2.40
10:00 PM	11:00 PM	1.58	1.62	1.60
11:00 PM	12:00 M	1.00	1.02	1.01

Notes:

1. The seven (7) highest hours are shown in green highlight and the eighth (8th) highest hour is shown in orange highlight.
2. The average traffic volumes hourly percentages shown were based traffic volume data collected at 504 representative traffic count locations (e.g. 126 locations per Region).
3. Values shown are calculated and rounded up which may result in small rounding errors.

Table 4.2 – TDOT Region 1 Average Traffic Volumes Hourly Percentages

TRAFFIC OPERATIONS DIVISION - TRAFFIC ENGINEERING OFFICE
2017 TRAFFIC VOLUMES HOURLY PERCENTAGES
TDOT REGION 1 AVERAGE FOR ARTERIAL FACILITIES

TN TDOT Department of Transportation

AVERAGE FOR TWO LANE FACILITIES							
Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 M	1:00 AM	0.41	0.65	0.56	0.65	0.67	0.59
1:00 AM	2:00 AM	0.22	0.35	0.29	0.36	0.43	0.33
2:00 AM	3:00 AM	0.18	0.32	0.28	0.22	0.34	0.27
3:00 AM	4:00 AM	0.26	0.29	0.28	0.27	0.44	0.31
4:00 AM	5:00 AM	0.56	0.53	0.70	0.42	0.94	0.63
5:00 AM	6:00 AM	1.56	1.62	1.99	1.20	2.37	1.75
6:00 AM	7:00 AM	4.07	3.50	3.87	2.92	3.74	3.62
7:00 AM	8:00 AM	9.03	6.16	7.58	7.03	6.40	7.24
8:00 AM	9:00 AM	6.78	5.53	5.96	6.47	5.57	6.06
9:00 AM	10:00 AM	4.94	5.01	4.79	5.37	5.17	5.06
10:00 AM	11:00 AM	4.58	5.54	4.67	5.43	5.33	5.11
11:00 AM	12:00 N	4.68	5.99	5.73	5.92	5.68	5.60
12:00 N	1:00 PM	5.17	6.61	6.27	6.11	6.03	6.04
1:00 PM	2:00 PM	5.54	6.54	5.83	6.17	6.03	6.02
2:00 PM	3:00 PM	6.34	6.67	6.36	6.84	6.48	6.54
3:00 PM	4:00 PM	7.83	7.46	7.81	7.66	7.70	7.69
4:00 PM	5:00 PM	8.79	8.00	8.81	8.09	8.18	8.37
5:00 PM	6:00 PM	9.64	8.53	9.13	8.36	8.25	8.78
6:00 PM	7:00 PM	7.17	6.40	6.49	6.57	6.33	6.59
7:00 PM	8:00 PM	4.33	4.75	4.35	4.74	4.67	4.57
8:00 PM	9:00 PM	3.26	3.96	3.38	3.71	3.62	3.58
9:00 PM	10:00 PM	2.48	2.73	2.46	2.62	2.83	2.62
10:00 PM	11:00 PM	1.38	1.76	1.52	1.75	1.72	1.63
11:00 PM	12:00 M	0.80	1.06	0.91	1.12	1.07	0.99

AVERAGE FOR MULTI-LANE FACILITIES							
Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 AM	1:00 AM	0.48	0.68	0.61	0.67	0.48	0.59
1:00 AM	2:00 AM	0.34	0.44	0.38	0.41	0.34	0.38
2:00 AM	3:00 AM	0.27	0.34	0.29	0.31	0.27	0.30
3:00 AM	4:00 AM	0.31	0.35	0.37	0.30	0.31	0.33
4:00 AM	5:00 AM	0.63	0.51	0.71	0.47	0.63	0.59
5:00 AM	6:00 AM	1.47	1.44	2.01	1.38	1.47	1.55
6:00 AM	7:00 AM	3.57	3.29	4.29	2.75	3.57	3.50
7:00 AM	8:00 AM	7.20	6.63	7.01	5.70	7.20	6.75
8:00 AM	9:00 AM	6.60	5.80	5.93	5.50	6.60	6.09
9:00 AM	10:00 AM	5.07	5.27	5.27	5.41	5.07	5.22
10:00 AM	11:00 AM	5.05	5.43	5.26	6.00	5.05	5.36
11:00 AM	12:00 PM	5.52	5.92	5.71	6.53	5.52	5.84
12:00 PM	1:00 PM	6.11	6.50	6.27	6.70	6.11	6.34
1:00 PM	2:00 PM	6.24	6.48	6.22	6.70	6.24	6.38
2:00 PM	3:00 PM	6.39	6.70	6.59	7.12	6.39	6.64
3:00 PM	4:00 PM	7.34	7.51	7.53	7.69	7.34	7.48
4:00 PM	5:00 PM	8.48	7.78	7.77	7.79	8.48	8.06
5:00 PM	6:00 PM	9.50	8.41	8.21	7.89	9.50	8.70
6:00 PM	7:00 PM	6.87	6.29	6.06	6.04	6.87	6.43
7:00 PM	8:00 PM	4.54	4.53	4.43	4.67	4.54	4.54
8:00 PM	9:00 PM	3.36	3.96	3.70	3.68	3.36	3.61
9:00 PM	10:00 PM	2.38	2.75	2.69	2.80	2.38	2.60
10:00 PM	11:00 PM	1.40	1.86	1.68	2.17	1.40	1.70
11:00 PM	12:00 AM	0.89	1.11	1.01	1.31	0.89	1.04

Notes:
1. The seven (7) highest hours are shown in green highlight and the eighth (8th) highest hour is shown in orange highlight.
2. The population tier locations are as follows:
   - Population Tier A → Knoxville
   - Population Tier B → Johnson City and Kingsport
   - Population Tier C → Bristol, Maryville, Morristown, and Oak Ridge
   - Population Tier D → Farragut, Greenville, and Sevierville
   - Population Tier E → All other cities not shown above and rural areas
3. Values shown are calculated and rounded up which may result in small rounding errors.

3/15/2017

Table 4.3 – TDOT Region 2 Average Traffic Volumes Hourly Percentages

TRAFFIC OPERATIONS DIVISION - TRAFFIC ENGINEERING OFFICE
2017 TRAFFIC VOLUMES HOURLY PERCENTAGES
TDOT REGION 2 AVERAGE FOR ARTERIAL FACILITIES

AVERAGE FOR TWO LANE FACILITIES

Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 M	1:00 AM	0.68	0.52	0.60	0.66	0.42	0.57
1:00 AM	2:00 AM	0.46	0.33	0.39	0.42	0.36	0.39
2:00 AM	3:00 AM	0.34	0.30	0.28	0.28	0.34	0.31
3:00 AM	4:00 AM	0.29	0.52	0.41	0.29	0.45	0.39
4:00 AM	5:00 AM	0.52	1.00	0.86	0.70	0.77	0.77
5:00 AM	6:00 AM	1.37	2.23	1.88	1.64	1.94	1.81
6:00 AM	7:00 AM	3.63	3.28	3.51	3.59	4.74	3.75
7:00 AM	8:00 AM	7.32	6.88	7.73	6.36	7.64	7.18
8:00 AM	9:00 AM	7.03	5.63	5.55	5.57	5.37	5.83
9:00 AM	10:00 AM	5.20	4.80	5.47	5.01	5.03	5.10
10:00 AM	11:00 AM	5.08	5.11	5.69	5.10	5.29	5.25
11:00 AM	12:00 N	6.06	5.61	6.27	5.60	5.38	5.79
12:00 N	1:00 PM	6.66	6.26	6.43	6.19	6.06	6.32
1:00 PM	2:00 PM	6.23	6.41	6.54	6.31	6.30	6.36
2:00 PM	3:00 PM	6.74	6.80	6.97	6.87	7.31	6.94
3:00 PM	4:00 PM	8.09	8.03	7.92	7.78	7.88	7.94
4:00 PM	5:00 PM	8.63	8.27	8.02	8.65	8.09	8.33
5:00 PM	6:00 PM	8.83	8.31	7.93	8.82	7.49	8.28
6:00 PM	7:00 PM	5.34	6.00	5.42	6.81	6.36	5.99
7:00 PM	8:00 PM	3.74	4.82	4.02	4.55	4.01	4.23
8:00 PM	9:00 PM	2.82	3.85	3.20	3.41	4.25	3.51
9:00 PM	10:00 PM	2.14	2.50	2.24	2.60	2.28	2.35
10:00 PM	11:00 PM	1.58	1.47	1.66	1.75	1.34	1.56
11:00 PM	12:00 M	1.23	1.08	1.01	1.05	0.93	1.06

AVERAGE FOR MULTI-LANE FACILITIES

Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 AM	1:00 AM	0.64	0.61	0.60	0.53	0.56	0.59
1:00 AM	2:00 AM	0.43	0.44	0.42	0.38	0.46	0.43
2:00 AM	3:00 AM	0.36	0.35	0.29	0.27	0.47	0.35
3:00 AM	4:00 AM	0.39	0.48	0.35	0.37	0.66	0.45
4:00 AM	5:00 AM	0.82	0.90	0.65	0.66	1.37	0.88
5:00 AM	6:00 AM	1.88	1.98	1.77	1.72	2.85	2.04
6:00 AM	7:00 AM	4.47	3.78	3.00	3.69	4.42	3.87
7:00 AM	8:00 AM	7.52	6.77	6.18	6.48	6.05	6.60
8:00 AM	9:00 AM	6.71	5.47	5.54	5.92	5.33	5.80
9:00 AM	10:00 AM	5.17	5.09	5.50	5.56	5.52	5.37
10:00 AM	11:00 AM	5.06	5.30	5.98	5.98	5.69	5.60
11:00 AM	12:00 PM	5.58	6.11	6.86	6.65	6.29	6.30
12:00 PM	1:00 PM	6.06	6.54	7.37	6.80	6.65	6.68
1:00 PM	2:00 PM	5.97	6.25	7.11	6.69	6.73	6.55
2:00 PM	3:00 PM	6.48	6.63	7.17	6.75	7.05	6.82
3:00 PM	4:00 PM	7.53	8.02	7.83	7.67	7.55	7.72
4:00 PM	5:00 PM	8.36	8.03	7.99	8.02	7.86	8.05
5:00 PM	6:00 PM	8.40	8.05	7.45	7.74	7.26	7.78
6:00 PM	7:00 PM	5.69	6.11	5.64	6.03	5.13	5.72
7:00 PM	8:00 PM	3.91	4.27	4.33	4.47	3.87	4.17
8:00 PM	9:00 PM	3.31	3.38	3.19	3.12	3.35	3.27
9:00 PM	10:00 PM	2.33	2.63	2.30	2.13	2.31	2.34
10:00 PM	11:00 PM	1.74	1.78	1.52	1.36	1.57	1.59
11:00 PM	12:00 AM	1.20	1.04	0.95	0.99	1.02	1.04

Notes:
1. The seven (7) highest hours are shown in green highlight and the eighth (8th) highest hour is shown in orange highlight.
2. The population tier locations are as follows:
   - Population Tier A → Chatanooga
   - Population Tier B → Cleveland
   - Population Tier C → Cookeville
   - Population Tier D → East Ridge and Tullahoma
   - Population Tier E → All other cities not shown above and rural areas
3. Values shown are calculated and rounded up which may result in small rounding errors.

3/15/2017

Table 4.4 – TDOT Region 3 Average Traffic Volumes Hourly Percentages

TRAFFIC OPERATIONS DIVISION - TRAFFIC ENGINEERING OFFICE
2017 TRAFFIC VOLUMES HOURLY PERCENTAGES
TDOT REGION 3 AVERAGE FOR ARTERIAL FACILITIES

AVERAGE FOR TWO LANE FACILITIES

Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 M	1:00 AM	0.76	0.26	0.54	0.58	0.71	0.57
1:00 AM	2:00 AM	0.47	0.15	0.35	0.35	0.56	0.37
2:00 AM	3:00 AM	0.45	0.11	0.26	0.31	0.35	0.29
3:00 AM	4:00 AM	0.45	0.15	0.33	0.44	0.56	0.39
4:00 AM	5:00 AM	0.75	0.32	0.71	1.06	1.30	0.83
5:00 AM	6:00 AM	2.20	1.20	2.42	2.55	3.42	2.36
6:00 AM	7:00 AM	5.47	4.72	4.58	4.80	5.36	4.99
7:00 AM	8:00 AM	7.46	8.35	6.40	7.13	6.96	7.26
8:00 AM	9:00 AM	5.89	6.99	5.31	5.32	4.94	5.69
9:00 AM	10:00 AM	4.85	5.27	5.17	5.16	4.67	5.02
10:00 AM	11:00 AM	4.61	5.03	5.38	5.31	4.86	5.04
11:00 AM	12:00 N	4.94	5.60	5.96	6.08	5.56	5.63
12:00 N	1:00 PM	5.52	6.18	6.33	6.28	6.01	6.06
1:00 PM	2:00 PM	5.65	6.08	6.40	6.68	5.61	6.08
2:00 PM	3:00 PM	6.63	6.77	6.90	7.35	7.01	6.93
3:00 PM	4:00 PM	7.65	7.69	7.59	8.28	8.06	7.85
4:00 PM	5:00 PM	8.44	8.69	7.96	7.69	8.24	8.20
5:00 PM	6:00 PM	8.42	8.80	7.81	7.42	7.98	8.08
6:00 PM	7:00 PM	6.40	6.65	6.22	5.40	5.55	6.04
7:00 PM	8:00 PM	4.28	4.28	4.59	4.12	4.21	4.30
8:00 PM	9:00 PM	3.42	3.06	3.71	3.11	3.25	3.31
9:00 PM	10:00 PM	2.37	2.01	2.53	2.22	2.35	2.30
10:00 PM	11:00 PM	1.63	1.10	1.58	1.47	1.51	1.46
11:00 PM	12:00 M	1.30	0.55	0.97	0.91	0.95	0.94

AVERAGE FOR MULTI-LANE FACILITIES

Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 AM	1:00 AM	0.71	0.44	0.58	0.50	0.56	0.56
1:00 AM	2:00 AM	0.49	0.29	0.37	0.33	0.40	0.37
2:00 AM	3:00 AM	0.38	0.27	0.32	0.29	0.31	0.31
3:00 AM	4:00 AM	0.44	0.30	0.39	0.36	0.57	0.41
4:00 AM	5:00 AM	0.83	0.61	0.84	0.87	1.15	0.86
5:00 AM	6:00 AM	2.01	2.00	2.53	2.10	3.01	2.33
6:00 AM	7:00 AM	4.42	4.92	4.83	4.28	5.18	4.73
7:00 AM	8:00 AM	7.08	6.97	6.21	6.36	6.78	6.68
8:00 AM	9:00 AM	6.31	6.15	5.34	5.30	5.29	5.68
9:00 AM	10:00 AM	5.67	5.15	5.16	5.21	5.28	5.30
10:00 AM	11:00 AM	5.61	5.00	5.38	5.42	5.54	5.39
11:00 AM	12:00 PM	6.25	5.67	6.08	6.42	6.26	6.14
12:00 PM	1:00 PM	6.51	6.43	6.50	6.98	6.54	6.59
1:00 PM	2:00 PM	6.43	6.26	6.40	6.69	6.35	6.43
2:00 PM	3:00 PM	6.64	6.58	6.77	6.75	6.64	6.68
3:00 PM	4:00 PM	7.27	7.62	7.48	7.67	7.85	7.58
4:00 PM	5:00 PM	7.83	8.13	7.92	7.91	7.99	7.96
5:00 PM	6:00 PM	7.25	8.13	7.79	7.86	7.53	7.71
6:00 PM	7:00 PM	5.35	6.51	6.10	6.05	5.44	5.89
7:00 PM	8:00 PM	3.93	4.50	4.41	4.47	3.75	4.21
8:00 PM	9:00 PM	3.00	3.35	3.60	3.49	3.11	3.31
9:00 PM	10:00 PM	2.47	2.32	2.48	2.36	2.23	2.37
10:00 PM	11:00 PM	1.88	1.52	1.51	1.51	1.42	1.57
11:00 PM	12:00 AM	1.25	0.87	1.00	0.81	0.84	0.95

Notes:
1. The seven (7) highest hours are shown in green highlight and the eighth (8th) highest hour is shown in orange highlight.
2. The population tier locations are as follows:
   - Population Tier A → Clarksville, Murfreesboro, and Nashville
   - Population Tier B → Brentwood, Franklin, Hendersonville, and Smyrna
   - Population Tier C → Columbia, Gallatin, La Vergne, Lebanon, Mount Juliet, and Spring Hill
   - Population Tier D → Dickson, Goodlettsville, Shelbyville, and Springfield
   - Population Tier E → All other cities not shown above and rural areas
3. Values shown are calculated and rounded up which may result in small rounding errors.

3/15/2017

Table 4.5 – TDOT Region 4 Average Traffic Volumes Hourly Percentages

TRAFFIC OPERATIONS DIVISION - TRAFFIC ENGINEERING OFFICE
2017 TRAFFIC VOLUMES HOURLY PERCENTAGES
TDOT REGION 4 AVERAGE FOR ARTERIAL FACILITIES

AVERAGE FOR TWO LANE FACILITIES

Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 M	1:00 AM	1.11	0.45	0.20	0.47	0.43	0.53
1:00 AM	2:00 AM	0.76	0.34	0.11	0.40	0.23	0.37
2:00 AM	3:00 AM	0.96	0.19	0.10	0.46	0.26	0.39
3:00 AM	4:00 AM	1.96	0.24	0.08	0.39	0.40	0.61
4:00 AM	5:00 AM	1.79	0.49	0.20	0.99	0.72	0.84
5:00 AM	6:00 AM	1.68	1.32	0.81	2.14	2.33	1.65
6:00 AM	7:00 AM	2.97	4.00	4.31	3.91	4.89	4.02
7:00 AM	8:00 AM	5.80	6.18	7.91	8.83	8.65	7.47
8:00 AM	9:00 AM	5.75	6.45	7.98	5.66	5.39	6.24
9:00 AM	10:00 AM	5.26	5.42	5.25	4.95	4.50	5.08
10:00 AM	11:00 AM	4.53	5.19	4.49	4.92	5.10	4.85
11:00 AM	12:00 N	5.15	5.95	4.88	5.96	5.40	5.47
12:00 N	1:00 PM	5.62	6.11	5.15	6.36	6.27	5.90
1:00 PM	2:00 PM	5.76	6.28	5.35	6.08	6.12	5.92
2:00 PM	3:00 PM	6.45	7.44	7.15	7.07	7.01	7.02
3:00 PM	4:00 PM	7.45	7.84	8.00	9.41	8.32	8.20
4:00 PM	5:00 PM	8.02	8.72	8.78	7.98	8.58	8.42
5:00 PM	6:00 PM	7.79	8.34	9.85	7.71	8.48	8.44
6:00 PM	7:00 PM	4.96	6.40	7.76	5.17	5.66	5.99
7:00 PM	8:00 PM	4.02	4.40	5.25	3.89	3.99	4.31
8:00 PM	9:00 PM	3.85	3.61	3.25	3.02	3.07	3.36
9:00 PM	10:00 PM	3.08	2.27	1.97	1.99	1.95	2.25
10:00 PM	11:00 PM	3.38	1.48	0.81	1.26	1.43	1.67
11:00 PM	12:00 M	1.94	0.88	0.35	0.99	0.83	1.00

AVERAGE FOR MULTI-LANE FACILITIES

Hour		Population Tier Location (See Note 2 Below)					Overall Regional Average
From	To	A	B	C	D	E	
12:00 AM	1:00 AM	0.94	0.65	0.32	0.62	0.58	0.62
1:00 AM	2:00 AM	0.60	0.36	0.17	0.44	0.45	0.41
2:00 AM	3:00 AM	0.58	0.28	0.11	0.46	0.38	0.36
3:00 AM	4:00 AM	0.59	0.36	0.13	0.44	0.66	0.44
4:00 AM	5:00 AM	0.91	0.65	0.26	0.92	1.14	0.77
5:00 AM	6:00 AM	2.17	1.54	0.86	1.91	2.70	1.84
6:00 AM	7:00 AM	4.42	4.01	3.53	3.52	4.98	4.09
7:00 AM	8:00 AM	6.01	7.20	8.64	6.50	7.39	7.15
8:00 AM	9:00 AM	5.89	6.33	7.23	5.58	5.85	6.18
9:00 AM	10:00 AM	5.22	5.04	5.61	5.30	5.30	5.29
10:00 AM	11:00 AM	5.15	4.92	5.15	5.64	5.43	5.26
11:00 AM	12:00 PM	5.87	5.44	5.77	6.58	6.02	5.94
12:00 PM	1:00 PM	6.76	6.76	6.31	6.95	6.25	6.61
1:00 PM	2:00 PM	6.63	6.48	6.23	6.76	6.29	6.48
2:00 PM	3:00 PM	6.91	6.92	7.03	7.24	6.61	6.94
3:00 PM	4:00 PM	7.42	7.59	7.21	8.44	7.68	7.67
4:00 PM	5:00 PM	7.43	8.54	8.11	8.12	8.27	8.09
5:00 PM	6:00 PM	7.24	8.47	8.98	7.61	7.81	8.03
6:00 PM	7:00 PM	5.41	5.79	6.50	5.15	5.22	5.61
7:00 PM	8:00 PM	4.04	4.15	4.35	3.93	3.67	4.03
8:00 PM	9:00 PM	3.38	3.36	3.36	3.05	2.77	3.18
9:00 PM	10:00 PM	2.84	2.44	2.27	2.19	2.18	2.38
10:00 PM	11:00 PM	2.14	1.60	1.21	1.61	1.47	1.60
11:00 PM	12:00 AM	1.44	1.11	0.64	1.06	0.89	1.03

Notes:
1. The seven (7) highest hours are shown in green highlight and the eighth (8th) highest hour is shown in orange highlight.
2. The population tier locations are as follows:
   - Population Tier A → Memphis
   - Population Tier B → Bartlett, Collierville, and Jackson
   - Population Tier C → Germantown
   - Population Tier D → Dyersburg
   - Population Tier E → All other cities not shown above and rural areas
3. Values shown are calculated and rounded up which may result in small rounding errors.

3/15/2017

Figure 4.2 – Condition Diagram Example

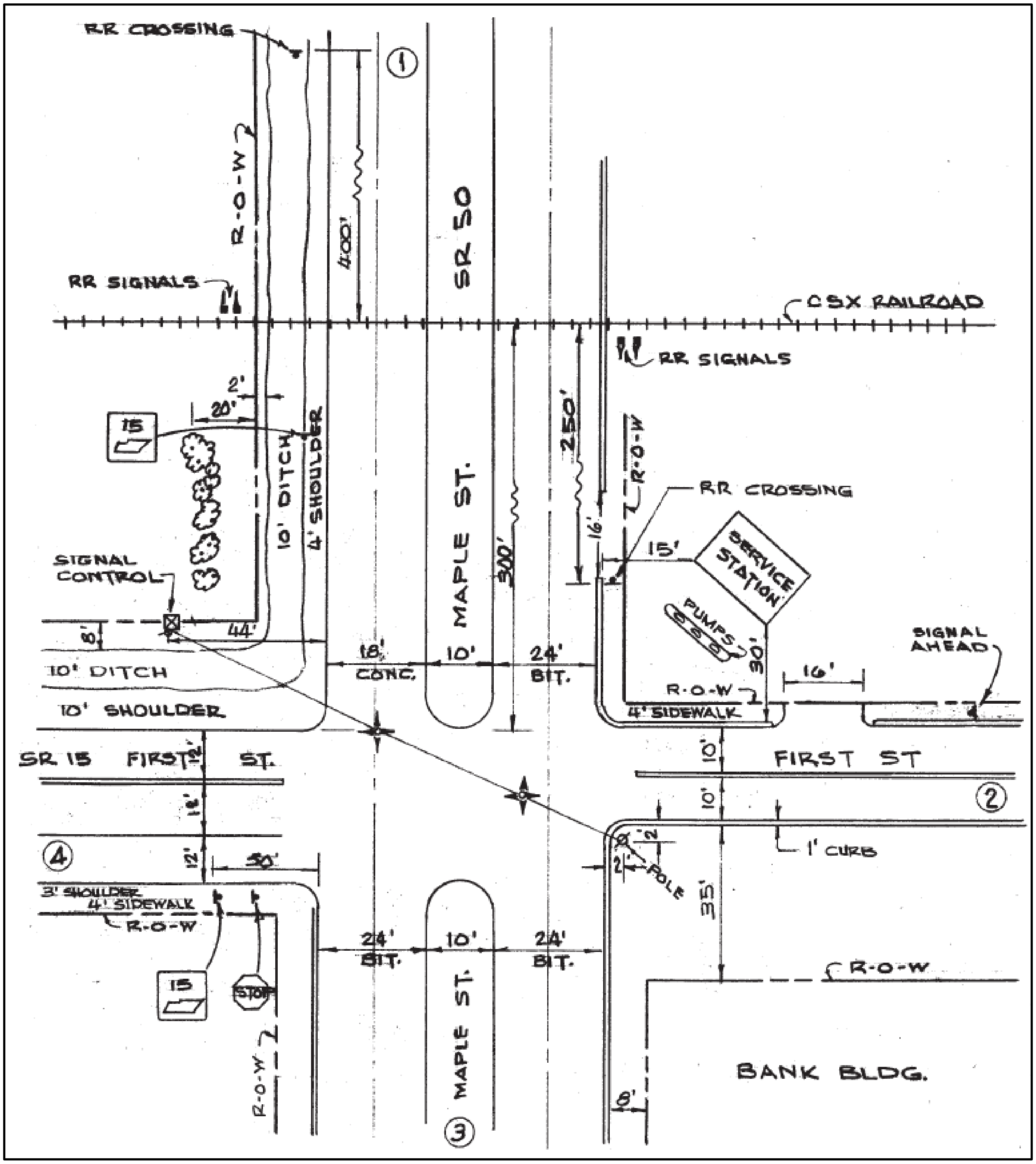
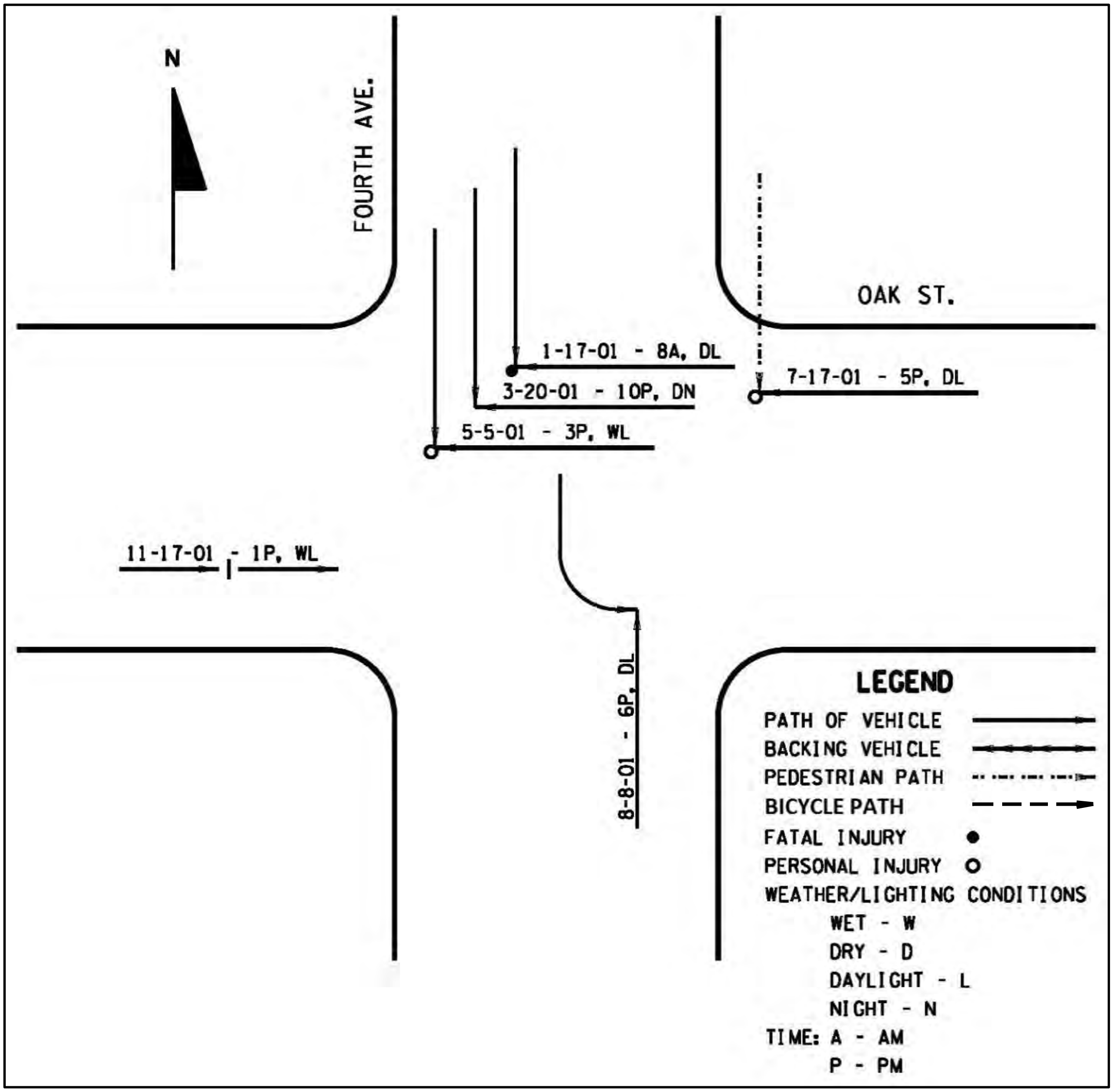


Figure 4.3 – Collision Diagram Example



4.1.2 Traffic Signal Warrants

Traffic signal warrants define minimum threshold levels of vehicular volume, pedestrian volume, progression conditions, crashes, delay, and proximity to railroad crossings that need to be met for an intersection to become a candidate for a traffic control signal. Once met, signal warrants become part of an engineering study that will determine if the installation of a traffic control signal will improve the overall safety and/or operation of the intersection. The *MUTCD* identifies nine traffic signal warrants as follows:

- Warrant 1 – Eight Hour Vehicular Volume
- Warrant 2 – Four Hour Vehicular Volume
- Warrant 3 – Peak Hour
- Warrant 4 – Pedestrian Volume
- Warrant 5 – School Crossing
- Warrant 6 – Coordinated Signal System
- Warrant 7 – Crash Experience*
- Warrant 8 – Roadway Network
- Warrant 9 – Intersection Near a Grade Crossing

  *In addition to the MUTCD Traffic Signal Warrant 7 – Crash Experience, FHWA has provided an interim approval for optional use of an Alternative Signal Warrant 7 – Crash Experience (IA-19). TDOT applied and received IA-19 (Optional Use of Alternative Signal Warrant 7 – Crash Experience) from FHWA for all state and local jurisdictions in Tennessee. Any jurisdiction in Tennessee that chooses the option of IA-19 must coordinate the traffic signal warrant with the TDOT State Traffic Engineer.

Even though these nine warrants can justify a traffic signal installation, TDOT considers Warrant 1 and Warrant 7 as the primary warrants that should be utilized for traffic signal installation approval. If geometric improvements are proposed as part of the project, Warrant 7 may not be applicable if the proposed improvements are expected to reduce crashes. The following are additional considerations for use in an engineering study:

- **Effect of Right-Turning Vehicles:** Engineering judgment should be used to determine what, if any, portion of the right-turn traffic is subtracted from the minor-street traffic count when evaluating the count against the signal warrant threshold tables.
  - **Shared Right-Turn Lane:** Right-turn traffic should be considered when a shared lane contains both through and right-turning traffic.
  - **Exclusive or Channelized Right-Turn Lane:** Right-turn traffic should not be considered when an exclusive or channelized right-turn lane is present.

- **Lane Configuration:** Engineering judgment should also be used when determining if an approach should be considered a one-lane or a two-lane approach for signal warrant analysis.
  - **Left-turn Lane:** For an approach with one lane for through and right-turning traffic plus an exclusive left-turn lane, if engineering judgment indicates that it should be considered a one-lane approach because the traffic using the left-turn lane is minor, the total traffic volume approaching the intersection should be applied against the signal warrants as a one-lane approach. The approach should be considered two lanes if approximately half of the traffic on the approach turns left and the left-turn lane is of sufficient length to accommodate all left-turn vehicles.
  - **Right-Turn Lane:** If an exclusive right-turn lane is present on an approach, it may be considered an approach lane if it has a significant volume of traffic, has sufficient storage capacity to store right turning traffic, and is not channelized away from the intersection. However, if right-turn volumes have been eliminated from the approach volumes for warrant analysis, then any exclusive right-turn lane present should not be included in the number of approach lanes.
- **Estimating Future Conditions:** At a location where a signal study is requested, but the future development is not yet in place, the hourly generated traffic volumes must be estimated based on the phase of development to be completed at the time of signal installation using the following procedures:
  - **Similar Developments:** Where similar developments, in both type and size, exist in the same or similar size community, actual hourly generated traffic volumes can be measured and applied to the new site. Signal warrants can then be applied using these volumes.
  - **Estimating Procedure:** Where similar developments do not exist, peak hour trip generated volumes can be estimated using the current ITE *Trip Generation Manual* or based on an existing similar development. In all cases, all assumptions and trip estimates shall be pre-approved by a TDOT Region Traffic Engineer and/or the State Traffic Engineer prior to developing traffic volumes.
- **Access to Adjacent Signals:** Consideration is to be given as to whether the side street or driveway traffic being studied has access to an existing traffic signal. If access to an adjacent signal exists, a new signal may not be needed.

- **Capacity and Progression Analysis:** A capacity analysis should be considered to determine the impacts of installing traffic signal control at an intersection. If the traffic signal control is to be installed on an existing coordinated system or if progression on the corridor should be considered, a progression analysis should also be completed.

In all cases, engineering judgment must be exercised in the justification of a traffic signal installation.

4.2 Authorization for Installation and Ownership of Traffic Signal Control

Even though they may be installed under TDOT construction projects, TDOT does not own, operate, or maintain traffic signal devices after the conclusion of a project unless there are special circumstances. Therefore, ownership of the traffic signal installation, along with responsibility for operation and maintenance, reverts to the local governing agency.

- **TDOT Projects (State or Local Routes):** It shall be the responsibility of the Traffic Signal Design Manager, a Regional Traffic Engineer, and/or the State Traffic Engineer to review, comment, and/or approve the installation or upgrade of any traffic signals installed as part of a TDOT managed project. All TDOT studies proposing traffic signals are to be reviewed by Headquarters and Regional Traffic Engineers prior to final study approval. Proposed signal operation should safely, economically, and efficiently accommodate current and future traffic and safety needs. Although some local governmental agencies may request certain aesthetic features, enhancement of signal systems with materials or equipment that goes beyond meeting basic operational needs may require the local agency to cover the additional costs with local funds. The local agency will be required to execute a *Local Agency Program Agreement* accepting ownership and responsibility for the operation and future maintenance of the traffic signals.
- **Non-TDOT Projects (on State Routes):** Per TCA 54-5-603, an incorporated municipality wishing to install traffic signals is not required to obtain approval from TDOT, but they must comply with the requirements of the *MUTCD*. An incorporated municipality may seek concurrence from TDOT regarding a signal in which case the parties will execute a MOU. All other locally initiated signal design projects shall follow procedures and conform to guidelines given in this manual. The local agency must submit an installation request to the Regional Traffic Engineer along with an engineering study signed by a registered professional engineer. The local agency will be required to execute a MOA accepting ownership and responsibility for the operation and future maintenance of the traffic signals. It is TDOT's goal to provide a safe, reliable, and economically sound traffic control installation that is best suited to the maintenance capabilities of the local agency. In this regard and in limited cases, TDOT has prepared *Special Provisions* for inclusion in contract documents that address the specific requirements of several local government agencies. TDOT also provides special notes and details on certain projects to conform to other agency practices.

4.2.1 Additional Requirements

- **Environmental Requirements:** Basic signal installation projects usually require little in the way of environmental permits due to the minimal impact of locating poles, pull boxes, and conduit. However, larger projects involving installation of turn lanes or widening of the road may require various permits. Permit needs are assessed and applications are processed and acquired by TDOT's Environmental Planning Division. The Environmental Planning Division may require some special maps, forms, and plan sheets as prepared by the design engineer. Hydrological permits may include:

  - **Tennessee Department of Environment and Conservation (TDEC):**
    - Notice of Intent (NOI)
    - Aquatic Resource Alteration Permit (ARAP)
    - Class V Injection Well Permit
  - **Corps of Engineers (COE):** Section 404 of the Clean Water Act requires permit applications for any stream, spring, wetland, or sinkhole impact or total project impact of ½ acre or more.
  - **Tennessee Valley Authority (TVA):** Section 26a is required when any project impacts any water resource in the Tennessee River Valley or on TVA lands. If the impact is low, TVA may issue a letter of no objection.
  - **Tennessee Wildlife Resources Agency (TWRA):** Any impact on the Reelfoot Lake Basin requires a TWRA permit.

  Projects that contain federal funds shall require an environmental study. The design engineer shall consult with the Environmental Division for the latest requirements and guidelines for any environmental permits.

- **Right-of-Way:** Right-of-way impacts are categorized as acquisitions or easements. If no right-of-way impacts are involved in the project, then the project is categorized as Utilities Only. The goal of most traffic signal projects are to minimize the right-of-way impacts, as most impacts are usually limited to pole and controller foundations, pull boxes, and conduits. All right-of-way activities are handled within the Right-of-Way Division.

- **Erosion Control:** Most simple traffic signal projects require minimal erosion control, as the impact is usually limited to pole foundations and trenching for conduit. A short list of items (hay bales, etc.) and standard drawings is all that is usually required. No separate plan is required. On larger projects with grading and drainage, an erosion control plan will be required. Any project involving grading and drainage should also include a drainage map.

CHAPTER 5

TRAFFIC SIGNAL DESIGN – GENERAL INFORMATION

5.1 General Information

Highway traffic signal is a generic term that applies to intersection stop-and-go signals, flashing beacons, lane use control signals, ramp entrance signals, and other types of devices. A traffic control signal (traffic signal) shall be defined as any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed. Traffic is defined as vehicles, pedestrians, bicyclists, streetcars, and other conveyances using any highway or private road open to the public for purposes of travel. This chapter presents the design of traffic control signals. In this manual, the term traffic signal applies to a traffic control signal unless otherwise noted. Standards for traffic control signals are important because they need to attract the attention of a variety of road users, including those who are older, those with impaired vision, as well as those who are fatigued or distracted, or who are not expecting to encounter a signal at a particular location. The designer responsible for any type of traffic signal design project, including traffic control signals, should be aware that the design must comply with various standards. In addition to TDOT Standard Specifications, the following standards shall be consulted:

- ***MUTCD:*** The *MUTCD* defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public travel. The *MUTCD* is published by FHWA under 23 CFR, Part 655, Subpart F. As a minimum, the requirements of the *MUTCD* must be met on all roads in Tennessee.
- ***Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals:*** These specifications are published by AASHTO to provide structural design criteria.
- ***NEC:*** The *NEC* contains provisions that are considered necessary for the practical safeguarding of persons and property from hazards arising from the use of electricity. The *NEC* is published by the NFPA.
- **NEMA Standards:** This publication describes the physical and functional requirements of TS-1 and TS-2 signal controllers.
- **ATC Standards:** This publication by AASHTO, ITE, and NEMA is intended to provide an open architecture hardware and software platform that can support a wide variety of ITS applications, including traffic management, safety, security, and other applications.
- **TDOT Design Standards (www.tn.gov/tdot):** These standards are composed of a number of standard drawings that address specific situations that occur on a large majority of construction projects.

This chapter is structured to document the recommended concepts of traffic signal design as they apply to traffic signal timing and to traffic signal infrastructure in the State of Tennessee. The first few sections will introduce basic concepts related to traffic signal design elements, followed by a discussion of traffic signal modes of operation. Next, guidelines to the selection of traffic signal phasing will be presented leading into traffic signal detection design. The following sections will explore traffic signal timing parameters for different modes of operation and preemption guidelines, concluding with several traffic signal infrastructure requirements.

5.2 Site Reviews

A very necessary, but sometimes overlooked, part of a complete traffic signal design is the need for site reviews. The number of site reviews will be dependent on the complexity of the project. It is prudent that the designer have at least one site review during the right-of-way design phase, preferably before the right-of way field review plans are submitted for review. The following benefits may be obtained through site reviews:

- Site reviews can provide information that is not always visible from the survey, such as drainage structures, clusters of trees, ditches and steep slopes. The designer should be aware of the location of these obstacles to avoid pole placement in their vicinity. Removal of vegetation and trees should be considered only as a last resort;
- Site reviews clearly show the roadway configuration and can provide the designer with a better idea of the magnitude and proximity of overhead obstructions, hazards or structures to the roadway;
- Site reviews will enable the designer to select potential service point locations by identifying power sources within the project area;
- Site reviews will enable the designer to verify that the locations of proposed poles are not in conflict with existing or proposed utilities including at-grade and aerial roadway structures.

Sign-in sheets are required during site reviews to document those in attendance. Typical site review attendees include the maintaining agency, local officials, utility companies (especially the power company), railroad (if applicable), TDOT project manager, TDOT HQ project manager (if different), TDOT Region traffic engineer, and consultant engineers/designers. After the site review has concluded, a summary of the meeting minutes shall be prepared by the designer to document the discussions in the field and to identify action items required along with who is responsible for those action items. Site review guidance information is contained in Appendix B.

5.3 Proprietary Equipment for Traffic Signal Systems

Proprietary, as part of a traffic signal installation project, means that a particular piece of equipment (i.e. brand, manufacture, model number, etc.) can be specified in the construction plans (i.e. sole source). Typically, the proprietary item is the predominate piece of equipment installed or being installed by the local maintaining agency. For TDOT consideration and approval of proprietary items, the local maintaining agency (i.e. city, county, etc.) shall make a formal written request to TDOT and justify the need for the proprietary item based on the reasons given in the CFR 23, Part 635.411. The requested item shall also be included in a traffic signal specifications document that is posted on the local maintaining agency's website. Typically, traffic signal proprietary items that are requested include traffic signal controllers, traffic signal monitors, Ethernet switches, radar/video detection, decorative traffic signal poles, and emergency preemption equipment. The specification of proprietary items will not be allowed except in special pre-approved cases by the Director of the Traffic Operations Division. The following are considered during TDOT's review for certification of proprietary items:

5.3.1 Necessary for Synchronization with Existing Facilities

The local maintaining agency shall provide written documentation that the required proprietary item is needed for synchronization with existing facilities. Synchronization means that a product matches specific current or desired characteristics of a project and shall be based on the following or a combination of the following factors:

- **Function:** The proprietary product is necessary for the satisfactory operation of the existing facility;
- **Aesthetics:** The proprietary product is necessary to match the visual appearance of existing facilities; and
- **Logistics:** The proprietary product is interchangeable with products in an agency's maintenance inventory.

Other factors as they relate to synchronization include:

- **Lifecycle:** The relative age of existing systems that will be expanded and the remaining projected life of the proposed proprietary element in relation to the remaining life of the existing elements; and
- **Size/Extent of Products and Systems to be Synchronized To/With:** The relative cost of the proprietary elements compared with replacing the elements requiring synchronization

5.3.2 Unique Product for which there is No Equally Suitable Alternative

The local maintaining agency shall provide written documentation that the required proprietary item does not have an equivalent. The documentation may also include the submission of specific material(s) or product(s) to evaluate in TDOT's review of the proprietary item.

5.3.3 Experimental Products

The local maintaining agency shall provide written documentation that the required proprietary item is for research or for a distinctive type of construction at an intersection for experimental purposes. The documentation shall include an experimental product work plan for review and approval. The work plan should provide for the evaluation of the proprietary product, and where appropriate, a comparison with current technology. Products which have been approved under special funding/evaluation programs do not require additional certification for the use of patented or proprietary products.

CHAPTER 6

TRAFFIC SIGNAL DESIGN – CABINETS AND EQUIPMENT

6.1 Traffic Signal Cabinet

The traffic signal cabinet houses the control equipment at an individual intersection. The traffic signal cabinet equipment shall be in accordance with current TDOT standards and specifications, the *NEC* and the *NESC*. The following information should be considered in regards to traffic signal cabinets:

- **Location:** Traffic signal cabinets should be located as far as practical off the edge of the roadway and in the same intersection quadrant as the power source whenever possible. Traffic signal cabinets shall not be placed within the pedestrian walkway portion of a sidewalk if it obstructs ADA pathway and protection requirements. Traffic signal cabinets should have easy access for parking of maintenance vehicles and should be oriented for maintenance personnel to simultaneously see the inside of the cabinet and traffic signal displays for several phases, thus making troubleshooting and field observations more effective. In other words, the traffic signal cabinet door should not be facing the roadway. Consideration should also be given to the effect of cabinet placement on sight distance.
- **Cabinet Mounting:** The are two types of mounting for traffic signal cabinets:
  - Pole-Mounted Cabinets
  - Ground-Mounted Cabinets
- **Service Pads:** All ground-mounted controller cabinet installations not immediately adjacent to a sidewalk shall be provided with a service pad in front of the cabinet door for use by maintenance personnel.
- **Cabinet Construction:** Cabinets shall be constructed of aluminum. Standard cabinet sizes are shown in TDOT *Standard Drawing T-SG-5*.
- **Bonding and Grounding Requirements:** All bonding and grounding shall be in accordance with the NEC. Bonding is defined in the NEC as the permanent joining of metallic parts required to be electrically connected. Grounding is defined in the NEC as a conducting connection between an electrical circuit or equipment and the earth, or to some conductive body that serves in place of earth. The NEC requires all traffic signal cabinets to be grounded to equipment ground.
- **Interconnect/Communications:** Where installed in a system, the traffic signal cabinet shall have facilities for the appropriate communications.

6.2 Traffic Signal Controllers

The controller is the piece of equipment in the signal cabinet that translates input information from the detectors into output information for the displays. Signal timing parameters (programmed into the controller software) determine how the controller interprets the detector and display information. The standard controller to be used at all new signalized intersections is an 8-phase, NEMA traffic signal controller that meets current TDOT standards and specifications. An 8-phase controller should be used even when 4-phase cabinets are installed.

6.3 Traffic Signal Detector Cards

Detector cards (i.e. detector amplifiers) when used with inductive loops, identify user actuations from the field detectors and pass the information along to the signal controller. Most detector cards can handle between one and four detector channels and various modes of operation. Adequate detector rack space should be provided to allow for near-term and possible long-term needs.

6.4 Traffic Signal Load Switches and Flasher

Load switches are relay devices that allow the controller, which operates in a 12/24-volt DC environment, to direct a 120-volt AC current to various signal displays. Each load switch (and associated wiring) plugs into the back panel of the cabinet into load switch bays. The number of load switch bays will dictate the number of output channels that the signal designer has to work with at the intersection. Ensuring that there are enough load switch bays for existing and future phasing is recommended. A load switch is typically required for each vehicle signal phase, each pedestrian phase, and each overlap. Similar to a load switch, a flasher controls the signal displays when the intersection is in flashing mode.

6.5 Traffic Signal Monitor

The NEMA MMU and the older CMU are traffic signal monitors that work completely independent from the traffic signal controller and serve to ensure intersection safety. Invalid signal voltage levels, burnt lamps, conflicting green movements, improper sequencing, incorrect timing, and several other features are monitored by the equipment. Traffic signal monitors will identify the type of fault (e.g., conflict, red fail, clearance fail, dual indication), which signal faces were active at the time of the fault, and can retrieve historical data about the fault. The monitors will remain in fault mode until reset.

6.6 Traffic Signal Power Supply

Power supply to traffic signal cabinets shall adhere to local utility company requirements. The source power service location through coordination with the local utility company may support the location of new traffic signal cabinets, but that information is not to be detailed on the traffic signal plans or associated bid documents.

The traffic signal power supply is an electrical device in the cabinet that converts AC to correct DC voltage for various devices in the traffic signal cabinet. If the power supply cable travels underground, it shall be run in a separate RGS conduit from detector, signal, and communications cables. If it travels overhead, it shall be run on a separate messenger cable above all other signal cables. Where street lights are installed on traffic signal poles, they shall have their own circuit breaker on the service pole and the power conductor routing shall not pass through the controller cabinet.

When utility power is disrupted and not available at times, a back-up power supply unit (i.e. BBS or UPS) can be utilized to provide emergency power to connected equipment by supplying power from a separate source (i.e. batteries). The *MUTCD Section 4D.27* recommends that traffic control signals that are adjacent to highway-rail grade crossings and that are coordinated with the flashing-light signals or that include railroad preemption features be provided with a back-up power supply unit. The use of a back-up power supply unit is also recommended on high-volume intersections where maintenance of traffic signal operations during power outages is critical to traffic flow.

[This page intentionally left blank.]

CHAPTER 7

TRAFFIC SIGNAL DESIGN – OPERATIONS AND COORDINATION

7.1 Traffic Signal Operation Basic Concepts

The following are basic concepts in traffic signal operation:

7.1.1 Traffic Signal Movements

Traffic signal movements refer to the actions of users at a signalized intersection. Typical movements include vehicles turning left, turning right or traveling through the intersection, and pedestrian crossings. In a four-legged intersection it is possible to have twelve vehicle movements and four two-way pedestrian movements. The *HCM* assigns numbers to each of these movements, as shown on Figure 7.1, with the major street on the East–West orientation. Figure 7.2 shows a typical movement numbering with the major street on the North–South orientation.

7.1.2 Traffic Signal Phases

A phase is a timing process, within the signal controller, that facilitates serving one or more movements at the same time (for one or more modes of users). Phase numbers must be assigned to the movements at a signalized intersection in order to begin selecting signal timing values. Even phases are typically associated with vehicular through movements and odd phases are typically associated with vehicular left-turn movements. Pedestrian phases are typically set up to run concurrently with the even-numbered vehicular phases and are generally assigned the same phase number as the adjacent parallel vehicular phases. A four-legged intersection with protected left-turn movements will generally follow the phase numbering as shown in Figures 7.1 and 7.2. This standard NEMA phase numbering system combines the right-turn movements with the through movements into single phases. Figure 7.3 illustrates the typical movement and phase numbering (4-phase or 8-phase) used at an intersection with permitted left-turn movements where all of the movements on an approach are assigned to one phase. It is common practice to maintain a consistent phase-numbering scheme within a specific jurisdiction.

Figure 7.1 – Movement and Phase Numbering (East-West as Major Street)
Source: Adapted from Traffic Signal Timing Manual

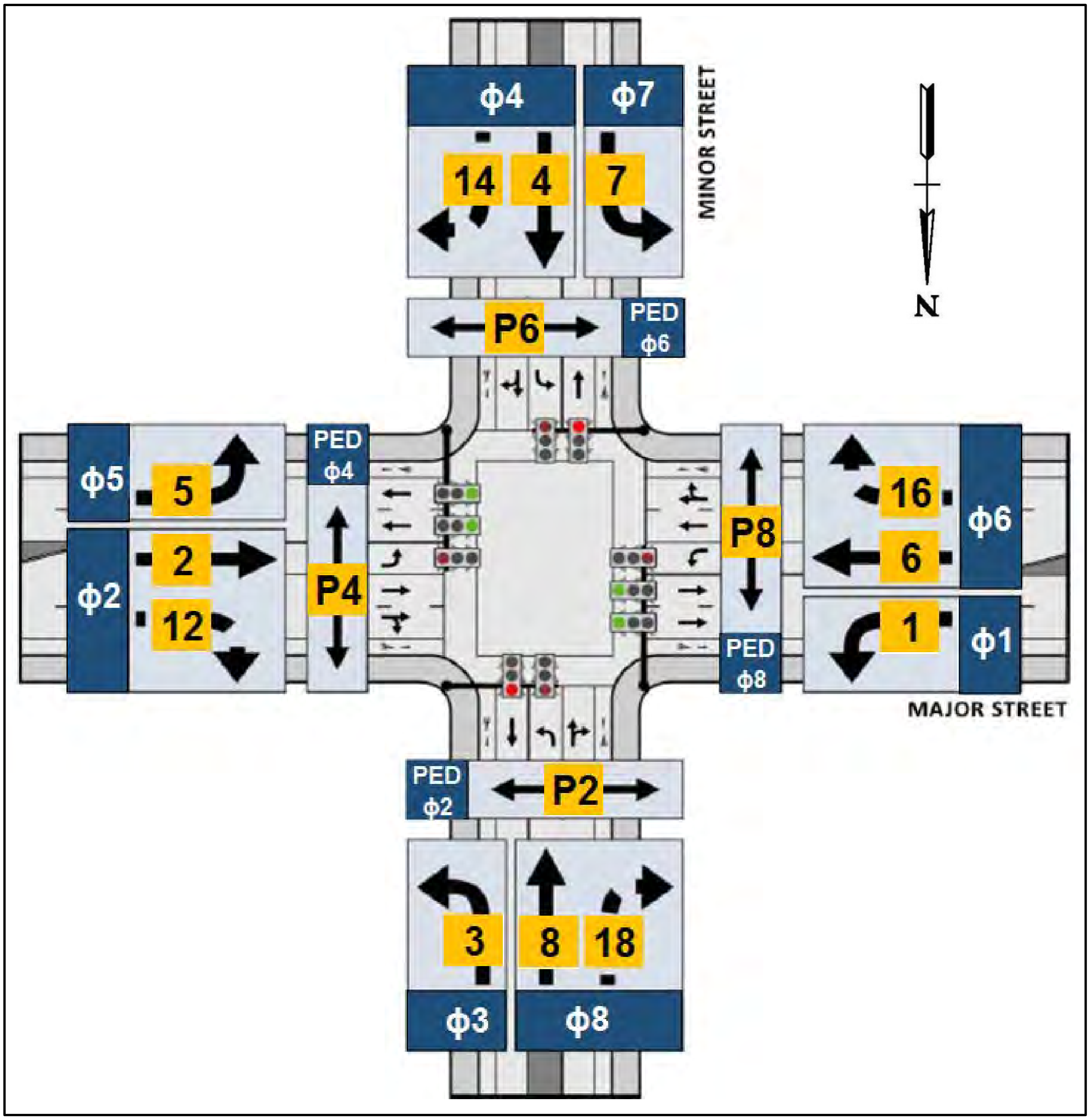


Figure 7.2 – Movement and Phase Numbering (North-South as Major Street)
Source: Adapted from Traffic Signal Timing Manual

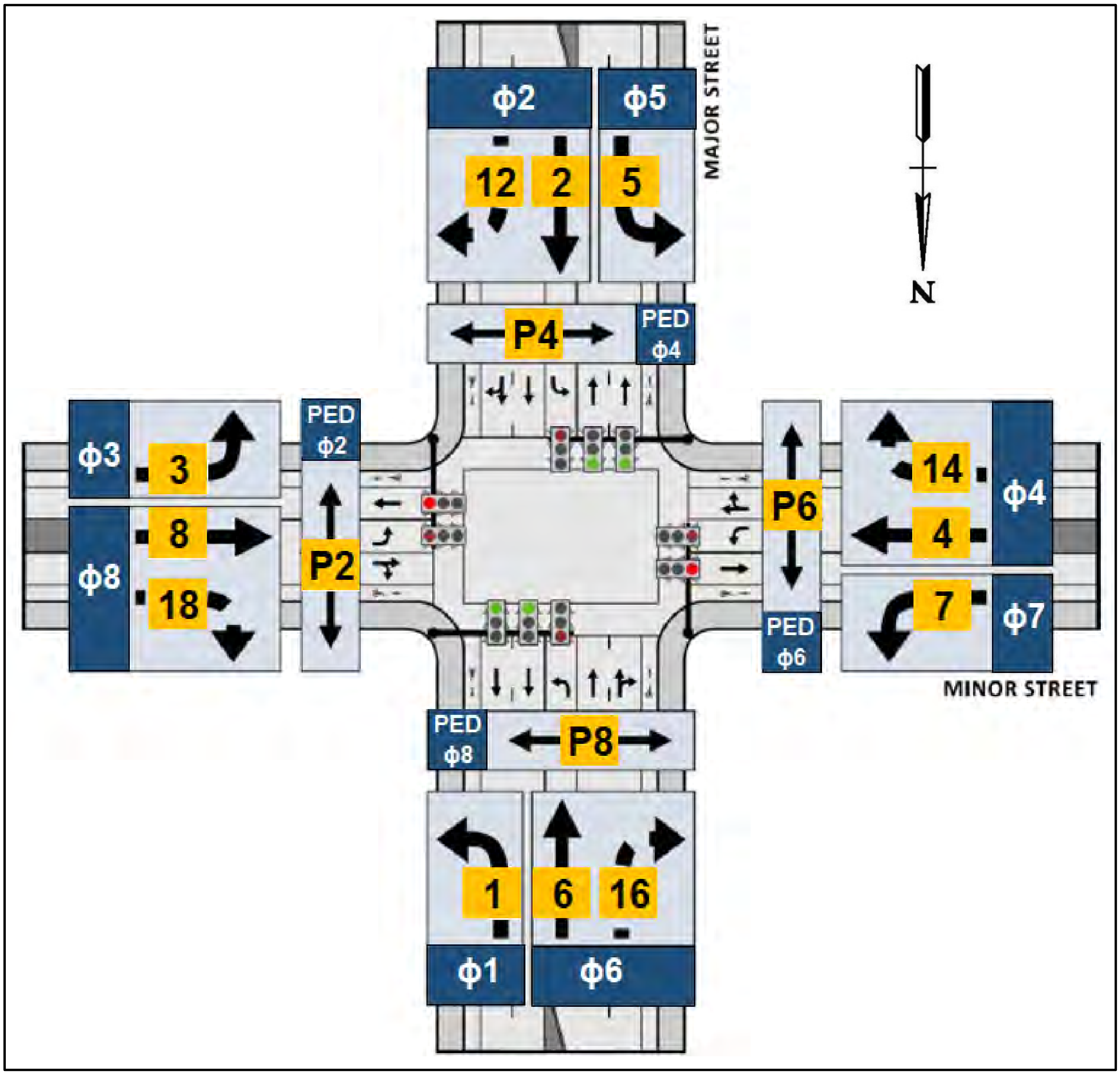
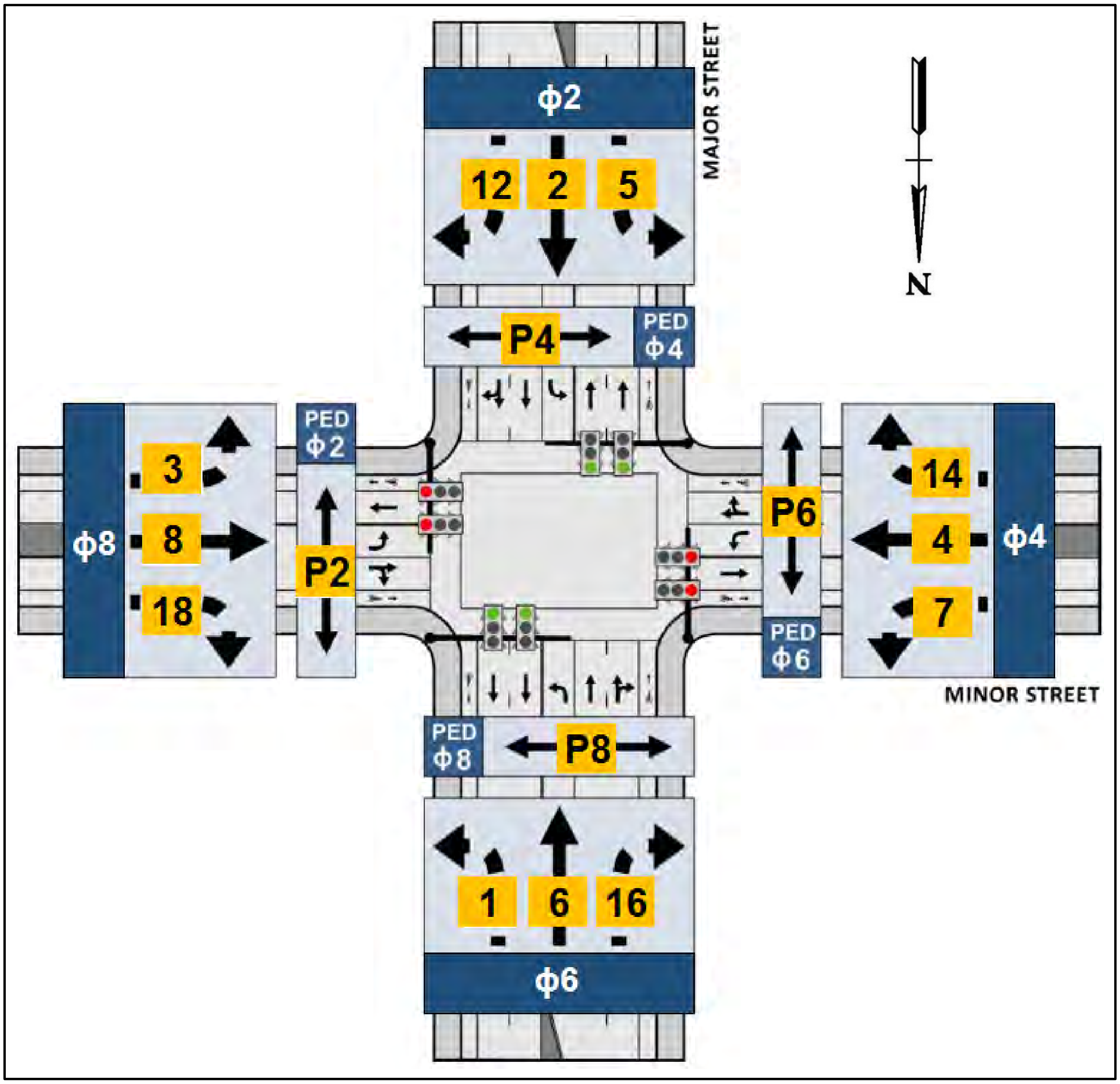


Figure 7.3 – Movement and Phase Numbering (Permissive Left-Turns)
Source: Adapted from Traffic Signal Timing Manual



7.1.3 Ring-and-Barrier Diagrams

Traffic signal phases and their sequence are represented graphically by a ring-and-barrier diagram composed of:

- **Rings:** Each ring identifies phases that may operate one after another, but never simultaneously. At any moment there may be only one phase active per ring. Dual ring operations allow concurrent (non-conflicting) phases in separate rings to operate at the same time.
- **Barriers:** In dual ring operation, a barrier is the point at which the phases in both rings must end simultaneously. Barriers typically separate major and minor street phases.

Figure 7.4 provides an example of a standard NEMA eight-phase, dual ring-and-barrier diagram, with protected leading left-turns (See Section 7.3) on all approaches. A table of active and concurrent phases and a standard NEMA eight-phase actuated controller phase sequence are also shown.

7.2 Traffic Signal Modes of Operation

An intersection may be controlled independently (isolated operation) or have the ability to synchronize to multiple intersections in a coordinated operation. Isolated and coordinated intersections can operate either in pre-timed (fixed) or actuated mode, where detectors will monitor traffic demand. Furthermore, actuated operation can be characterized as fully-actuated or semi-actuated, depending on the number of traffic movements that are being detected (See Section 7.2.2). Advanced types of operation include volume density, traffic responsive, and adaptive control. Finally, signalized intersections may also operate under special conditions like preemption or priority, or they may be set up to operate in the flashing mode. The selected mode of operation on a signalized intersection will determine its safety and efficiency. The following paragraphs will briefly describe each mode of operation and additional detailed information will be further explored in subsequent sections.

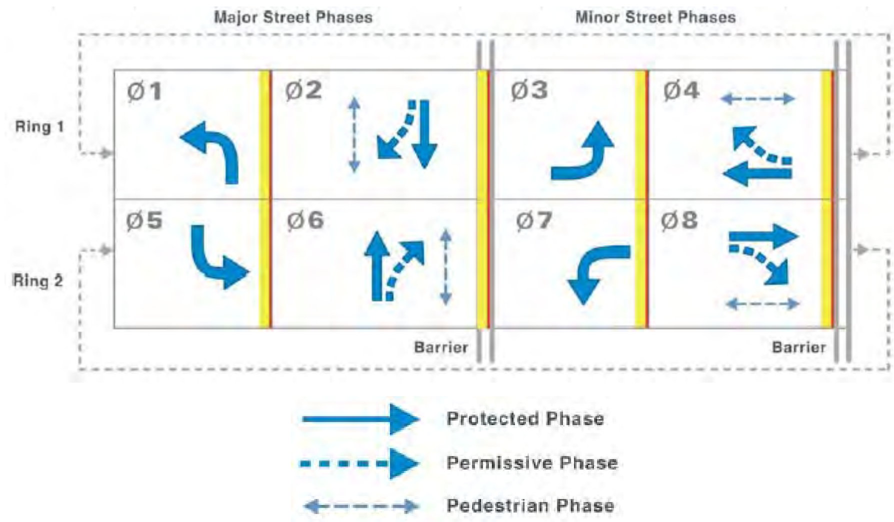
7.2.1 Pre-timed (Fixed Time) Operation

During pre-timed operation, the total green time allocated to a phase will always have a preset time, regardless of demand. For each specific TOD plan the phase sequence is also fixed and phases cannot be skipped. Therefore, a complete sequence of signal indications (i.e. cycle) will be displayed every time (i.e. fixed cycle length). Figure 7.5 illustrates pre-timed operation.

- *Advantages:* Ideally suited to coordination of closely spaced intersections with consistent daily traffic volumes and patterns, since both the start and end of green phases are predictable. Such conditions are often found in CBD or downtown grid areas. Also, pre-timed operation does not require detection, thus reducing maintenance needs.
- *Disadvantages:* Inability to adjust to fluctuations in traffic demand potentially generating excessive delays to users of the intersection.

Figure 7.4 – Standard NEMA Dual Ring-and-Barrier Diagram

Source: Traffic Signal Timing Manual



	Active Phase							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Concurrent Phases	5 & 6	5 & 6	7 & 8	7 & 8	1 & 2	1 & 2	3 & 4	3 & 4

NEMA 8-PHASE ACTUATED CONTROLLER PHASE SEQUENCING

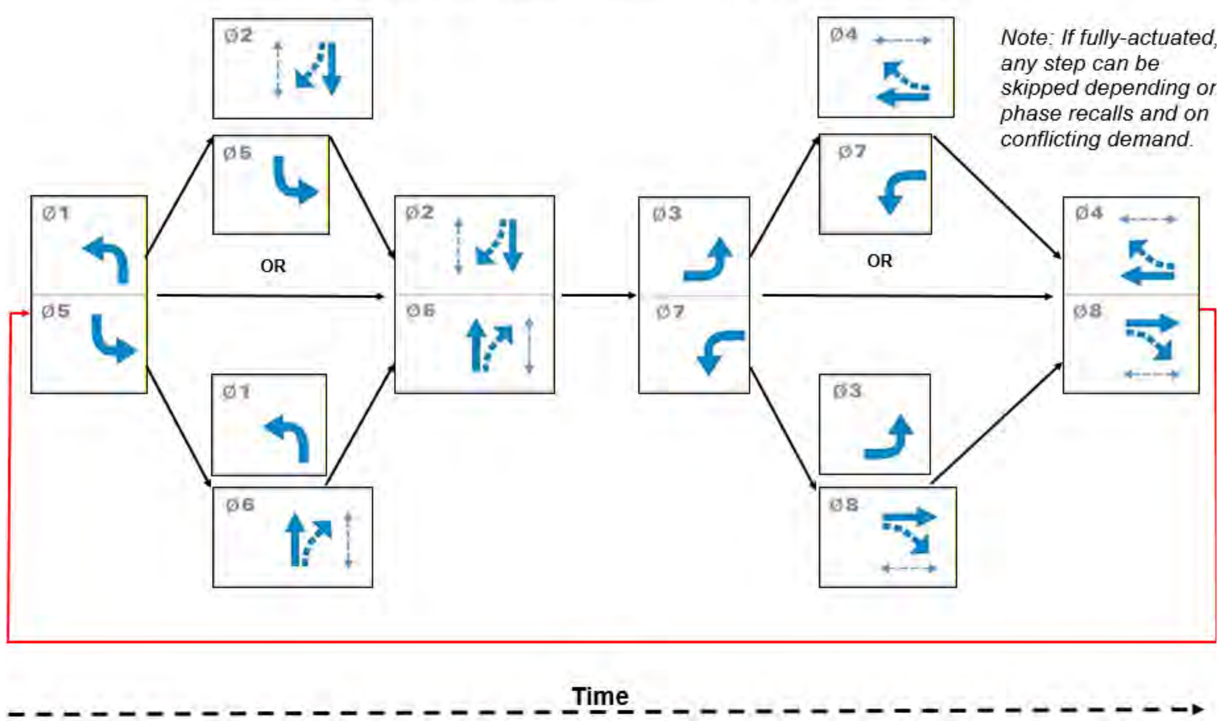
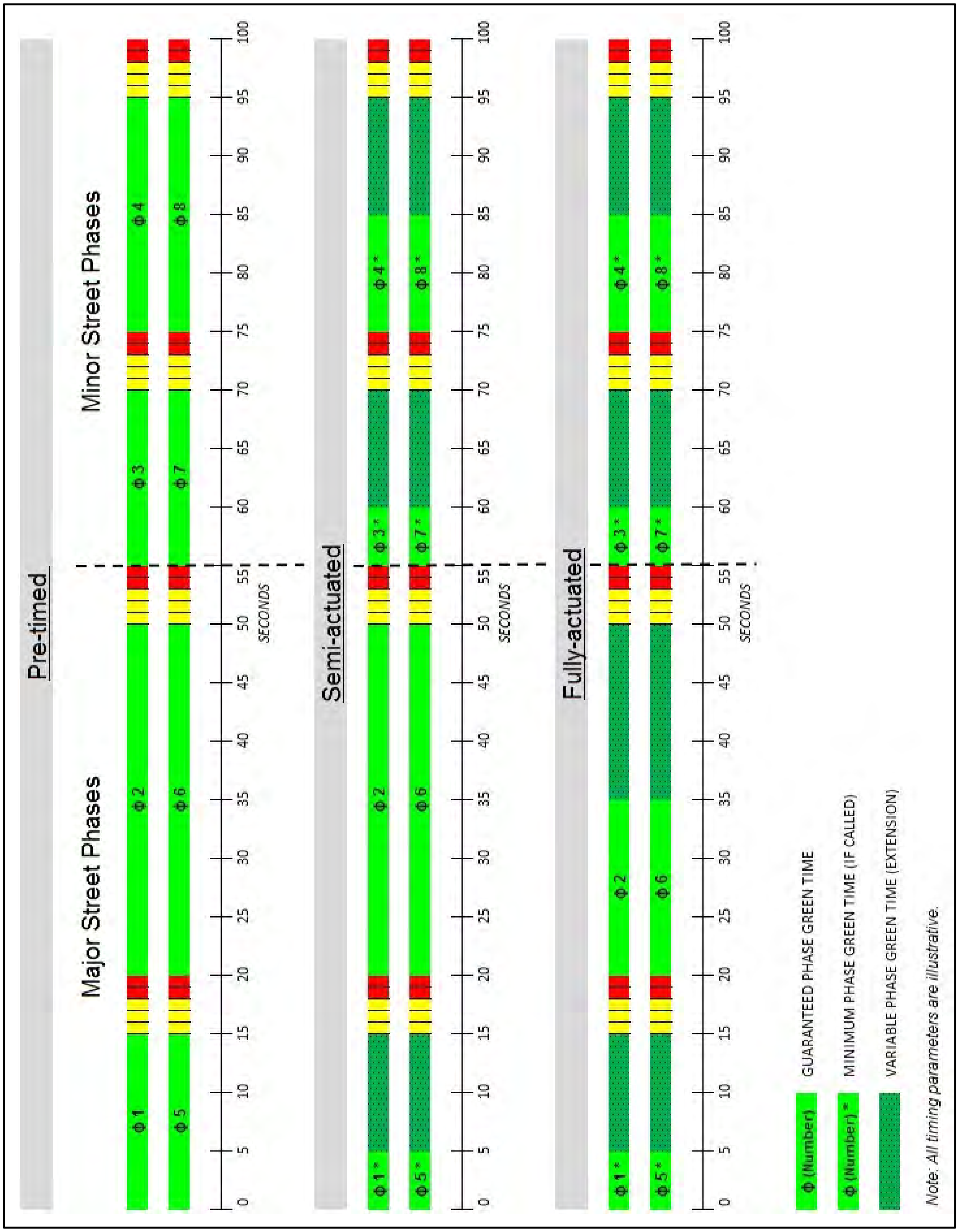


Figure 7.5 – Pre-timed and Actuated Operation
Source: Traffic Signal Timing Manual



7.2.2 Actuated Operation

During actuated operation, detection actuations will determine phases to be called as well as phase extension. The duration of each phase is determined by detector input and corresponding controller parameters. For each specific TOD plan, the phase sequence is fixed but phases can be skipped due to traffic demand being monitored by detection. Therefore, when not coordinated, actuated operation may not always display a complete sequence of signal indications (i.e. cycle) leading to a variable cycle length.

- *Advantages:* Ability to adjust to fluctuations in traffic demand potentially reducing delay to users of the intersection.
- *Disadvantages:* Higher equipment cost and more extensive maintenance needs due to the need of detection.

Actuated operation can be characterized as fully-actuated or semi-actuated, depending on the number of traffic movements provided with detection. Figure 7.5 illustrates both actuated operations.

- **Fully-Actuated Operation:** In fully-actuated operation, detection is provided to all the phases at an intersection. This type of operation is ideally suited to isolated intersections where less predictable traffic demand exists on all approaches.
- **Semi-Actuated Operation:** In semi-actuated operation, detection is provided only to the phases controlling the minor movements at an intersection. The major movements (typically major road through movements) are operated non-actuated. Locations with sporadic or low volumes on the side streets are best suited for semi-actuated operation. This type of operation is common under coordinated systems where the coordinated phases are guaranteed service every cycle and minor movements are serviced only when demand exists. It is necessary to note that semi-actuated operation under a non-coordinated system (e.g.: free operation during early morning hours) will require the programming of the traffic signal controller to recall the non-actuated phases.

7.2.3 Coordinated Operation

During coordinated operation, multiple signalized intersections are synchronized to enhance the progression of vehicles on one or more directional movements in a system. Pre-timed coordination provides better progression from a driver standpoint, but higher delay is also experienced. Actuated coordination is more efficient, but progression is not consistently achieved. Section 7.6 explores coordination design parameters and coordination challenges in detail.

7.2.4 Volume-Density Operation

Volume-density (also known as density timing) is an enhanced actuated operation where actuated controller parameters (minimum green and passage time) are automatically adjusted to improve intersection efficiency according to varying traffic demand. Section 7.8.1 explores volume-density design parameters in detail.

7.2.5 Traffic Responsive Operation

Traffic responsive is an advanced mode of operation that uses data from traffic detectors, rather than time of day, to automatically select the timing plan best suited to current traffic conditions. A predetermined library of timing plans is necessary. Section 7.8.2 explores traffic responsive design parameters in detail.

7.2.6 Adaptive Signal Control Technology Operation

Adaptive traffic signal control is an advanced mode of operation where vehicular traffic is monitored by upstream and/or downstream detection and an algorithm is used to automatically implement timing adjustments to accommodate fluctuations in traffic demand. Section 7.8.3 explores adaptive signal control technology design parameters in detail.

7.2.7 Traffic Signal Preemption

Traffic signal preemption is a type of preferential treatment based on the immediate transfer of normal operation of a traffic control signal to a special control mode of operation to accommodate the most important classes of vehicles during their approach to and passage of the intersection (e.g. railroad, LRT, emergency vehicle, etc.). Preemption may interrupt signal coordination. A request for preemption shall be serviced by the traffic signal equipment. Section 7.10 explores traffic signal preemption design parameters in detail.

7.2.8 Traffic Signal Priority

Traffic signal priority is a type of preferential treatment based on an operational strategy communicated between vehicles and traffic signals to alter the signal timing for the benefit or priority of those vehicles (mostly transit and heavy trucks). Coordination will not be affected by priority. Service is not guaranteed during a priority request. Section 7.9 explores traffic signal priority design parameters in detail.

7.2.9 Flashing Mode Operation

A signalized intersection is operating under the flashing mode when at least one traffic signal indication in each vehicular signal face of a highway traffic signal is turned on and off repetitively. Flashing mode operation can be characterized by planned or unplanned circumstances:

- **Planned Operation:** Based on engineering study or engineering judgment, traffic control signals may be operated in the flashing mode on a scheduled basis during one or more periods of the day (night time, off-peak) rather than operated continuously in the steady (stop-and-go) mode.
- **Unplanned Operation:** A signalized intersection will be forced into the flashing mode when a malfunction is detected in the traffic signal equipment or it may be forced into the flashing mode when it is undergoing maintenance. A signalized intersection may also be operating under flashing mode during preemption. Additional information is provided in Section 7.11.

7.3 Traffic Signal Phasing

The determination of the traffic signal phasing and its sequence is an important step in traffic signal design. The design should incorporate the fewest number of signal phases that can safely and efficiently move traffic. Additional phases will increase the total start-up lost time experienced at the beginning of each green interval as well as the number of signal clearance intervals (yellow change plus red clearance) per cycle, leading to larger cycle lengths and higher intersection delay. Special consideration is necessary for the selection of left-turn treatments. There are four options for the left-turn phasing at an intersection: permissive only, protected only, protected/permissive or the left-turn movement can be prohibited. When protected left-turn phasing is used, it is also necessary to select its sequence relative to the complimentary through movement: leading left-turns, lagging left-turns, a combination of the two sequences (lead-lag left-turns), or split phasing. Additional consideration is needed on the selection for right-turn treatments. For example, the use of overlaps and the use of RTOR will influence overall intersection operation.

7.3.1 Need for Left-Turn Phasing

The primary factors to consider in the need for protection are the left-turn volume and the degree of difficulty in executing the left-turn through the opposing traffic. The designer should be aware that left-turn phases can sometimes significantly reduce the efficiency of an intersection. Left-turn phasing should be considered on an approach with a peak hour left-turn volume of at least 100 vehicles and a capacity analysis showing that the overall operations are improved by the addition of the left-turn phase. In addition, the following guidelines may be used when considering the addition of separate left-turn phasing at either a new or existing signalized intersection. The following warrants may be used in the analysis of the need for the installation of separate left-turn phases.

- **Left-Turn Volume Cross-Product:** Left-turn phasing may be considered based on a cross-product threshold as defined by the product of the left-turning peak hour volume multiplied by the peak hour volume of opposing traffic (opposing traffic includes both opposing through and opposing right-turning traffic volumes) during the same peak hour. Left-turn phasing should be considered on any approach that meets the following product thresholds:
    - **One Opposing Lane – 50,000**
    - **Two or Three Opposing Lanes – 100,000**
- **Left-Turn Delay:** Left-turn phasing may be considered if the left-turn delay is greater than or equal to two vehicle hours on the left-turn approach during the peak hour. Also, a minimum left-turn volume of two vehicles per cycle should exist with the average delay per vehicle being no less than 35 seconds.
- **Left-Turn Crash:** Left-turn phasing may be considered if an analysis of the critical left-turn related crashes is recommended, depending on the availability of crash data. Table 7.1 shows the minimum critical left-turn related crashes for an approach.

Table 7.1 – Minimum Critical Left-Turn Related Crashes

Number of Left Turn Lanes on the Critical Approach	Crash Year Period (Years)	Minimum Critical Left-Turn Related Crashes
1	1	4
	2	6
	3	7
2	1	6
	2	9
	3	13

- **Horizontal and Vertical Sight Distance:** Left-turn phasing may be considered if an analysis of the available sight distance for left-turning vehicles is recommended. Figure 7.6 presents a table from AASHTO's *A Policy on Geometric Design of Highways and Streets* with horizontal intersection sight distance for left-turns from the major road (Case F) made by passenger cars. The table also considers the number of major-road lanes to be crossed. For other conditions, including vertical intersection sight distance and design vehicles, the sight distance should be recalculated in accordance to the above manual.
- **High Speed, Wide Intersections:** Left-turn phasing may be considered where two or more opposing lanes of traffic having a posted speed limit of 45 miles per hour or greater must be crossed for the left-turn movement.
- **Offset Left-Turn Lanes:** Left-turn phasing may be considered to improve

sight distance and safety for left-turning vehicles. At signalized intersections, the use of offset left-turn lanes is preferred where feasible. Sight distance for left-turning vehicles ranges from a negative offset (Figure 7.7a), to being aligned with no offset (Figure 7.7b), and to a positive offset (Figure 7.7c).

Figure 7.6 – Horizontal Intersection Sight Distance for Left-Turns
Source: AASHTO's A Policy on Geometric Design of Highways and Streets

SIGHT DISTANCE

Design Speed (mph)	Passenger Car Lanes Crossed 1	2	3
20	165	180	195
25	205	225	240
30	245	265	290
35	285	310	335
40	325	355	385
45	365	400	430
50	405	445	480
55	445	490	530
60	490	530	575
65	530	575	625
70	570	620	670

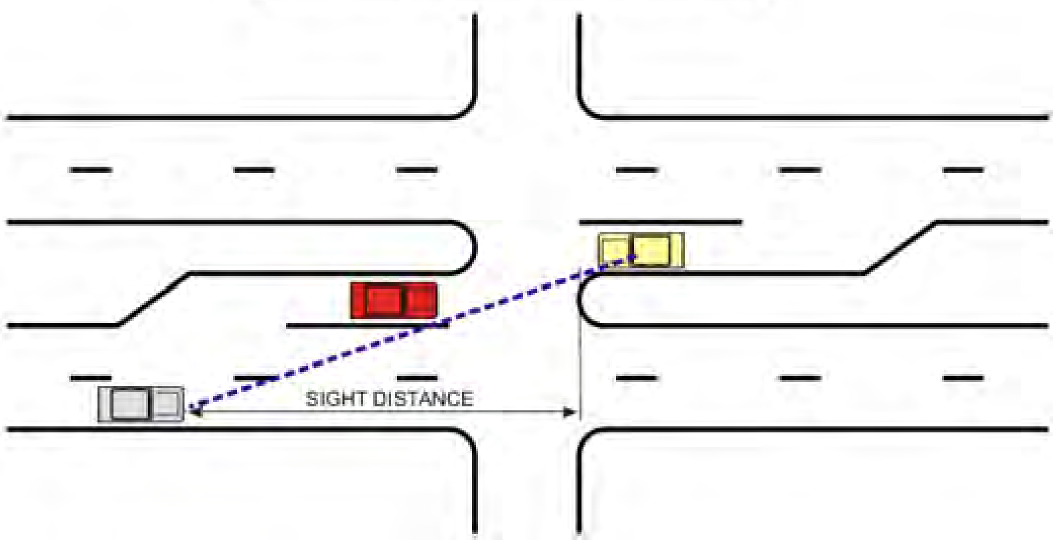
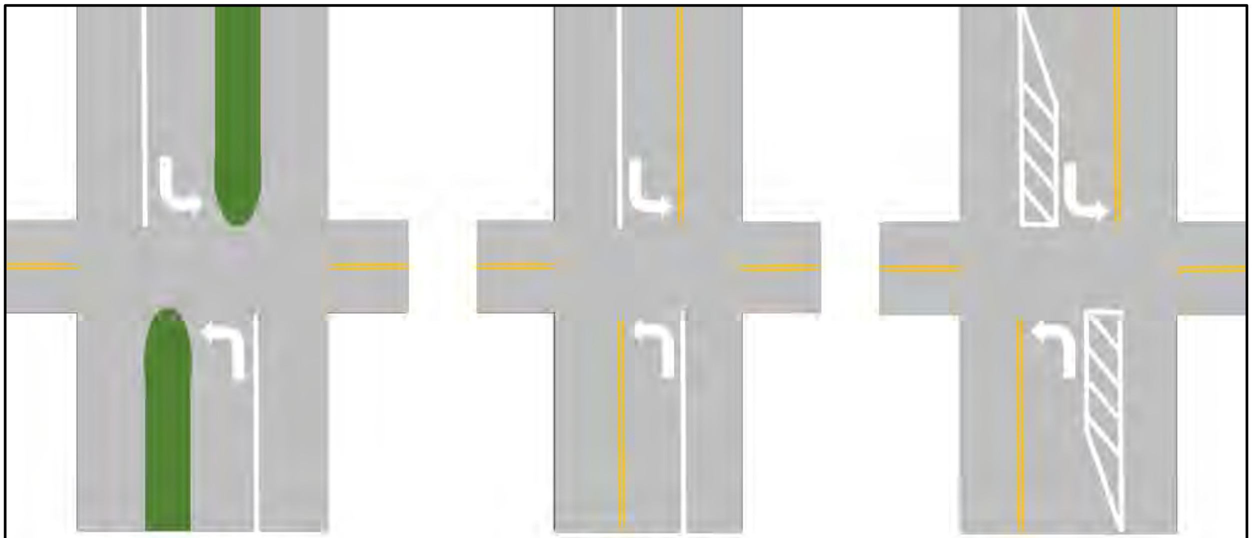


Figure 7.7 – Offset Left-Turn Lanes

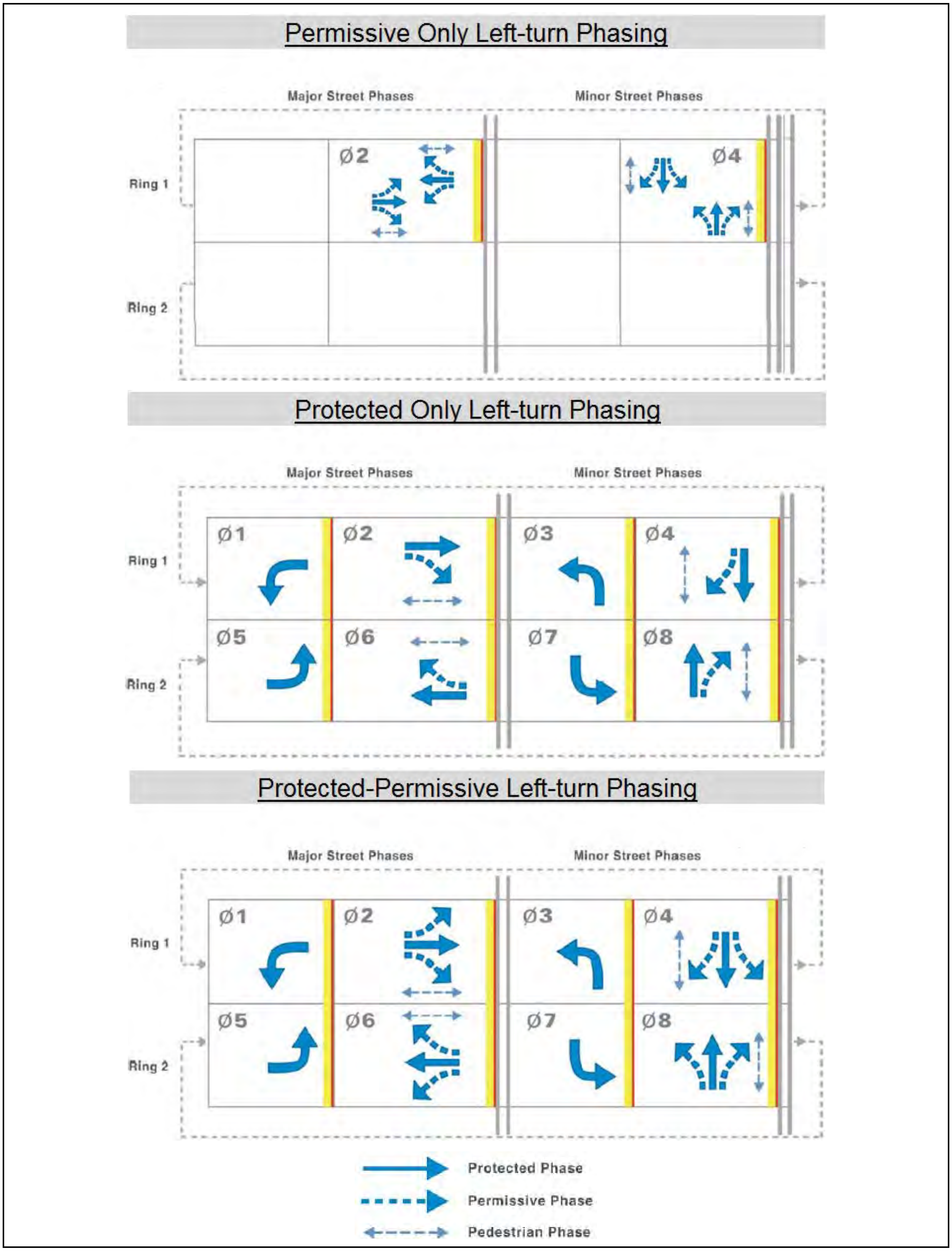


7.3.2 Types of Left-Turn Phasing

Figure 7.8 illustrates the typical ring-and-barrier diagram arrangement for different types of left-turn phasing.

- **Permissive Only Left-Turn Phasing:** This phase is served concurrently with the adjacent through movement, and requires left-turning vehicles to yield to conflicting vehicle and pedestrian movements.
  - *Advantages:* Reduced intersection delay and efficient green allocation.
  - *Disadvantages:* Requires users to choose acceptable gaps in traffic and, left-turn yellow trap (See Section 7.3.4) can occur if opposing movement is a lagging left-turn.
  - *Signal Display:* Circular green or flashing left-turn yellow arrow (See Section 7.3.5).
- **Protected Only Left-Turn Phasing:** This phase gives left-turning vehicles the right-of-way without any conflicting movements.
  - *Advantages:* Reduced delay for left-turning vehicles and because users always receive exclusive right-of-way, gaps in traffic do not need to be identified; higher degree of safety for left-turning vehicles.
  - *Disadvantages:* Increased intersection delay.
  - *Signal Display:* Green arrow.

Figure 7.8 – Ring-and-Barrier Diagram and Left-Turn Phasing
Source: Traffic Signal Timing Manual



- **Protected/Permissive Left-Turn Phasing:** Left-turning vehicles receive exclusive right-of-way, but can also make permissive left-turn movements during the complementary through movement green indication, when yielding to conflicting vehicle and pedestrian movements is required.
  - *Advantages:* Compromise between safety of protected left-turn phase and efficiency of permissive left-turn phase with no significant increase in delay for other movements.
  - *Disadvantages:* Left-turn yellow trap (see Section 7.3.4) can occur if opposing movement is a lagging left-turn.
  - *Signal Display:* Green arrow followed or preceded by circular green or flashing left-turn yellow arrow (see Section 7.3.5).
- **Prohibited Left-Turn Phasing:** Implemented to maintain mobility at an intersection, particularly during times of day when gaps are unavailable and operation of permissive left-turn phasing may be unsafe.
  - *Advantages:* Reduced conflicts at intersection.
  - *Disadvantages:* Users must find alternative routes.
  - *Signal Display:* A No Left-Turn sign (R3-2) is necessary and should be supplemented with time and day restrictions, if applicable.
- **Left-Turn Phasing for Inadequate Geometry of the Intersection:** Two operational strategies can be applied at intersections where there is inadequate room for opposing left-turn movements to move simultaneously without a conflict:
  - The use of split phasing left-turn sequence (See Section 7.3.4) that requires the use of protected only left-turn phasing on both approaches; or
  - The use of lead-lag left-turn phasing sequence (See Section 7.3.4) that allows the use of protected only left-turn phasing on both approaches or the use of protected-only left-turn phasing for the leading left-turn movement while the lagging left-turn movement can operate as protected/permissive left-turn phasing.
- **Lack of Exclusive Left-Turn Lane:** Protected only left-turn phasing shall not be used at intersections where there is no exclusive left-turn lane, unless split phasing (See Section 7.3.4) is used (*MUTCD Section 4D.17*). It is acceptable to use protected/permissive phasing without an exclusive left-turn lane if the following two conditions are satisfied:
  - A red indication is never shown to straight-through traffic on the approach at the same time as the green or yellow left-turn arrow is shown; and
  - A red left-turn arrow is never shown to straight-through traffic on the approach at the same time as the a green indication is shown.

7.3.3 Guidelines for Selecting Left-Turn Phasing

If the need for left-turn phasing on an intersection approach has been established, the guidelines in Section 7.3.4 should be used to select the type of left-turn phasing to provide. Care should be taken to avoid a yellow trap which can occur in some combinations of the type and sequence of left-turn movements. The flowchart presented in Figure 7.9 is a recommendation from the *Traffic Signal Timing Manual*, with the objective of providing practitioners with a structured procedure for the evaluation and selection of left-turn phasing. The selection of left-turn phasing should be movement specific; therefore, it is necessary to check each approach separately. The following information supports the information utilized in Figure 7.9:

- **Critical Left-Turn Related Crashes:** Depending upon the critical number of left-turn related crashes, Table 7.2 shows the threshold crash numbers in considering the implementation of two types of left-turn phasing: protected only and protected/permissive.

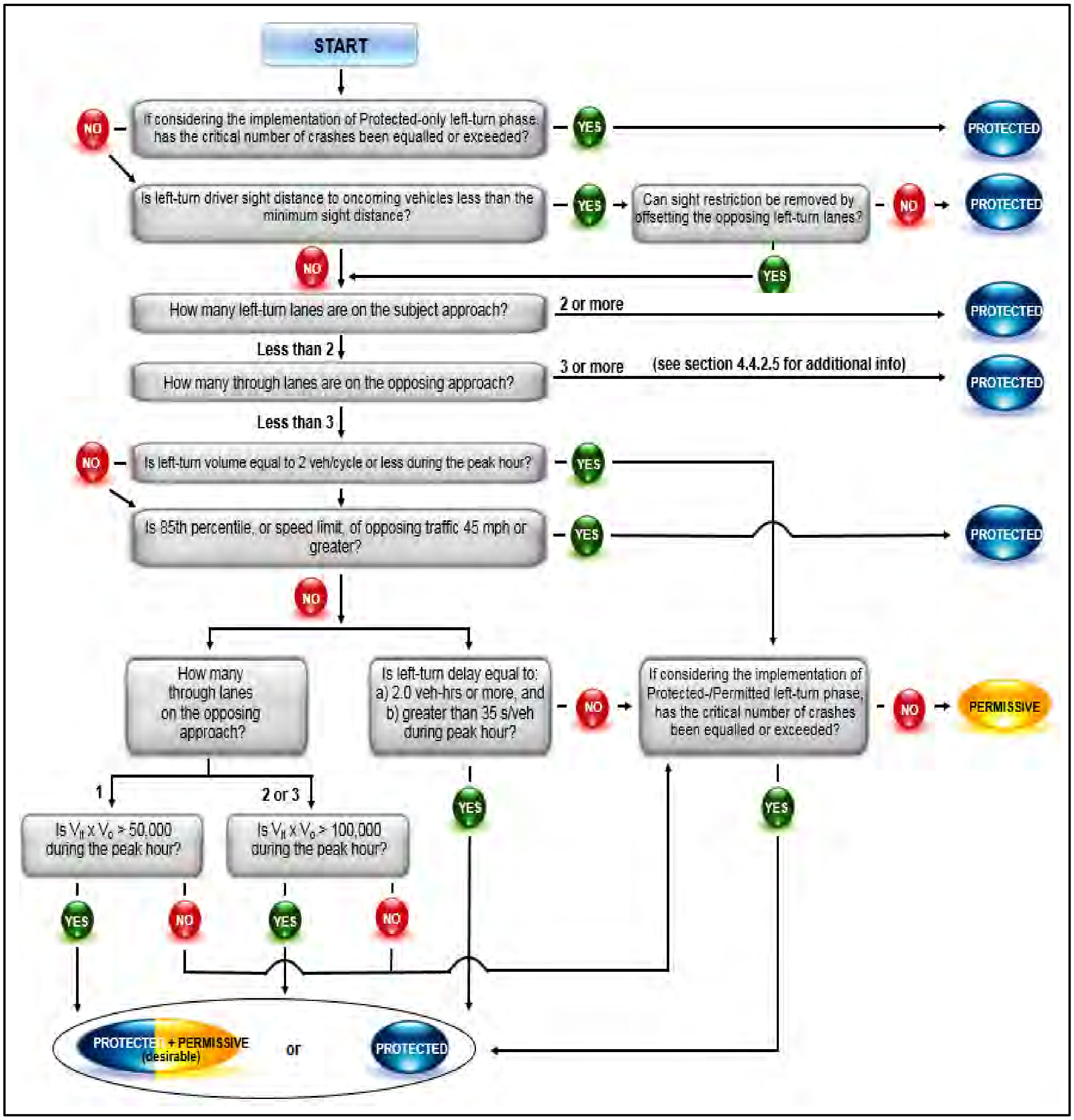
Table 7.2 – Minimum Critical Left-Turn Related Crashes for Left-Turn Phasing (Single Left Turn Lanes)

Crash Year Period (Years)	Minimum Critical Left-Turn Related Crashes for Left-Turn Phasing	
	Protected Only	Protected/Permissive
1	6	4
2	11	6
3	14	7

- **Horizontal and Vertical Sight Distance:** See Section 7.3.1.
- **Offset Left-Turn Lanes:** See Section 7.3.1.
- **Multiple Left-Turn Lanes:** On approaches with two or more adjacent left-turn lanes, protected only left-turn phasing is the recommended operation.
- **Number of Opposing Through Lanes:** On approaches where left-turning vehicles must cross four or more opposing through lanes, protected only left-turn phasing is the recommended operation. Engineering judgment should be used to determine if permissive movement may be allowed (use of flashing yellow arrow, use of left-turn lane offset, etc.).
- **Speed of Opposing Through Traffic:** Approaches where left-turning vehicles must cross less than three through lanes and the 85th percentile speed or the posted speed limit of opposing traffic is 45 mph or greater should operate with protected only left-turn phasing.
- **Left-Turn Delay:** See Section 7.3.1.
- **Left-Turn Volume Cross-Product (i.e. V_{lt} x V_o):** See Section 7.3.1.

Figure 7.9 – Guidelines for Selecting Left-Turn Phasing

Source: Traffic Signal Timing Manual



7.3.4 Sequence of Left-Turn Phasing

When protected left-turn phasing is used, it is necessary to select its sequence relative to the complementary through movement. However, special attention is necessary when selecting the left-turn sequence phasing regarding the potential for the left-turn yellow trap. Figure 7.10 illustrates the typical ring-and-barrier diagram arrangement for different types of left-turn phasing sequence. Although there is no standardized method to select the sequence of left-turn phasing, practitioners can base their selection on the advantages and disadvantages provided in Table 7.3 and on the following operational characteristics:

- **Leading Left-Turns:** The protected left-turn phase is served prior to the complementary through movement on an approach. The use of leading left-turn phasing on both approaches (lead-lead) is the most common type of operation.
- **Lagging Left-Turns:** The protected left-turn phase is served after the complementary through movement on an approach. The use of lagging left-turn phasing on both approaches (lag-lag) is most commonly used in coordinated systems with closely spaced intersections, such as diamond interchanges.
- **Lead-Lag Left-Turns:** During this operation, leading left-turn phasing and lagging left-turn phasing are provided on opposing approaches of the same street. This operation produces independence between the through phases, being desirable under coordinated operations, and to accommodate platoons of traffic arriving from each direction at different times.
- **Split Phasing Left-Turns:** During this operation, all movements of a particular approach are serviced followed by the servicing of all movements of the opposing approach. Typically, it is the minor street (side street) that operates under split phasing left-turns at intersections with geometry constraints or crash issues, where allowing concurrent left-turn movements is problematic. Split phase left-turns are usually less efficient than standard eight-phase operation when opposing traffic volumes are fairly well balanced and there is a need for left-turn protection. However, in cases where one approach carries substantially more traffic than the other or where there are large volume differences between opposing left-turn movements, then split phasing left-turns may not be significantly less efficient than standard eight-phase operation. If there is a need for split phasing left-turns at an intersection of a coordinated system, it is recommended to lead the lower volume side street split phase prior to servicing the higher volume side street split phase. The controllers at such locations should be programmed to transfer any unused green time from the lower-volume side street to the higher-volume side street, which in turn provides for more efficient operating conditions.

Figure 7.10 – Sequence of Left-Turn Phasing
Source: Traffic Signal Timing Manual

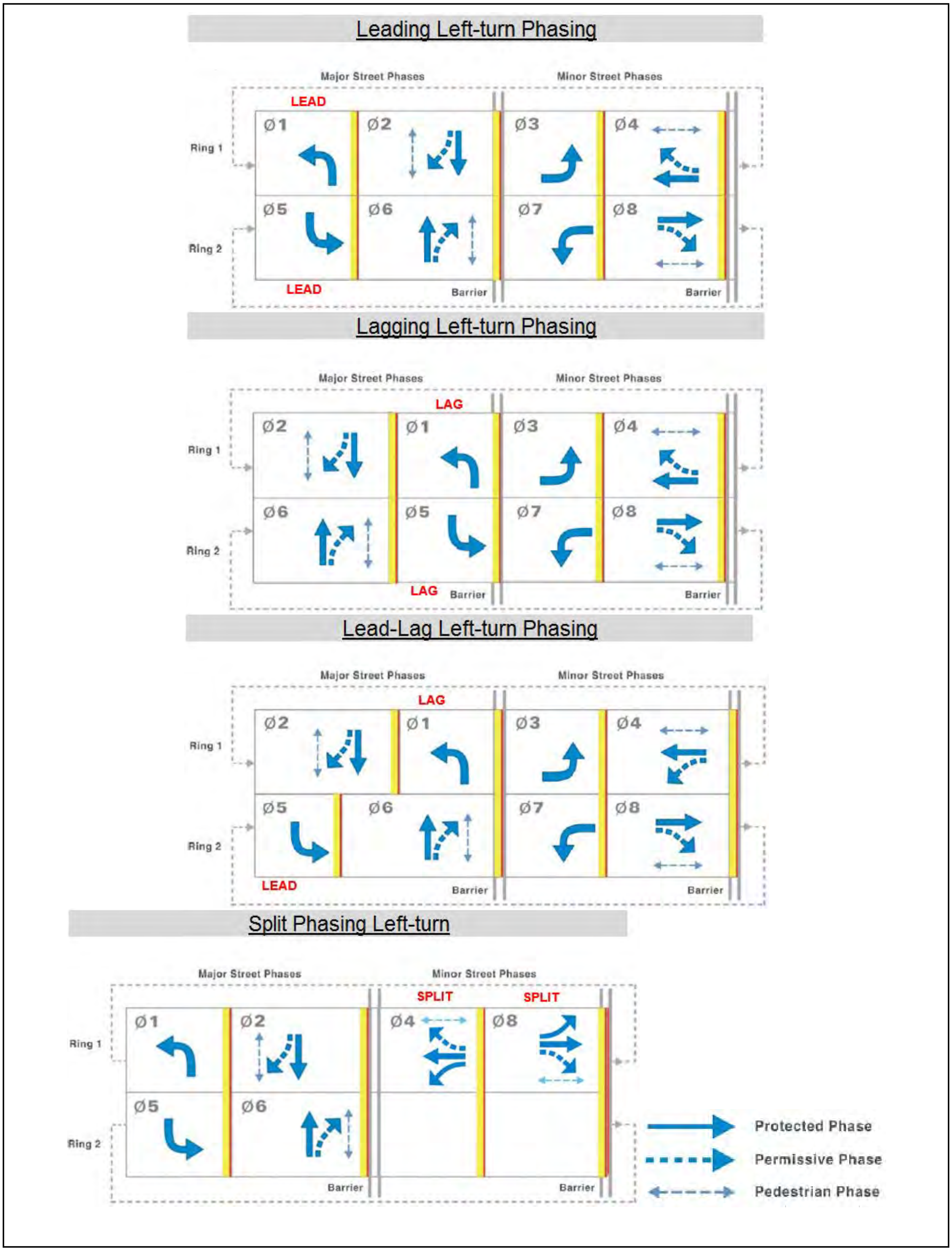


Table 7.3 – Left-Turn Phase Sequence Advantages and Disadvantages

Left-Turn Phase Sequence	Advantages	Disadvantages
Leading	• Drivers tend to react more quickly to a leading green arrow indication than to a lagging left-turn. • Minimizes conflicts between left-turns and opposing through movements by clearing left-turning vehicles first and reducing the need of left-turn drivers to find safe gaps. • Minimizes conflicts between left-turns and through movements on the same approach when the left-turn volume exceeds the available storage bay length.	• Potential for the left-turn yellow trap. • Left-turning vehicles may continue to turn after the green arrow display ends. • Through vehicles in the adjacent lane may make false starts in an attempt to move with turning vehicles. • Potential pedestrian conflicts at the beginning of the left-turn phase due to pedestrian expectation of a Walk signal display.
Lagging	• Provides operational benefits when the through movement queue blocks access to the left-turning bay and the left-turn is "starved" of traffic; • Left-turning vehicles may clear the intersection during the permissive phase (if operating under protected/permissive left-turn phasing) and not bring up the protected phase, increasing intersection efficiency; • Less pedestrian conflicts.	• Potential for the left-turn yellow trap. • Drivers usually react slower to a lagging left-turn than to a leading left-turn.
Lead-Lag	• Beneficial in accommodating through movement progression in a coordinated system by providing a larger bandwidth. • Accommodates approaches that lack left-turn lanes.	• Potential for the left-turn yellow trap.
Split Phase	• Eliminates conflicts when opposing left-turn paths overlap because of intersection geometry; • Accommodates approaches that lack left-turn lanes; • Accommodates the use of shared lanes (left/through lane) on intersections with high left-turn and through volumes, providing more efficient operation; • Useful where crash history indicates an unusually large numbers of side-swipe or head-on crashes in the middle of the intersection that involve left turning vehicles.	• Less efficient than other types of left-turn phasing. • Increased coordinated cycle length, particularly if both split phases have concurrent pedestrian phases.

- **Left-Turn Yellow Trap:** The left-turn yellow trap is a condition where a left-turn driver sees the onset of a steady yellow ball indication (when a 5-section signal display is used) and incorrectly assumes oncoming through traffic sees the same steady yellow ball indication. This scenario can be problematic, leading to a potential crash, if the left-turn driver attempts to "sneak" through the intersection on yellow when oncoming traffic still sees a green ball indication. Technically, the left-turn yellow trap occurs during the change from permissive left-turn phasing in both directions of traffic to a lagging left-turn protected phasing in one direction. Therefore, the potential for the left-turn yellow trap does not occur when an intersection is operating under protected only left-turn phasing in both directions of traffic. Figure 7.11 illustrates the left-turn yellow trap. The use of flashing left-turn yellow arrow signal displays (See Section 7.3.5) is recommended to avoid the left-turn yellow trap. In locations where a 5-section signal display is used, the following strategies are alternatives to minimize the risk of the left-turn yellow trap for different left-turn phasing sequences:

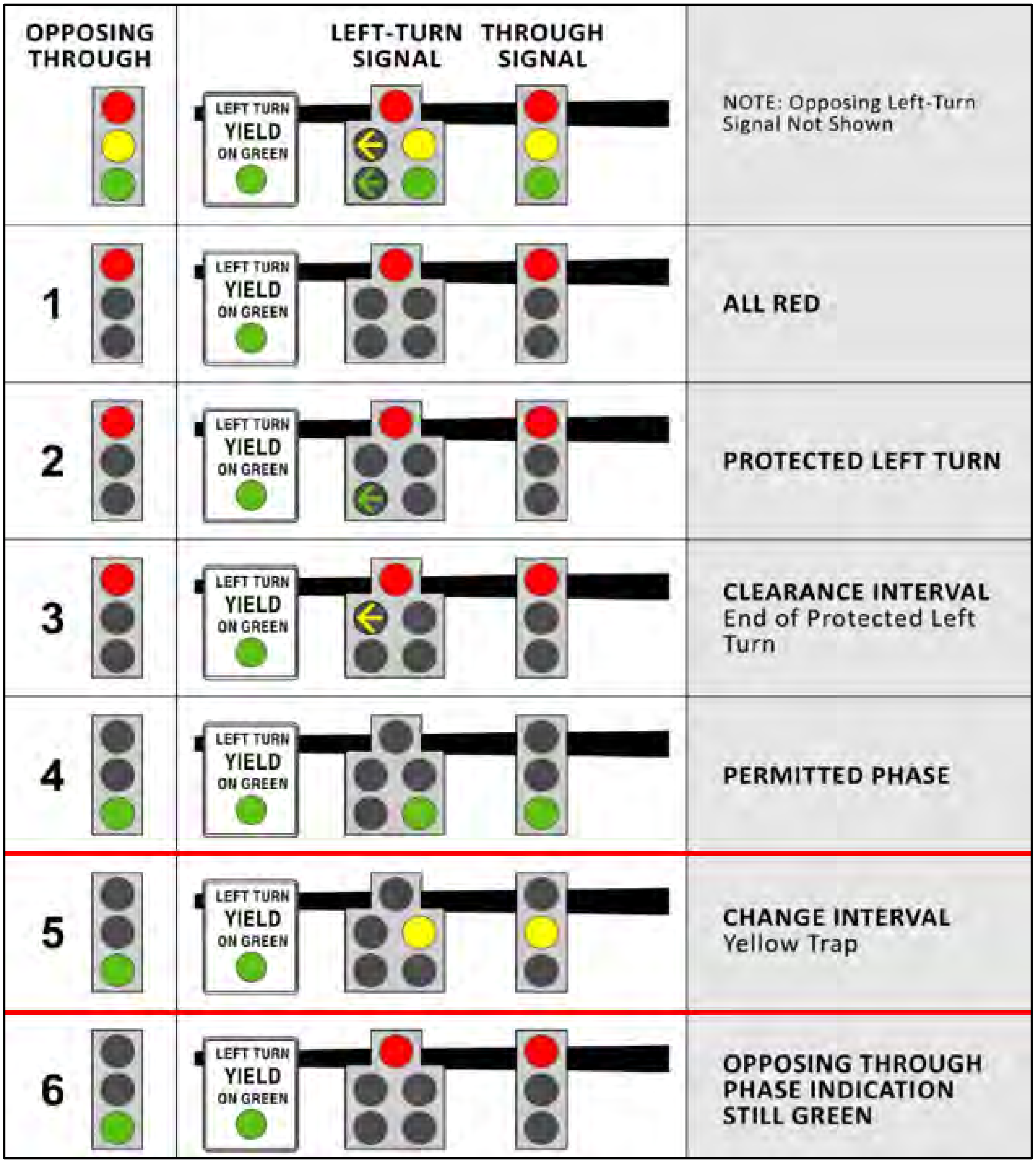
  - **Leading Left-Turns:** When an intersection is operating under protected/permissive leading left-turn phasing on opposing approaches during light traffic conditions and, in the absence of minor street traffic, there is the possibility for the protected left-turn phase to be re-serviced after the permissive movement. This results in a lagging left-turn and a potential for the left-turn yellow trap. Practitioners should explore controller features that provide left-turn backup protection or that ensures the servicing of side street phases prior to returning to the protected left-turn phase.

  - **Lagging Left-Turns:** When an intersection is operating under permissive/protected lagging left-turn phasing on opposing approaches, practitioners should design the signal timing and settings so that the through movement phases clear (end) simultaneously, before the protected left-turn phases. Using a single ring-and-barrier structure will also prevent the potential for the left-turn yellow trap in this case.

  - **Lead-Lag Left-Turns:** When an intersection is operating under lead-lag left-turn phasing, practitioners should use protected-only left-turn phasing for the leading left-turn movement while the lagging left-turn movement may still operate as protected/permissive left-turn phasing.

Figure 7.11 – Left-Turn Yellow Trap

Source: FHWA Signalized Intersections: Informational Guide



7.3.5 Flashing Yellow Arrow for Left-Turn Movement Phasing

The *MUTCD* under Sections 4D.17 through 4D.20 and Sections 4D.25 through 4D.26 discusses the Flashing Yellow Arrow for left-turn phasing. The Flashing Yellow Arrow is an alternative for the typical circular green indication used for permissive left-turns. Figure 7.12 presents information on the Flashing Yellow Arrow. Research has demonstrated that there is the potential for drivers to misinterpret the meaning of the circular green indication for a permissive left-turn movement. A Flashing Yellow Arrow for permissive left-turn movement shall not be used when an engineering study demonstrates that the subject left-turning vehicle has limited sight distance and when intersection geometrics create a conflicting left-turn path.

- **Operational advantages of the Flashing Yellow Arrow:**
  - Eliminate the left-turn yellow trap;
  - Minimize the circular green indication confusion;
  - Potential environment benefits due to more efficient left-turn operations, reducing driver delay;
  - Allow the use of different left-turn modes of operation during different times of the day, for example:
    - Eight-phase protected-only operation during peak hour;
    - Eight-phase protected/permissive operation during non-peak hours;
    - Two-phase permissive only operation during low-volume periods.
- **Flashing Yellow Arrow Sequence:** When the Flashing Yellow Arrow for permissive left-turn movement indication is used and when protected/permissive operation is active, a minimum of three seconds should be programmed for the red-clearance interval (all-red interval) when transitioning from protected left-turn mode to the permissive left-turn mode.
- **Flashing Yellow Arrow Retrofits:** When retrofitting existing traffic signal faces from the circular green indication to the Flashing Yellow Arrow, additional signal faces will be needed on the approach. Therefore, the following should be considered:
  - Mast arm length;
  - Traffic signal pole and mast arm structural design;
  - Vertical clearance at new Flashing Yellow Arrow signal face;
  - Preemption equipment compatibility;
  - Ensuring a second through lane display is available;

- Intersection geometry (sight distance);
- Pedestrian conflicts;
- Check cabinet load switch assignments;
- Check controller capability (software version, etc.);
- Check conflict monitor / malfunction management unit.

➢ **Additional Information on the Flashing Yellow Arrow:** In addition to the *MUTCD* standards and guidelines on the Flashing Yellow Arrow, the FHWA has provided an interim approval for optional use of 3-section Flashing Yellow Arrow Signal Faces (IA-17).

Figure 7.12 – Flashing Yellow Arrow (Permissive Left-Turn Movement Display)

SOLID RED ARROW

Drivers intending to turn left must stop and wait.
Do not enter an intersection to turn left when a solid red arrow is being displayed.

SOLID YELLOW ARROW

The left-turn signal is about to change to red. Prepare to stop or to complete the left turn if legally within the intersection and there is no conflicting traffic present.

FLASHING YELLOW ARROW

Drivers are allowed to turn left after yielding to all oncoming traffic and to any bicyclists and pedestrians in the crosswalk. Drivers must wait for a safe gap in oncoming traffic before turning. Oncoming traffic has a green light.

SOLID GREEN ARROW

Left turners have the right of way. Proceed.
Oncoming traffic has a red light.

7.3.6 Right-Turn Treatments

Right-turn movements typically operate under permissive only phasing from shared through/right-turn lanes. The use of protected only or protected/ permissive phasing is also allowed. The existence of exclusive right-turn lane(s) and how the pedestrian phases are serviced will dictate the right-turn movement treatment selection.

- **Overlaps:** An overlap is a separate traffic signal controller output that uses logic to improve intersection operations by combining two or more phases for any non-conflicting movements. An overlap should not be used to achieve a phasing operation that can be accomplished without an overlap in a standard cabinet and controller configuration. Overlaps are most often used for right-turn movements where exclusive right turn lanes exist. For right-turn overlaps, the parent phase is typically the compatible protected left-turn phase on the intersecting road. Figure 7.13 illustrates a right-turn overlap. Figure 7.14 illustrates a typical phase lettering scheme for right-turn overlaps. Practitioners should consider the following when designing a right-turn overlap:
    - **Cabinet Set-up:** An overlap requires its own load switch (See Section 6.4) and shall not be set-up by hard-wiring multiple movements together in the signal cabinet. Eliminating the use of an overlap load switch has operational safety issues and decreases flexibility in the signal timing.
    - **Signage:** U-turns from the complementary protected left-turn phase on the intersecting road shall be prohibited or signed to yield. The use of sign R10-16 is recommended in this case.
    - **Adjacent Through Phase:** Available current technology allows an intersection to operate the right-turn overlaps with both the compatible left-turn phase and the adjacent through phase, improving intersection operational efficiency. However, additional consideration to potential pedestrian conflicts is necessary. Practitioners should explore the availability of controller features on the selected project equipment that allow a right-turn overlap to be omitted when the conflicting pedestrian phase (associated with the through vehicular movement) is active. Therefore, the right-turn overlap will be displayed with the adjacent through phase only when a pedestrian call has not been placed, providing better right-turn movement efficiency.

- **Right Turn On Red:** The prohibition of RTOR at signalized intersections warrants appropriate traffic signal display and signage design. The *TCA Section 55-8-110* states:

  > *"A right-turn on a red signal shall be permitted at all intersections within the state; provided, that the prospective turning car shall come to a full and complete stop before turning and that the turning car shall yield the right-of-way to pedestrians and cross traffic traveling in accordance with their traffic signals; provided, further, such turn will not endanger other traffic lawfully using the intersection. A right turn on red shall be permitted at all intersections, except those that are clearly marked by a "No Turns On Red" sign, which may be erected by the responsible municipal or county governments at intersections which they decide require no right turns on red in the interest of traffic safety."*

  See Section 14.2.7 for application of the No Turn On Red signs. Furthermore, the Tennessee Rule 1680-03-01 adopts the *MUTCD*. Therefore, designers should consider the use of the following traffic signal displays for RTOR:

  - **RTOR Allowed:** A steady circular red (typically used) or a steady red arrow plus a LED blank-out (illuminated) R10-17a sign. The second option is used when right-turning vehicular traffic and pedestrian traffic conflict is to be avoided, in conjunction with railroad preemption, and during exclusive pedestrian phases. The LED blank-out R10-17a sign would be illuminated only when the conflicting pedestrian phase is not active.

  - **RTOR Not Allowed:** A steady circular red plus a No Turn On Red sign or a steady red arrow plus a No Turn On Red sign.

  Figure 7.15 illustrates the recommended traffic signal displays for RTOR and Section 8.2.3 explores detection strategies, like the delay parameter, to be used with RTOR.

Figure 7.13 – Right-Turn Overlap
Source: Traffic Signal Timing Manual

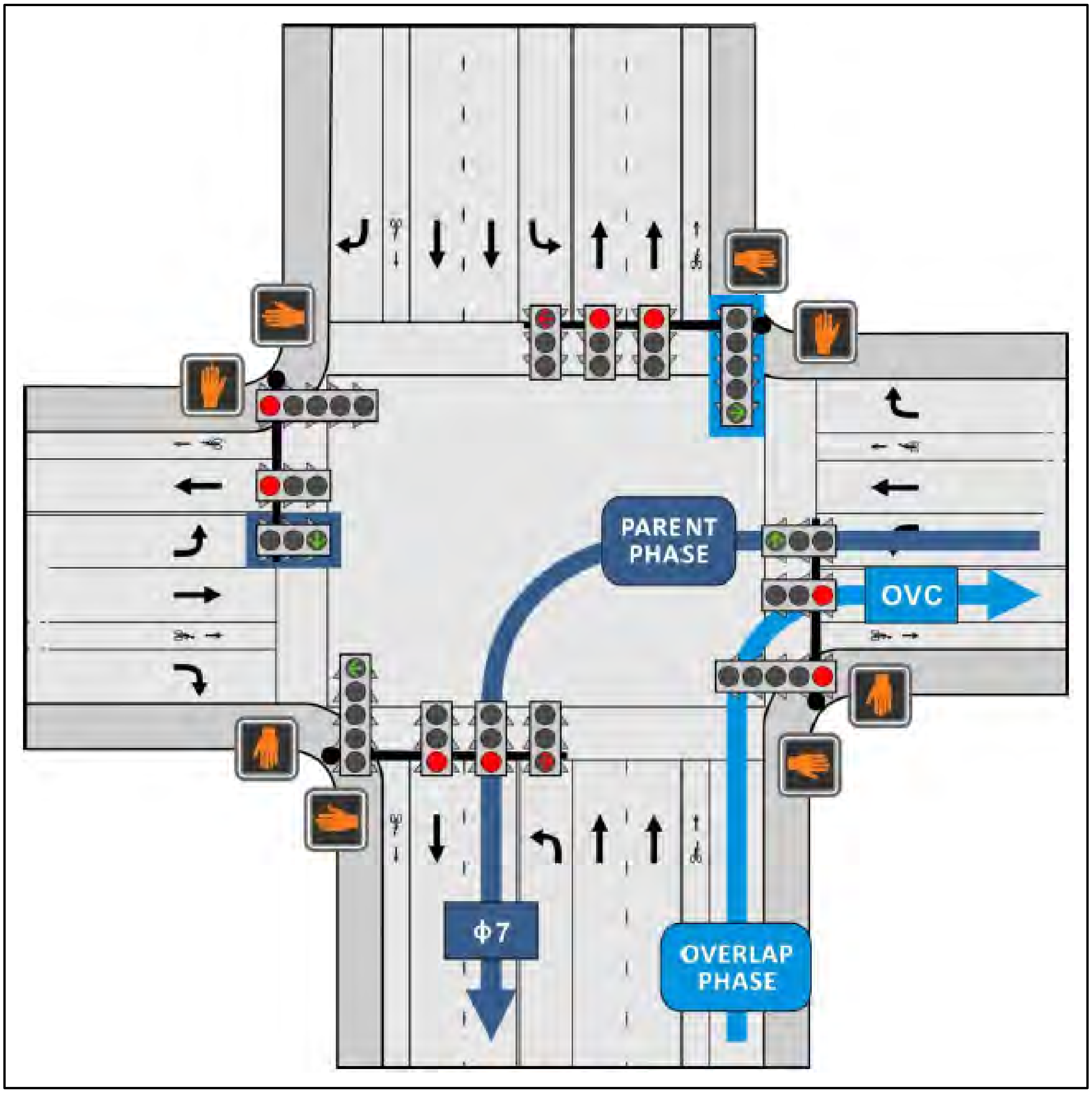
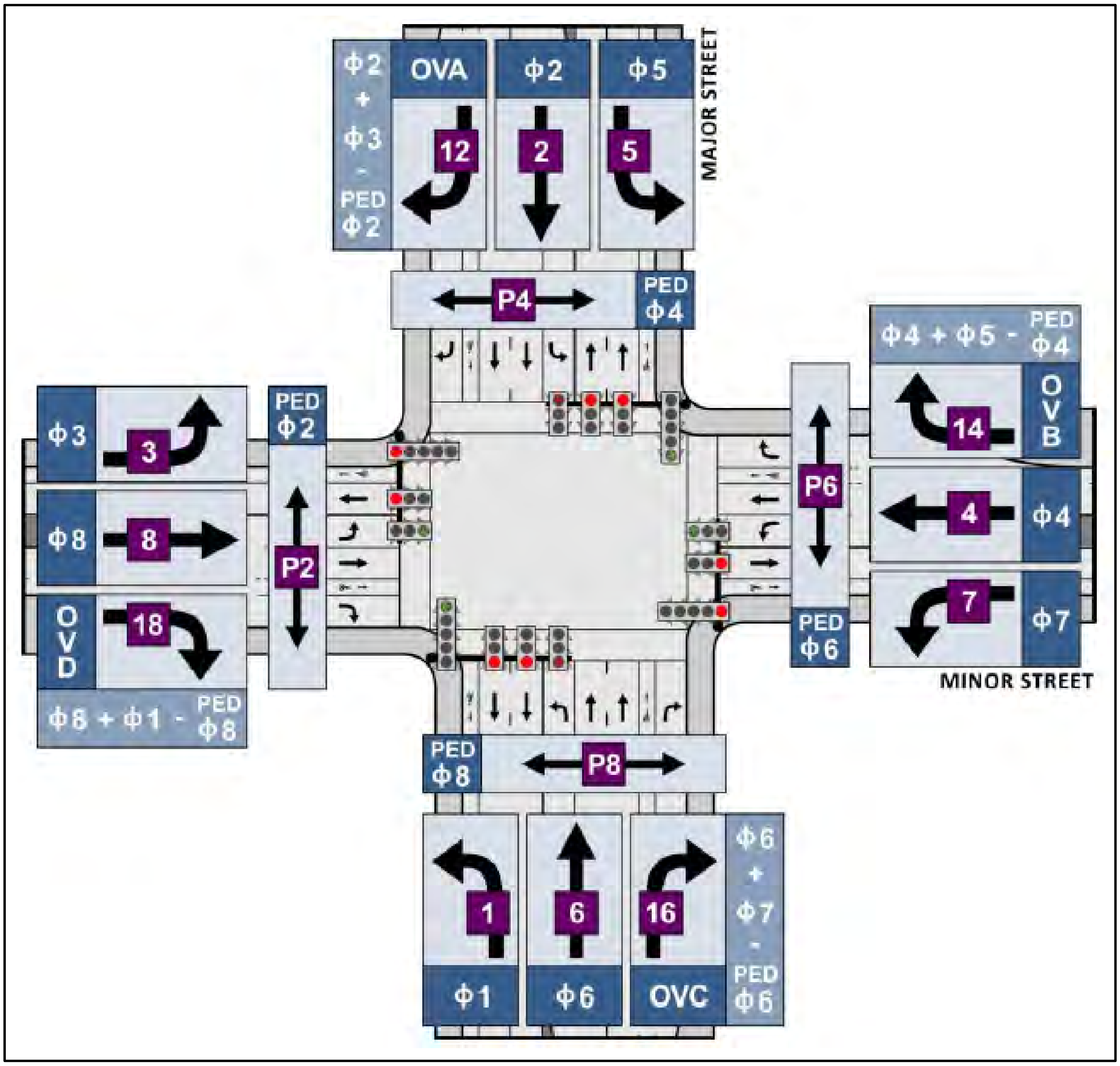


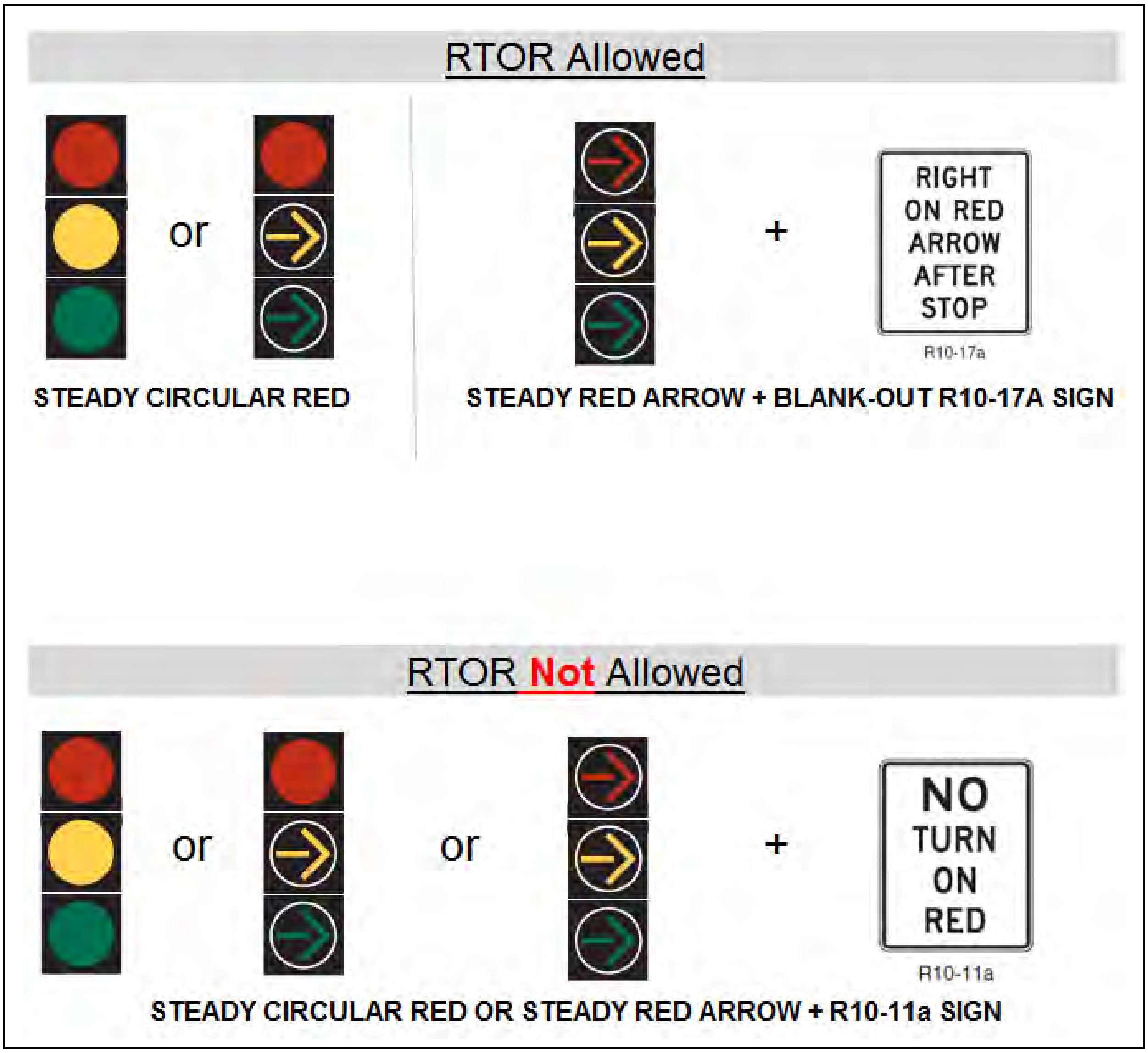
Figure 7.14 – Right-Turn Overlap Phase Lettering Scheme
Source: Traffic Signal Timing Manual



Overlap	Parent Phase		Pedestrian Phase
	Left-turn	Through	
A	3	2*	2P
B	5	4*	4P
C	7	6*	6P
D	1	8*	8P

* Inclusion of the Through Phase as an overlap parent phase depends on controller feature availability allowing a right-turn overlap to be omitted when a conflicting pedestrian phase is active.

Figure 7.15 – Right-Turn On Red (RTOR) Signal Displays



7.4 Pedestrian Signal Phasing

Pedestrian movements are typically served concurrently with the adjacent parallel vehicular phase at an intersection. This type of pedestrian phasing simplifies the operation of the intersection, but puts pedestrians in conflict with right-turning vehicles and vehicles turning left permissively by allowing their movement at the same time. In the case of protected phasing, where an arrow signal (left or right) is used to indicate a mandatory traffic turning movement, the green arrow phase is never actuated at the same time as the walk signal for the adjacent crosswalk across which the traffic will turn. A pedestrian phase is initiated by demand on activation of a pedestrian pushbutton (detection) or by setting a traffic signal controller recall that would activate selected pedestrian phases automatically (See Section 8.3.4). The following discussion provides guidelines on pedestrian signal phasing alternatives, as well as on pedestrian signal warrants and on accessible pedestrian signals.

7.4.1 Pedestrian Warrants and Signal Heads

When pedestrian signal phasing is being considered for signalized intersections, see *MUTCD Sections 4C.05, 4C.06, and 4E.03* for standards, guidance, and support information. In addition, this manual contains pedestrian phase timing parameters, pedestrian detection guidelines, including accessible pedestrian signals, and pedestrian signal head requirements (See Sections 7.4, 7.5.6, and 9.2.14).

7.4.2 Pedestrian Signal Phasing Alternatives

The use of exclusive pedestrian phasing and the leading pedestrian interval can mitigate some of the potential pedestrian conflicts occurring during vehicular turning movements, providing additional safety to pedestrians.

- **Exclusive Pedestrian Phase:** An exclusive pedestrian phase dedicates an additional phase for the exclusive use of all pedestrians. During this additional phase, no vehicular movements are served concurrently with pedestrian traffic. Pedestrians can simultaneously cross any of the intersection legs and may even be allowed to cross the intersection in a diagonal path. This type of pedestrian phasing has an advantage of reducing conflicts between turning vehicles and pedestrians, but it comes at a penalty of reduced vehicular capacity and longer cycle lengths, increasing delay to some users. An exclusive pedestrian phase is recommended at locations that may experience high pedestrian volumes and high conflicting vehicle turning movements during specific hours of the day. Practitioners should determine when the exclusive pedestrian phase is serviced, either after the major road movements or after the minor road movements. Figure 7.16 illustrates a ring-and-barrier diagram for an exclusive pedestrian phase.
- **Leading Pedestrian Interval:** A leading pedestrian interval allows the walk indication for a pedestrian phase to be displayed prior to the associated vehicle phase. This treatment allows a pedestrian to establish

right-of-way in an intersection, and can also aid in pedestrian visibility for drivers, bicyclists, and other system users. The *MUTCD* states that if a leading pedestrian interval is used, it should be at least three seconds in duration. Figure 7.17 illustrates a ring-and-barrier diagram for a leading pedestrian interval.

Figure 7.16 – Exclusive Pedestrian Phasing
Source: Traffic Signal Timing Manual

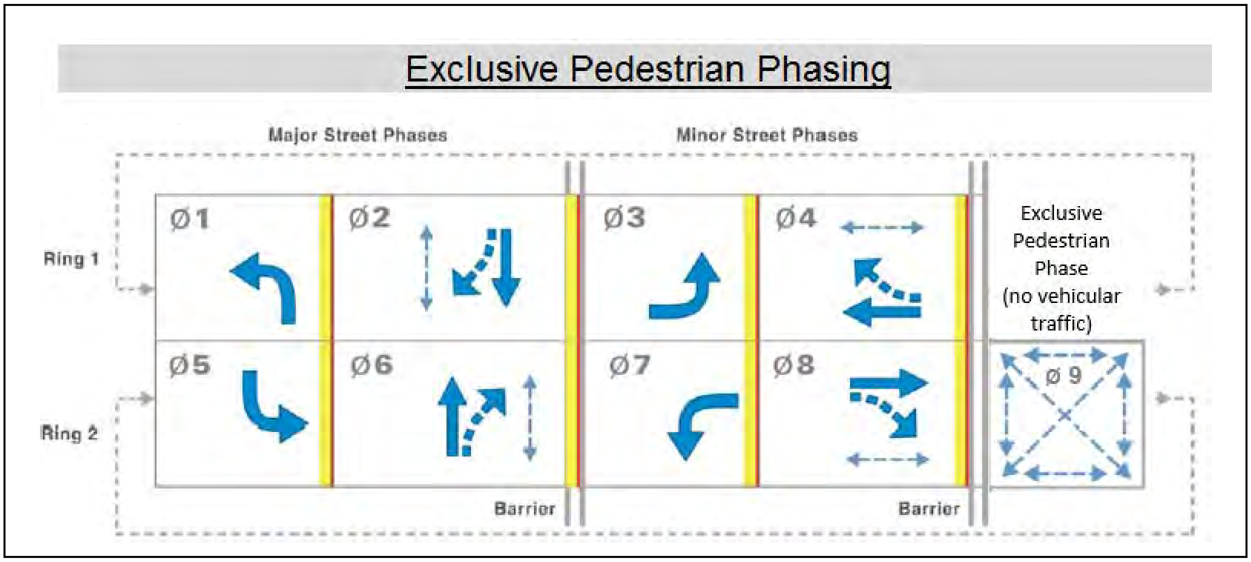
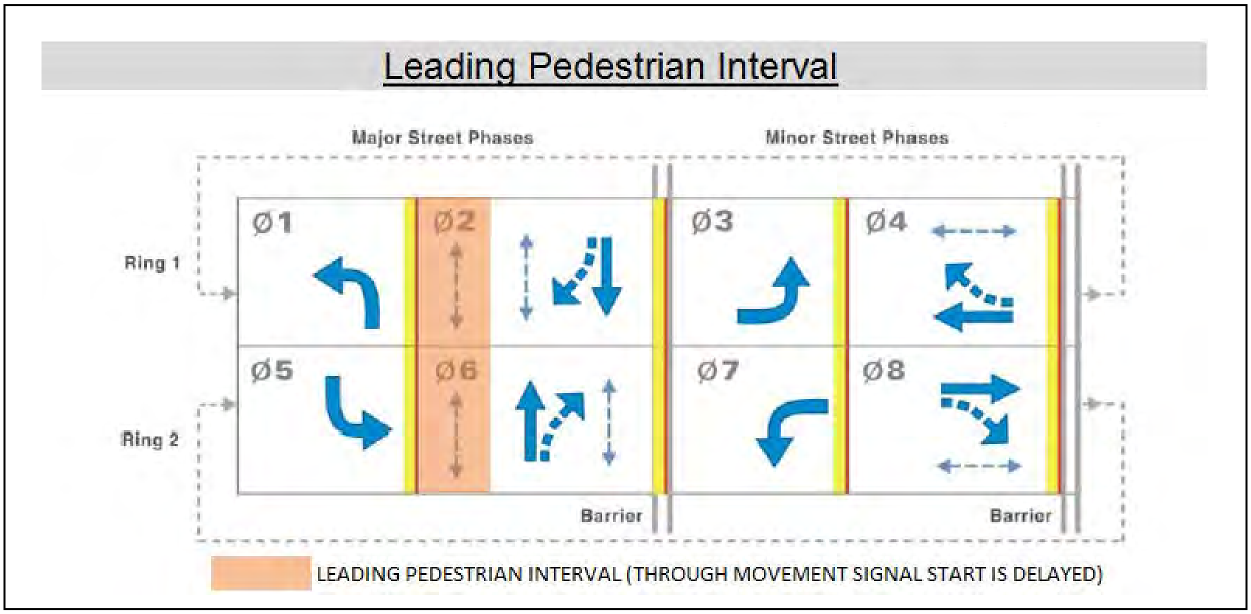


Figure 7.17 – Leading Pedestrian Interval
Source: Traffic Signal Timing Manual



7.5 Traffic Signal Timing

Proper signal timing is essential to the efficient operation of a signalized intersection. The determination of appropriate user phase timings (vehicular, pedestrian, bicycle, and/or preferential treatment) and the determination of appropriate clearance timings constitutes the basics of signal timing. It is important to note that the process of signal timing is not exact. There is not a one-size-fits-all method for signal timing. Practitioners should seek an outcome-based approach for signal timing, observing the operating environment, user priorities, and local operational objectives. Therefore, signal timing involves judgmental elements and represents true engineering design in a most fundamental way. It is practically impossible to develop a complete and final signal timing plan that will not be subject to subsequent fine tuning. No straightforward signal design and timing process can completely include and fully address all of the potential complexities that may exist in any given situation. The yellow change interval and the red clearance interval plus the pedestrian phase timings are traffic signal parameters that are calculated independent of mode of operation. However, the cycle length and individual phase green timing parameters may vary depending on the mode of operation. The following sections address initial signal timing considerations and provide guidelines on typical traffic signal timing controller parameters for different modes of operation.

7.5.1 TDOT's Role

Unless otherwise specified, TDOT typically provides basic traffic signal timings designed to allow the safe system startup of a signalized intersection project. Local agencies can provide initial signal timings with agreement from TDOT. Startup signal timing should emphasize safety over efficiency and be based on traffic volumes expected for the three years following completion of construction.

7.5.2 Traffic Signal Timing Considerations

Practitioners should initially consider the following basic information that may affect traffic signal timing:

- **Location:** Signalized intersections may be located in rural, suburban, or urban environments, requiring different signal timing objectives for each location. Rural areas typically experience isolated intersections with higher speeds and fewer pedestrians, cyclists, and transit vehicles. This scenario would require strategies to accommodate indecision zone issues (See Section 8.5.2). The focus on suburban areas is on achieving smooth flow by minimizing stops along arterials. This scenario would require coordinating intersections and appropriate timing plans to reflect changing traffic patterns. Urban environments, like downtown areas, would typically accommodate all users of the system and shorter cycle lengths may be the desired strategy used in this situation. Practitioners should also understand the roadway classification of the transportation network and identify if the signalized intersection is part of a major freight route, transit route, or has key pedestrian and bicycle crossings. Most important is the notion of a system of traffic signals operating in a corridor across multiple jurisdictions. Operating agencies should coordinate their signal timing efforts to provide users with a seamless transition and consistent operation.

- **Users:** The mix of users at an intersection will influence the operational effectiveness of signal timing. Practitioners should consider the potential multimodal environment at intersections, understanding the relationship and competing needs of light and heavy vehicles, pedestrians, bicycles, emergency vehicles, and transit vehicles. Prioritizing one or a group of users will require trade-offs of other users.

7.5.3 Data Collection

The minimum data requirements for the development of traffic signal timing is similar to the data in the engineering study used to justify the installation of traffic signals (See Section 4.1.1). Being time sensitive, care should be taken regarding the relevance and accuracy of the data used. The following sections detail additional information that can be collected to aid in the development of traffic signal timing.

- **Field Visits:** Practitioners should visit the location and observe the study area during the different times of the day to understand traffic behavior and user interactions. It is informative to drive the corridor and notice critical movements and platoon progression while being attentive to bottlenecks that can potentially influence traffic demand. Queue observation is critical for understanding capacity constrained intersections. Traffic demand may be different than collected traffic volume at such locations.
- **Traffic Counts:** In regards to traffic signal timing, the 24-hour traffic counts provide useful information on:
    - The number of timing plans that should be used during the weekdays and weekends;
    - When to transition from one timing plan to the next;
    - Directional distribution of traffic along the corridor.
- **Existing Traffic Signal Timing and Control Devices:** When retiming a signalized intersection (or group of intersections) is the task at hand, the following information may be helpful to understand the current operational situation:
    - Existing traffic signal head layout;
    - Existing type of traffic signal controller;
    - Existing detector layout and parameter settings;

- Existing timing plan parameter settings (minimum green, maximum green, passage time, pedestrian parameters, clearance parameters, cycle length, splits, offsets, etc.);
- Existing phase sequence (use of overlaps, etc.).

7.5.4 Operational Objectives

The selection of traffic signal operational objectives should reflect user needs and current traffic conditions. Signal timing strategies will change according to the chosen objectives. It is important to note that typical traffic signal timing software has a focus on minimizing system vehicle delay which may not be the desired operational objective. For example, if the operational objective is smooth arterial flow with minimal stops, then the output from a delay minimization software tool may need to be manually adjusted to obtain values that are appropriate for the operational objective. Increasing the cycle length slightly may not correspond to the minimum possible delay, but it may significantly reduce the number of stops. Similarly, when an intersection goes from an undersaturated state to one where demand exceeds capacity, queue management becomes the objective rather than delay minimization. The following operational objectives should be considered (see the *Traffic Signal Timing Manual* for additional objectives):

- **Vehicle Mobility – Capacity Allocation:** Serve vehicle movements as efficiently as possible, while also distributing capacity as fairly as possible across movements and modes. Prioritize movements according to need without excessively delaying other movements.
- **Vehicle Mobility – Corridor Progression:** Move vehicles along high-priority paths (typically along high-volume movements on corridors) as efficiently as possible without excessively delaying other movements.
- **Queue Length Management:** Prevent formation of excessive queues on critical lane groups, such as freeway exit ramps.
- **Pedestrian Safety and Accessibility:** Minimize pedestrian involvement in collisions, reduce pedestrian conflicts, and provide sufficient time for pedestrians to execute movements. Provide the ability for pedestrians, including special needs groups, to execute movements.
- **Pedestrian Mobility:** Serve pedestrian movements as efficiently as possible.

7.5.5 Yellow Change Interval and Red Clearance Interval

The yellow change interval and the red clearance interval (all-red interval) should provide enough time so that the motorist can either stop or proceed safely through the intersection prior to the release of opposing traffic. The purpose of the yellow change interval is to warn the driver that the green interval has ended and that there will be a change in right-of-way at the intersection. A red indication will be displayed immediately thereafter. The purpose of the red clearance interval is to allow time for vehicles that entered the intersection during the yellow change interval to clear the intersection before the display of a conflicting green signal indication. The red clearance interval is an optional signal timing parameter but its use is recommended by TDOT. The *TCA Section 55-8-110* requires a minimum of three seconds for the yellow change interval. The *2009 MUTCD (see Section 4D.26)* recommends that the duration of the yellow change interval and the duration of the red clearance interval shall be determined using engineering practices. The *MUTCD recommends* that the yellow change interval should have a minimum duration of three seconds and a maximum duration of six seconds, and that the red clearance interval should have a duration not exceeding six seconds. The *MUTCD* continues by stating that engineering practices can be found in the ITE *Traffic Control Devices Handbook* and in the ITE *Manual of Traffic Signal Design*. The first part of Equation 7.1 is used to calculate the yellow change interval, while the last part of the equation is used to calculate the all-red clearance interval.

$$CP = \overset{\textbf{Yellow}}{\boxed{t+\frac{1.47V}{2a+64.4g}}} + \overset{\textbf{Red}}{\boxed{\frac{W+L}{1.47V}-1}}$$

Equation 7.1 – Change Interval Formula

Where,

CP = Change Period (yellow change interval plus all-red clearance interval);
t = Perception-Reaction Time (sec), typically assumed to be 1 sec;
v = Approach Speed (mph), typically the posted speed limit;
a = Average Deceleration Rate (ft/sec^2), typically assumed to be 10 ft/sec^2;
g = Approach Grade (±%grade/100), plus for upgrade, minus for downgrade;
W = Intersection Width (ft);
L = Vehicle Length (ft), typically assumed to be 20 ft.

***Note*: The *NCHRP Report 731 – Guidelines for Timing Yellow and Red Intervals at Signalized Intersections* recommends the following guidelines regarding the use of Equation 7.1:**

When calculating the yellow change interval:

- For through movements, the approach speed (v) should be the 85th percentile speed determined under free flow conditions. If a speed study is unavailable, the approach speed (v) can be estimated as the posted speed limit plus seven mph.
- For left-turn movements, the approach speed (v) should be set at the posted speed limit minus five mph.

Tables 7.4 and 7.5 present the calculated and recommended values, respectively, for the yellow change interval based on Equation 7.1 for a 0% approach grade. If other approach grades are being considered, the designer should use Equation 7.1 accordingly.

Table 7.4 – Calculated Yellow Change Intervals (Based on 0% Approach Grade)

Approach Speed (MPH)	Calculated Yellow Change Interval (Seconds)		
	Through Movement		Left Turn Movement
	85th Percentile	(Posted Speed + 7 mph)	[Posted Speed – 5 mph]
20 (27) [15]	3.0*	3.0*	3.0*
25 (32) [20]	3.0*	3.4	3.0*
30 (37) [25]	3.2	3.7	3.0*
35 (42) [30]	3.6	4.1	3.2
40 (47) [35]	3.9	4.5	3.6
45 (52) [40]	4.3	4.8	3.9
50 (57) [45]	4.7	5.2	4.3
55 (62) [50]	5.0	5.6	4.7
60 (67) [55]	5.4	5.9	5.0
65 (72) [60]	5.8	6.0* (Add 0.5 seconds to red clearance)	5.4

* MUTCD minimum (3.0 seconds) and maximum (6.0 seconds) values.

Table 7.5 – Recommended Yellow Change Intervals (Based on 0% Approach Grade)

Approach Speed (MPH)	Recommended Yellow Change Interval (Seconds)		
	Through Movement		Left Turn Movement
	85th Percentile	(Posted Speed + 7 mph)	[Posted Speed – 5 mph]
20 (27) [15]	3.0*	3.0*	3.0*
25 (32) [20]	3.0*	3.5	3.0*
30 (37) [25]	3.5	4.0	3.0*
35 (42) [30]	4.0	4.5	3.5
40 (47) [35]	4.0	4.5	4.0
45 (52) [40]	4.5	5.0	4.0
50 (57) [45]	5.0	5.5	4.5
55 (62) [50]	5.0	6.0*	5.0
60 (67) [55]	5.5	6.0*	5.0
65 (72) [60]	6.0*	6.0* (Add 0.5 seconds to red clearance)	5.5

* MUTCD minimum (3.0 seconds) and maximum (6.0 seconds) values.

When calculating the red clearance interval:

- For through movements, the intersection width (W) should be measured from the upstream edge of the approaching movement stop line to the far side of the intersection, as defined by the extension of the curb line or outside edge of the farthest travel lane;
- For left-turn movements, the intersection width (W) should be the length of the approaching vehicle's turning path measured from the upstream edge of the approaching movement stop line to the far side of the intersection cross street, as defined by the extension of the curb line or outside edge of the farthest travel lane.
- For through movements, the approach speed (v) is the same approach speed used to calculate the yellow change interval;
- For left-turn movements, the approach speed (v) should be set at 20 mph regardless of the posted speed limit.
- The one second is deducted from the red clearance time result in Equation 7.1 to account for the delay that is typically exhibited by the lead vehicle waiting on the conflicting approach to react to the green signal display and begin moving forward. The designer has the option to add this one second back to the red clearance time result.
- Use a minimum of one second.

Table 7.6 presents the calculated values for the 85th percentile speed red clearance interval based on Equation 7.1 for a 0% approach grade. If other approach grades are being considered, the designer should use Equation 7.1 accordingly. Table 7.7 presents the recommended values for the 85th percentile speed red clearance interval for a 0% approach grade based on recommendations from *The NCHRP Report 731 – Guidelines for Timing Yellow and Red Intervals at Signalized Intersections*.

Table 7.6 – Calculated 85th Percentile Speed Red Clearance Intervals (Based on 0% Approach Grade)

Approach Speed (MPH)	Calculated 85th Percentile Speed Red Clearance Interval (Seconds)									
	Intersection Width (Feet)									
	30	40	50	60	70	80	90	100	110	120
20	0.7	1.0	1.4	1.7	2.1	2.4	2.7	3.1	3.4	3.8
25	0.4	0.6	0.9	1.2	1.4	1.7	2.0	2.3	2.5	2.8
30	0.1	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.9	2.2
35	-	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7
40	-	-	0.2	0.4	0.5	0.7	0.9	1.0	1.2	1.4
45	-	-	0.1	0.2	0.4	0.5	0.7	0.8	1.0	1.1
50	-	-	-	0.1	0.2	0.4	0.5	0.6	0.8	0.9
55	-	-	-	-	0.1	0.2	0.4	0.5	0.6	0.7
60	-	-	-	-	-	0.1	0.2	0.4	0.5	0.6
65	-	-	-	-	-	-	0.2	0.3	0.4	0.5

Table 7.7 – Recommended 85th Percentile Speed Red Clearance Intervals (Based on 0% Approach Grade)

Approach Speed (MPH)	Recommended 85th Percentile Speed Red Clearance Interval (Seconds)									
	Intersection Width (Feet)									
	30	40	50	60	70	80	90	100	110	120
20*	1.0	1.0	1.5	2.0	2.5	2.5	3.0	3.5	3.5	4.0
25	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	3.0
30	1.0	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5
35	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5	1.5	2.0
40	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5
45	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5
50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
55	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
65	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

In addition to the 85th percentile speed values, Table 7.8 presents the calculated values for the posted speed + 7 mph red clearance interval based on Equation 7.1 for a 0% approach grade. If other approach grades are being considered, the designer should use Equation 7.1 accordingly. Table 7.9 presents the recommended values for the posted speed + 7 mph red clearance interval for a 0% approach grade based on recommendations from *The NCHRP Report 731 – Guidelines for Timing Yellow and Red Intervals at Signalized Intersections*.

Table 7.8 – Calculated Posted Speed + 7 MPH Red Clearance Intervals (Based on 0% Approach Grade)

Approach Speed (MPH)	Calculated (Posted Speed + 7 MPH) Red Clearance Interval (Seconds)									
	Intersection Width (Feet)									
	30	40	50	60	70	80	90	100	110	120
20 (27)	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5
25 (32)	0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.8	2.0
30 (37)	-	0.1	0.3	0.5	0.7	0.8	1.0	1.2	1.4	1.6
35 (42)	-	-	0.1	0.3	0.5	0.6	0.8	0.9	1.1	1.3
40 (47)	-	-	-	0.2	0.3	0.4	0.6	0.7	0.9	1.0
45 (52)	-	-	-	-	0.2	0.3	0.4	0.6	0.7	0.8
50 (57)	-	-	-	-	0.1	0.2	0.3	0.4	0.6	0.7
55 (62)	-	-	-	-	-	0.1	0.2	0.3	0.4	0.5
60 (67)	-	-	-	-	-	-	0.1	0.2	0.3	0.4
65 (72)	-	-	-	-	-	-	-	0.1	0.2	0.3

Table 7.9 – Recommended Posted Speed + 7 MPH Red Clearance Intervals (Based on 0% Approach Grade)

Approach Speed (MPH)	Recommended (Posted Speed + 7 MPH) Red Clearance Interval (Seconds)									
	Intersection Width (Feet)									
	30	40	50	60	70	80	90	100	110	120
20 (27)	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5
25 (32)	1.0	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.0
30 (37)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5	2.0
35 (42)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5
40 (47)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
45 (52)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
50 (57)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
55 (62)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60 (67)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
65 (72)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

When there are unique conditions that may warrant modifying the parameters for calculating the yellow change and red clearance intervals, engineering judgment may be applied and documented with supporting information justifying the modifications.

- **Clearance Intervals and Left-Turn Phasing Considerations** – _NCHRP Report 731_ recommends that when calculating yellow change and red clearance intervals for left-turning vehicles, signal phasing should ideally be considered as follows:
    - For protected-only left-turn movements, the yellow and red intervals shall be calculated for each approach and implemented as calculated. The intervals do not have to be the same duration for opposing approaches.
    - For permissive-only left-turn movements, the yellow and red intervals shall be calculated for opposing approaches, including the through movements. The implemented intervals shall be the longest of the calculated values (left, through, or combination). The intervals shall be the same duration for the left-turn and through movements on opposing approaches to ensure that termination is concurrent.
    - For protected/permissive left-turn movements, the yellow and red intervals shall be calculated and implemented as described above for the respective protected and permissive portions of the phase.

7.5.6 Pedestrian Signal Timing Parameters

There are two parameters that need to be programmed on the controller to adequately serve pedestrians: the walk interval and the pedestrian change interval (i.e. FDW interval).

- **Walk Interval:** The walk interval typically begins at the start of the concurrent vehicular green interval and is timed so that a pedestrian that has pushed the pushbutton can leave the curb or shoulder and enter the crosswalk. The _MUTCD_ states that the walk interval should be at least seven seconds long. The _MUTCD_ allows the walk interval to be as low as four seconds if an engineering study demonstrates that, due to pedestrian volumes and intersection capacity constraints, there is no need for the full seven seconds to be used. In areas with higher pedestrian volumes (i.e. school zones, downtown areas, sport and entertainment venues, etc.) the walk interval may be longer (10 to 15 seconds) to allow all waiting pedestrians to enter the crosswalk before the walk interval concludes.
- **Flashing Don't Walk Interval:** The FDW interval (i.e. pedestrian change interval) is derived from the pedestrian clearance time. The _MUTCD_ states that the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk, who left the curb or shoulder at the end of the walk interval, to travel at a walking speed of 3.5 feet per second

to at least the far side of the traveled way (or to a median of sufficient width for pedestrians to wait). The pedestrian clearance time can be calculated using Equation 7.2.

$$PCT = \frac{D_c}{v_p}$$

Equation 7.2 – Pedestrian Clearance Time

Where,

PCT = Pedestrian Clearance Time (seconds);

D_c = Pedestrian Crossing Distance (feet);

v_p = Pedestrian Walking Speed (feet per second).

The *MUTCD* recommends that, where there are pedestrians who walk slower than 3.5 feet per second and/or pedestrians who use wheelchairs routinely at a crosswalk, a walking speed of less than 3.5 feet per second should be considered in determining the pedestrian clearance time. The group of pedestrians who walk slower than 3.5 feet per second may be represented by young children, the elderly, or the physically impaired. For these situations, the *ADA Accessibility Guidelines* recommend the use of three feet per second.

The *MUTCD* also requires the steady don't walk indication to be displayed following the FDW interval for at least three seconds prior to the release of any conflicting vehicular movement (buffer interval). Typically, the buffer interval will be the yellow change interval plus the red clearance interval. Therefore, the pedestrian change interval (i.e. FDW interval) can be determined from Equations 7.3 through 7.5.

- $FDW = PCT - Y$ (Equation 7.3)
- $FDW = PCT - (Y + R)$ (Equation 7.4)
- $FDW = PCT$ (Equation 7.5)

Equations 7.3 through 7.5 – Pedestrian Change Intervals

Where,

FDW = Flashing Don't Walk (seconds);

PCT = Pedestrian Clearance Time (seconds);

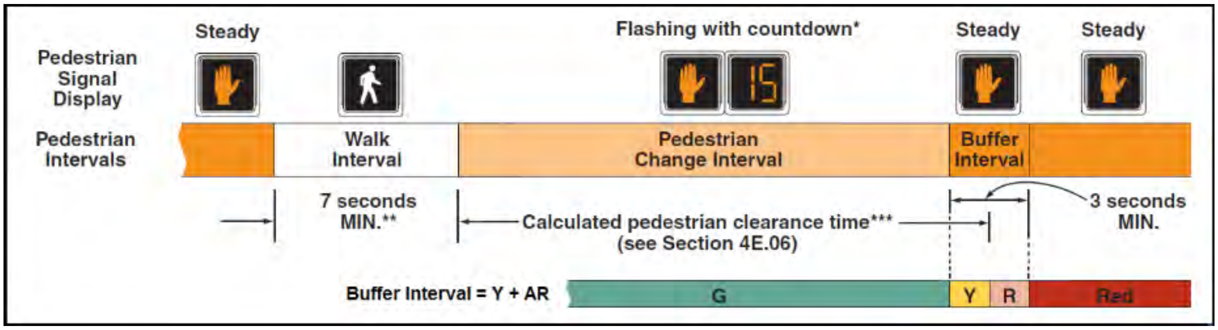
Y = Yellow Change Interval (seconds);

R = Red Clearance Interval (seconds).

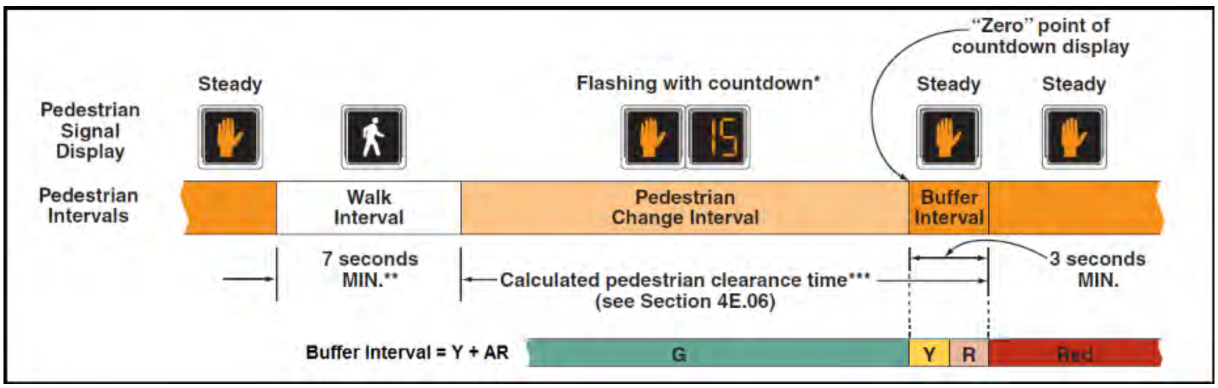
Equation 7.3 is preferred for most intersections; Equation 7.4 may be considered if there are capacity constraints in the intersection; and Equation 7.5 should be considered if there are special pedestrian crossing needs. The minimum recommended flashing don't walk interval is four seconds to account for pedestrian expectancy. FDW times should be rounded up to the nearest integer value. Figure 7.18 illustrates the three available pedestrian timing strategies.

Figure 7.18 – Pedestrian Intervals

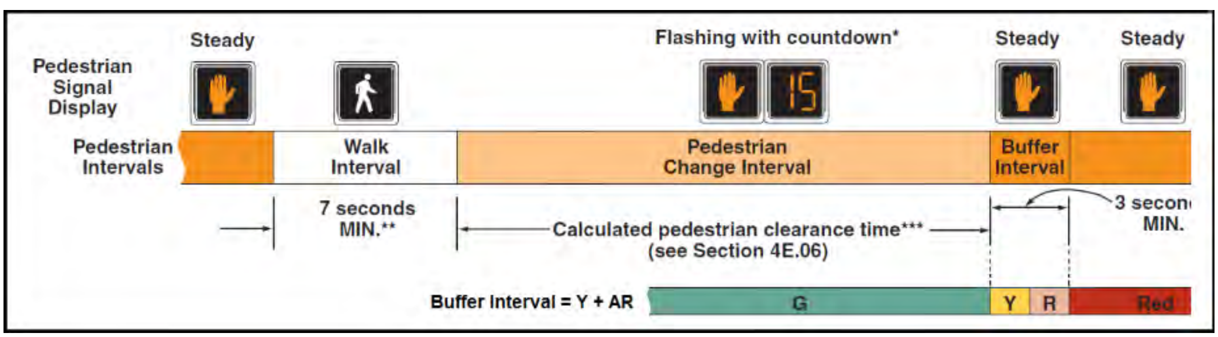
Source: 2009 MUTCD



FDW = PCT – Y (Equation 7.3)



FDW = PCT – (Y + R) (Equation 7.4)



FDW = PCT (Equation 7.5)

* The countdown display is optional for Pedestrian Change Intervals of 7 seconds or less.

** The Walk Interval may be reduced under some conditions (see Section 4E.06).

*** The Buffer Interval, which shall always be provided and displayed, may be used to help satisfy the calculated pedestrian clearance time, or may begin after the calculated pedestrian clearance time has ended.

G = Green Interval
Y = Yellow Change Interval (of at least 3 seconds)
R = Red Clearance Interval
Red = Red because conflicting traffic has been released
PCT = Pedestrian Clearance Time

The traffic signal controllers' timing tables require the input of a minimum of two pedestrian parameters: the walk interval and the pedestrian clearance interval. Practitioners should be cautious since the programmable pedestrian clearance interval is, in reality, the FDW interval calculated in Equations 7.3, 7.4, or 7.5.

The *MUTCD* guidance states that the combined sum of the walk interval plus the pedestrian clearance time should also be adequate to allow a pedestrian walking at a speed of three feet per second to travel from the location of the pedestrian detector (or if no detector is present, a location six feet from the edge of curb or pavement) to the far side of the traveled way or the median.

7.5.7 Pre-timed (Fixed Time) Operation Signal Timing Parameters

Pre-timed (fixed time) operation requires the calculation of the yellow change and red clearance intervals (See Section 7.5.5), walk and pedestrian clearance intervals (See Section 7.5.6), plus a cycle length and phase green times for each timing plan to be used throughout the day.

- **Cycle Length for Pre-timed Operation:** A cycle length is the total time required for a complete sequence of signal indications. Cycle length calculation is not standardized, and many different techniques are used to estimate its value. Typically, the cycle length needed to accommodate all of the vehicles at an intersection is estimated by identifying the movements that require the most time using the critical movement analysis. The critical movement analysis is a simplified technique based on the principal that for each phase, one of the movements will have the maximum traffic volume per lane (critical lane volume). If a phase is long enough to discharge the vehicles in the critical lane, then all vehicles in additional lanes serviced by the same phase will be discharged as well. Therefore, to estimate a cycle length, it is necessary to know the sum of the critical lane volumes (sample calculations of the critical movement analysis can be found in the *Traffic Signal Timing Manual*). Practitioners can then use the Webster formula in Equation 7.6 to estimate the cycle length:

$$C = \frac{1.5\,L + 5}{1.0 - Y}$$

Equation 7.6 – Webster's Cycle Length Estimate

Where,

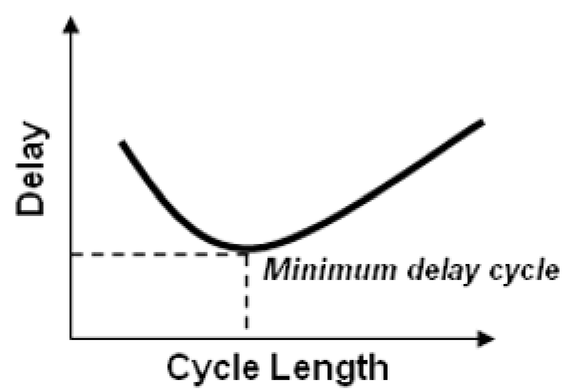
C = Optimum, minimum delay cycle length (seconds);
L = Lost time per cycle (seconds);
Y = Sum of the critical lane volumes divided by saturation flow rate.

Notes on Lost Time and Saturation Flow Rate:

- Lost time is defined as the portion of time at the beginning of each green interval (start-up lost time) and a portion of each yellow change plus red clearance intervals that is not used by vehicles. The *HCM* states:
    - Lost time = start-up lost time + clearance lost time;
    - Start-up lost time = two seconds per phase;
    - Clearance lost time = yellow change interval + red clearance interval – two seconds (assumed time motorists' use of yellow change and red clearance intervals).
- Saturation Flow Rate is defined as the maximum flow rate, that the conditions will allow, at which vehicles can traverse an intersection approach. The *HCM* states that saturation flow rate should be:
    - 1,900 pc/h/l (passenger cars per hour per lane) for metropolitan areas with population ≥ 250,000 people;
    - 1,750 pc/h/l for areas with population < 250,000 people.

When using the Webster formula, it is good practice to round the result up to the nearest multiple of five (i.e. 70, 75, 80, etc.). It is also important to recognize that, even though the result is theoretically an optimal minimum delay cycle as shown in Figure 7.19, the final intersection cycle length is dependent on pedestrian requirements and coordination requirements (See Sections 7.5.6 and 7.6, respectively).

Figure 7.19 – Webster's Minimum Delay Cycle



As a general rule, cycle lengths should be established at the lowest value that accommodates the required user demand. Longer cycle lengths theoretically increase the capacity of the intersection when considering all lanes operate under saturated flow rates. Longer cycle lengths can also increase queue length, potentially leading to turn bay storage being exceeded or access being blocked.

- **Phase Green Time for Pre-timed Operation:** The green time for each individual phase in an intersection can be calculated using the critical movement analysis. It is necessary to subtract the sum of all individual phases' change period (yellow change and red clearance times) from the calculated cycle length (Equation 7.7). The result is the available time that can be apportioned between all phases' green intervals. Then, Equation 7.8 is used to determine each individual phase green interval.

$$A_t = C - (\sum CP_i)$$

Equation 7.7

$$G_i = \frac{V_A}{V_T} \text{ x } A_t$$

Equation 7.8

Apportion All Phases' Green Intervals

Where,

A_t = Available time to apportion between all phases' green interval (sec);

C = Calculated cycle length (sec);

CP_i = Change Period (yellow change interval plus red clearance interval) for each phase (sec);

G_i = Phase green interval for each phase (sec);

V_A = Critical lane volume for phase i (vph or pc/h/l);

V_T = Sum of critical lane volumes for all phases (vph or pc/h/l).

Table 7.10 presents minimum values for phase green intervals for pre-timed (fixed) operation.

Table 7.10 – Minimum Values for Phase Green Intervals for Pre-timed Operation

Movement Type	Minimum Value for Phase Green Interval (Seconds)
Major Street Through (Speed Limit > 40 mph)	25
Major Street Through (Speed Limit ≤ 40 mph)	15
Major Street Left-Turn	5
Minor Street Through	10
Minor Street Left-Turn	5

The pedestrian timing requirements must be considered when determining the phase green time for pre-timed (fixed) operation. The concurrent phase green time shall be equal to or greater than the pedestrian timing requirements, independent of the presence of pedestrian signal heads. When phase green times estimated by the critical movement analysis are made longer due to pedestrian timing requirements, it is good practice to "rebalance" the green time of all additional phases to accommodate its potential additional demand. Furthermore, practitioners should consider extending the walk interval when the concurrent phase green time is greater than the pedestrian requirements.

7.5.8 Actuated Phase Operation Signal Timing Parameters

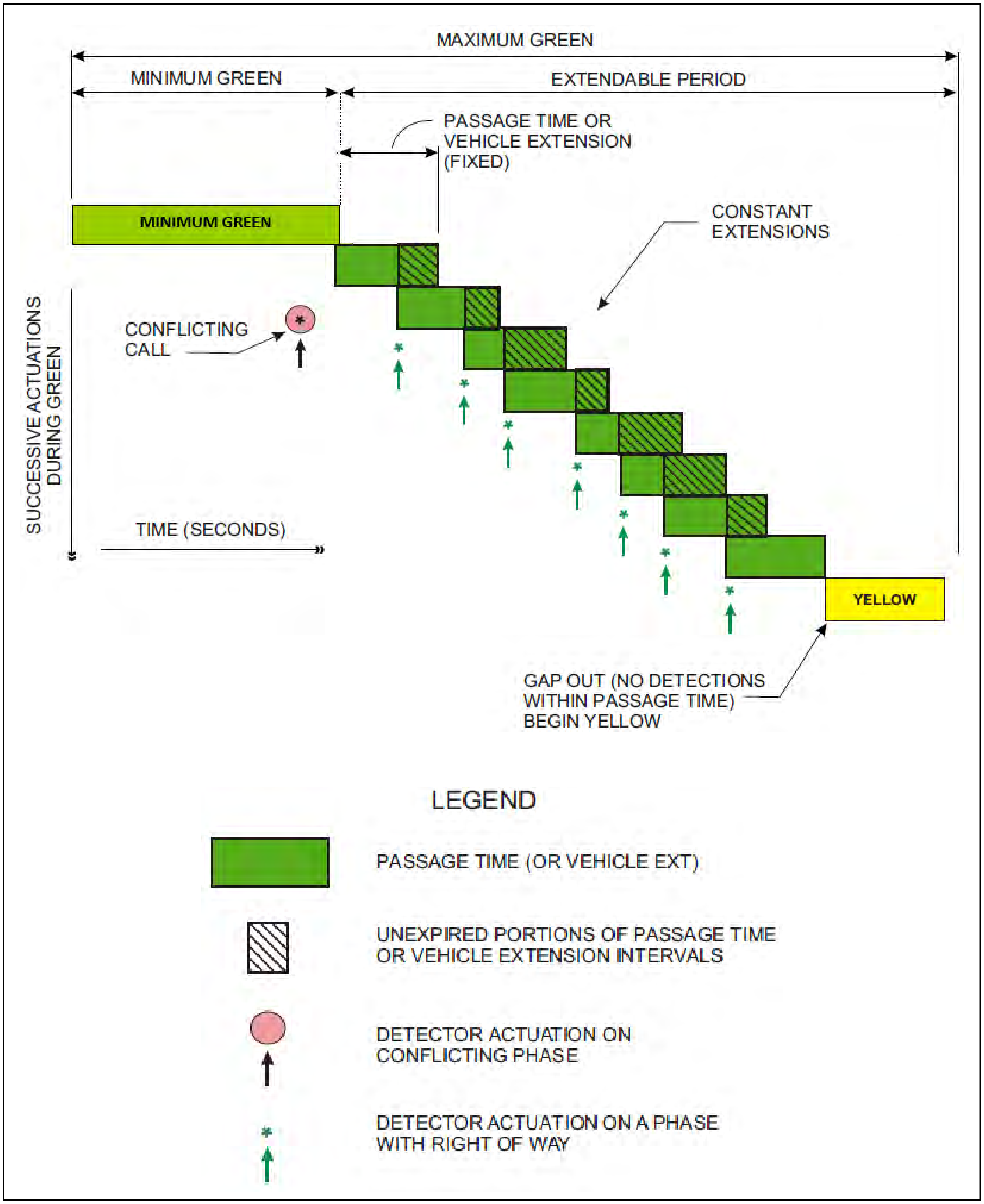
Actuated operation requires the calculation of the yellow change and red clearance intervals (See Section 7.5.5), walk and pedestrian clearance intervals (See Section 7.5.6) plus a minimum green, a maximum green, and a passage time for each timing plan to be used throughout the day. Figure 7.20 illustrates the relationship between actuated operation parameters.

- **Minimum Green Guidelines:** The minimum green parameter represents the least amount of time that a green signal indication will be displayed when a phase is called. The minimum green should be set to meet driver expectancy, but its duration may also be based on considerations of detection design or pedestrian timing requirements.
  - **Driver Expectancy:** The minimum green setting is intended to ensure that the green interval that is displayed is sufficiently long to allow the waiting queue enough time to perceive and react to the green indication. A minimum green that is too short may violate driver expectations, increasing the potential for rear-end crashes. Table 7.11 lists typical values for different facility types.

Table 7.11 – Typical Minimum Green Values Needed to Satisfy Driver Expectancy

Phase Type	Facility Type	Minimum Green Values Needed to Satisfy Driver Expectancy (Seconds)
Through	Major Arterial (Speed Limit > 40 mph)	10 to 15
	Major Arterial (Speed Limit ≤ 40 mph)	7 to 15
	Minor Arterial, Collector, Local, Driveway	5 to 10
Left-Turn	Any	5

Figure 7.20 – Actuated Phase Operation Parameters



- **Queue Clearance:** The duration of the minimum green can also be influenced by detector location. When no stop line detection is used and only advance detection is available, the minimum green setting shall be sufficiently long to allow vehicles queued between the stop line and the nearest advance detector to clear the intersection (to avoid vehicle(s) getting caught in the subject area and not being serviced). For this scenario, the minimum green can be calculated using a combination of Equations 7.9 and 7.10.

$$G_q = 3 + 2n$$

Equation 7.9

$$n = \frac{d}{L_v}$$

Equation 7.10

Minimum Green Duration for Queue Clearance

Where,

G_q = Minimum green duration for queue clearance (seconds);

n = number of vehicles between stop line and nearest advance detector in one lane;

d = distance between the stop line and the downstream edge of the nearest detector (feet);

L_v = length of average vehicle plus spacing between vehicles, assumed to be 25 feet

Table 7.12 lists typical values for minimum green for queue clearance. It is important to notice that the calculated minimum green time may lead to very inefficient intersection operations with low vehicular demand. Therefore, the use of Volume Density Variable Initial (See Section 7.8.1) is recommended.

Table 7.12 – Typical Minimum Green Values Needed to Satisfy Queue Clearance

Setback Detector Placement Distance from Stop Line (Feet)	n*	Minimum Green Values Needed to Satisfy Queue Clearance (Seconds)**
285	11	25
325	13	29
365	14	32
405	16	35
445	18	38
485	19	41

*n is calculated using setback detector size of 6x6 feet.

**Use volume density variable initial to minimize inefficient operation.

- **Pedestrian Timing Requirements:** The pedestrian timing requirements must be considered when determining the minimum green time for actuated operation. First, if no pedestrian signal heads are present, the minimum green time shall be equal to or greater than the pedestrian timing requirements. Where pedestrian signal heads are present, practitioners should explore controller capabilities when deciding on the minimum green parameter. Older technology requires the minimum green time to be equal to or greater than the pedestrian timing requirements. Newer technology allows the minimum green time to be calculated for vehicular needs and the controller logic will automatically extend the minimum green time (to meet pedestrian requirements) upon activation of the pushbutton, providing more efficient operation.

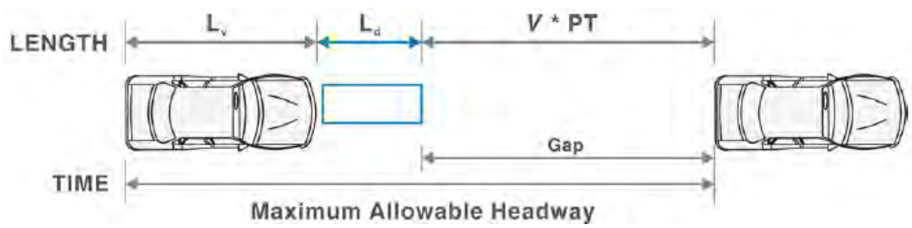
- **Maximum Green Guidelines:** The maximum green parameter represents the maximum amount of time that a green signal indication can be displayed in the presence of a serviceable conflicting call or another phase on recall. One common practice to estimate values for each phase maximum green parameter is to multiply the results for phase green time calculated using the critical movement analysis (See Section 7.5.7) by a factor of 1.25 to 1.50. With that, the maximum green has the potential to exceed the green duration to serve the typical maximum queue and thereby allow the phase to accommodate peaks in demand. Table 7.13 lists typical ranges for maximum green duration for different facility types. These values should be used as a starting point and adjusted based on field conditions.

Table 7.13 – Typical Values for Maximum Green

Phase Type	Facility Type	Maximum Green (Seconds)
Through	Major Arterial (Speed Limit > 40 mph)	50 to 70
	Major Arterial (Speed Limit ≤ 40 mph)	40 to 60
	Minor Arterial, Collector	30 to 50
	Local, Driveway	20 to 40
Left-Turn	Any	15 to 30

- **Passage Time Guidelines:** The passage time parameter represents a controller function that extends the green signal indication beyond the minimum green time up to the maximum green time. It operates through a timer that starts to count down (from a user defined value) from the instant a detector is not occupied and is reset to its initial value with each subsequent actuation if it has not yet expired. If a conflicting call exists on another phase, the phase will gap out when the passage timer expires before the maximum green time is reached. The phase will max out when there is enough demand to continue to extend the phase up to the maximum green time. If a conflicting call does not exist on another phase, the current phase *rests* in green. Passage time is also known as vehicle extension time or gap time. Practitioners should refer to traffic signal controller manuals to determine the appropriate parameter to be programmed. It is critical to understand that passage time is directly related to efficiency at a signalized intersection. A passage time of two seconds would theoretically maintain a flow rate of 1,800 vehicles per hour. A passage time of three seconds would theoretically maintain a flow rate of 1,200 vehicles per hour. Therefore, as the passage time increases, the amount of inefficient flow increases because of acceptable larger headways and because of *lost time* generated when the traffic signal remains green for the length of the selected passage time after the last vehicle is detected (stop line scenario). The objective when determining the passage time value is to make it large enough to ensure that all vehicles in a moving queue are served but to not make it so large that it extends the green for randomly arriving traffic. The appropriate passage time used for a particular signal phase is dependent on many considerations, including: number of detection zones per lane, location of each detection zone, detection zone length, detection operating mode, and approach speed (See Chapter 8). Ideally, the detection design is established and the passage time is determined so that the "detection system" provides efficient queue service and, for high-speed approaches, safe phase termination.

- **Passage time for stop line detection:** Equation 7.11 can be used to calculate the passage time for stop line detection (presence mode).



$$PT = MAH - \frac{L_v + L_d}{1.47\,v}$$

Equation 7.11 – Passage Time

Where,

PT = Passage Time (sec);

MAH = Maximum Allowable Headway (sec), use 3 seconds;

L_v = Length of Vehicle (use 20 feet);

L_d = Length of Detection Zone (feet);

v = Approach Speed (mph) (the Posted Speed Limit is Recommended).

For stop line detection, the longer the detection zone length, the shorter the passage time, thus providing snappier operation. Table 7.14 lists typical passage time values for stop line detection based on Equation 7.11. These values should be used as a starting point and adjusted based on field conditions.

Table 7.14 – Typical Values for Passage Time for Stop Line Detection

Detection Zone Length (Feet)	Passage Time (Seconds) for Approach Speed (mph)*				
	25**	30	35	40	45
20	1.9	2.1	2.2	2.3	2.4
25	1.8	2.0	2.1	2.2	2.3
30	1.6	1.9	2.0	2.1	2.2
35	1.5	1.8	1.9	2.1	2.2
40	1.4	1.6	1.8	2.0	2.1
45	1.2	1.5	1.7	1.9	2.0
50	1.1	1.4	1.6	1.8	1.9
55	1.0	1.3	1.5	1.7	1.9
60	0.8	1.2	1.4	1.6	1.8
65	0.7	1.1	1.3	1.6	1.7
70	0.5	1.0	1.2	1.5	1.6
75	0.4	0.8	1.1	1.4	1.6
80	0.3	0.7	1.1	1.3	1.5

*The passage time may be increased by up to 1.0 second if the approach is on a steep upgrade and/or there is a large percentage of heavy vehicles.

**For left-turn movements, use an approach speed of 25 mph.

- **Passage Time for Advance Detection:** Advance detection is typically used for indecision zone protection (See Section 8.5.2). Here, the passage time parameter should extend the green interval long enough for a vehicle to clear the indecision zone. A passage time of 3.5 seconds is typically sufficient to clear a vehicle for the indecision zones presented in Table 8.3, independent of approach speed. It is necessary to note that no extend parameter or volume density gap reduction (See Section 7.8.1) is used in combination with the recommended passage time. When a combination of stop line detection and advance detection is available at an intersection, typically the queue detector parameter is used and the passage time of 3.5 seconds is set for the advance detection.

7.6 Traffic Signal Coordination

Coordination can be defined as the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system. The following sections explore coordination objectives and fundamentals, introduce coordination parameter guidelines, and discuss coordination complexities.

7.6.1 Traffic Signal Coordination Objectives

The latest *National Traffic Signal Report Card* states a common objective for the coordination of traffic signals:

> *"The intent of coordinating traffic signals is to provide smooth flow of traffic along streets and highways in order to reduce travel times, stops and delay."*

In addition, coordination may be used to maximize throughput on a corridor during specific times of the day. Practitioners should be aware that typical software programs have a focus on system vehicle delay, which may not be the selected operational objective for coordination. Well-timed coordination systems may also be beneficial to reduce driver frustration, improve safety (less stops resulting in less rear-end crashes), and to reduce fuel consumption and emissions.

7.6.2 Fundamentals of Traffic Signal Coordination

The understanding of the following concepts and tools are fundamental for traffic signal coordination design.

- **Determining Intersections to be Included in the System:** Determining which intersections should be included in a coordinated system is important. Typically, intersections spaced within ½ mile of each other will benefit from coordination, especially during periods of large traffic demand when platoons of vehicles may form. Intersections spaced one mile or more apart may benefit from coordination if there is minimal access turbulence on segments. Otherwise, Equation 7.12 can be used to calculate the coupling index to assist in the decision process.

$$CI = \frac{V}{L}$$

Equation 7.12 – Coupling Index

Where,

CI = coupling index;

V = two-way traffic volume on the street to be coordinated (vehicles/hour);

L = segment length (feet), measured between the center of the subject intersection and the center of the adjacent signalized intersection.

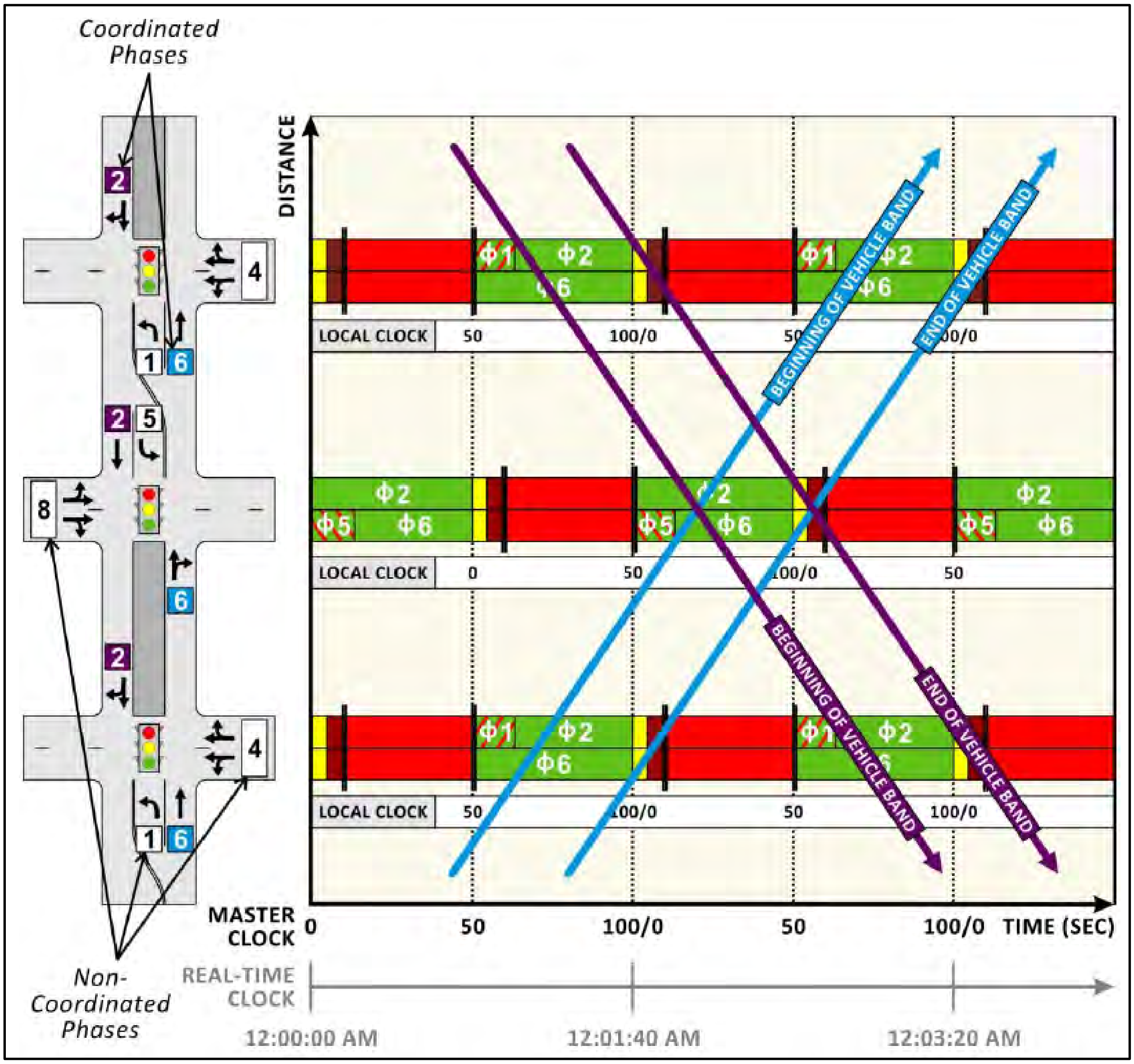
The coupling index should be analyzed for specific traffic conditions during different times of the day based on the scale below. Adjacent segments that have an index of 0.5 or more are considered for grouping in the signal system.

- 0.3 or less: unlikely to benefit from coordination;
- 0.3 to 0.5: segment likely to benefit if mid-segment access point activity is low and turn-bays are provided on the major street at each signalized intersection;
- 0.5 or more: likely to benefit from coordination.

It is important to notice that the system cycle length (See Section 7.6.3) may also end up influencing which signalized intersections should be included in the system. As additional intersections are added to a system, it becomes increasingly difficult to provide progression. Sometimes it is better to break a long corridor into smaller segments. Typically, the “stop” location should be where there is adequate distance between intersections to provide storage for vehicles without impacting the upstream intersection.

- **Coordinated Phases:** Coordination requires the designation of a phase or multiple phases as the coordinated phase(s). They are selected (toggled) at a specific traffic signal controller menu and all other phases being used at the intersection are automatically set as non-coordinated phases. Coordinated phases are distinguished from non-coordinated phases because they are guaranteed a minimum amount of green time every cycle. The guaranteed green interval can be used to maintain the coordinated relationship between intersections.
- **Time-Space Diagrams:** Time-space diagrams are a visual tool that practitioners use to analyze coordination strategies and modify traffic signal timing plans. A time-space diagram focuses on coordinated phases and illustrates the relationship between intersection spacing, signal timing, and vehicle movement. Figure 7.21 illustrates a typical time-space diagram. Basically, time-space diagrams have a graphical representation of distance on the y-axis and time on the x-axis, overlaid by the ring-and-barrier diagram for each intersection. Protected left-turn movements may be represented on each ring-and-barrier by directional hatching. This helps practitioners identify what point in the cycle a vehicle can progress. A very important component of time-space diagrams is to depict vehicle trajectory lines representing movement either north/south or east/west. Flat lines represent stopped vehicles and possible queuing while a diagonal line represents vehicles’ movement at design speed. Furthermore, the master clock and the local clock can also be represented in a time-space diagram. The master clock is the background timing mechanism within the controller logic that starts daily at a pre-defined time, usually midnight (lower traffic volumes). Each local controller clock is referenced to the master clock for coordination to occur.

Figure 7.21 – Time-Space Diagram
Source: Traffic Signal Timing Manual



- **Bandwidth:** By definition, bandwidth is the maximum amount of green time available for a vehicle travelling in a designated direction as it passes through a corridor at an assumed constant speed, typically measured in seconds. Bandwidth is an ideal representation of progression, in that it does not explicitly account for vehicle acceleration from a stop, dispersion of vehicles as they travel from one intersection to the next, or queued vehicles at the downstream intersections. Figure 7.21 illustrates the concept of bandwidth. The *Traffic Signal Timing Manual* provides additional information on bandwidth.

- **System Configurations:** The way that the coordinated system is configured depends on availability of communication at individual intersections. Under time base control, each intersection traffic signal controller works by itself and will be related to each other by the synchronized internal clocks (or external GPS clocks). No physical interconnect exists. Timing plans are developed and entered individually into each controller. Additional maintenance may be required due to drifting of individual controller clocks. Under a closed loop system, each intersection traffic signal controller is interconnected and communicates to an on-street master signal controller (which can be configured to communicate to a central system). Timing plans can be downloaded to individual intersections via the master signal controller. Lastly, a coordinated system may be configured to have all individual intersections communicating directly to a central system. The typical types of interconnection used in coordinated systems are twisted-pair, fiber optic, telephone lines, wireless radio, Ethernet, etc. Current technology enables the ability of interconnected systems to provide extensive system monitoring with data collection, analysis functions, reporting, and status information beyond the usual uploading and downloading of timing settings. It is recommended that signal timing plans reside in the local controllers in the field to avoid potential problems with communication failures.

7.6.3 Traffic Signal Coordination Parameters Guidelines

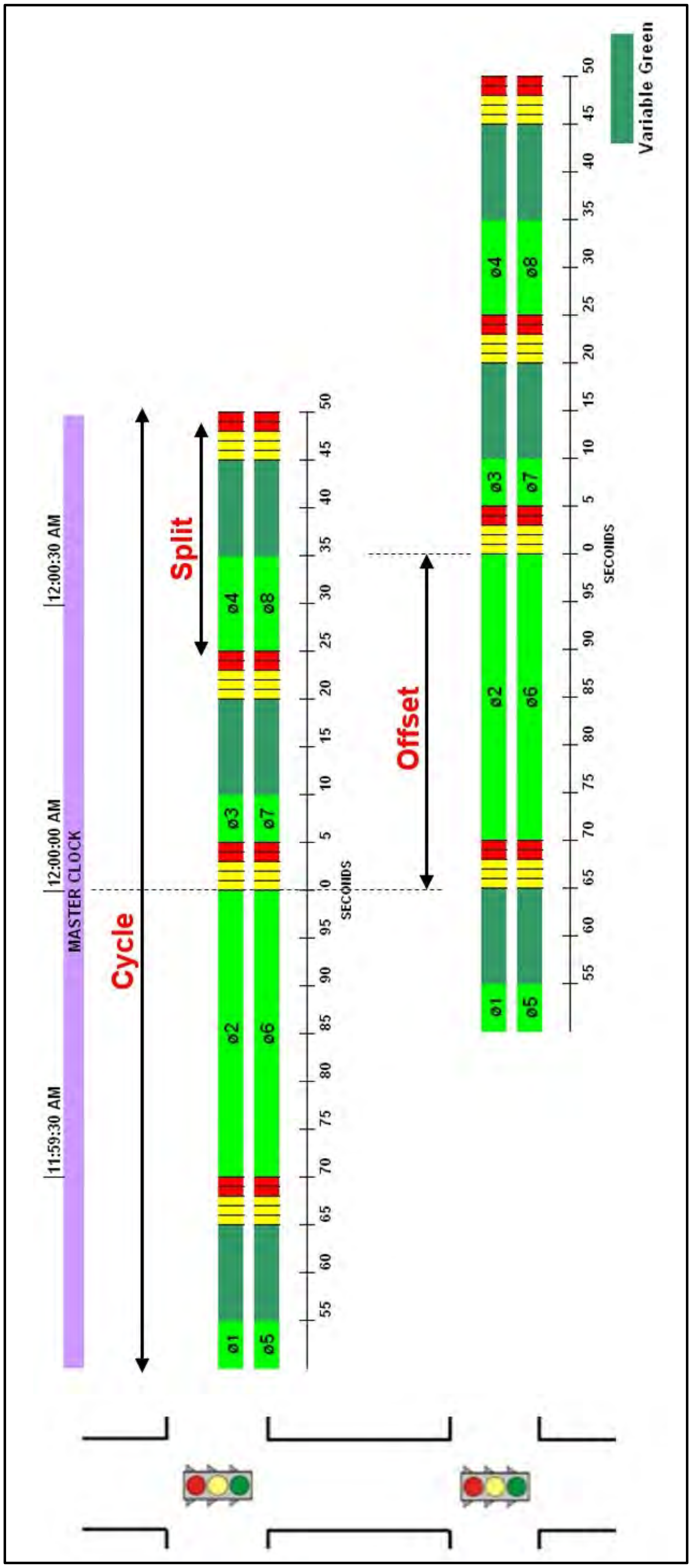
Several traffic signal parameters must be programmed in the traffic signal controller for coordination to work. The following sections provide guidelines regarding system cycle length, splits, offsets, force-offs, and pedestrian parameters.

- **System Cycle Length:** In coordination, all intersections included in a system must have a common cycle length in order to maintain a consistent time-based relationship between intersections. It is known as system cycle. For coordination, traffic signal timing software is typically used to determine appropriate system cycle lengths with data collected at representative periods of the day. Optimization models generally use a given set of inputs (including the range of preferred cycle lengths) and estimated performance measures to determine an optimal solution. Practitioners should have an understanding of desired objectives (See Section 7.6.1) and software limitations. Manual methods for determining system cycle length can also be used in simple networks, like downtown areas, based on constant block spacing. Nevertheless, system cycle lengths are frequently selected to address operations at a critical (or highest volume) intersection in a group of coordinated signalized intersections. It is good practice to perform an analysis on intersections requiring longer cycle lengths to determine if operation would benefit from having the particular intersection operating independently, in full actuated mode. Imposing a long system cycle length may increase overall congestion and delay in the system. A scenario with a smaller intersection requiring a shorter cycle length may benefit by running “double cycles” (half the system cycle length), where phases are serviced twice as often as other intersections in the system.

- **Splits:** Splits are the portion of the system cycle allocated to each phase, including the green interval, yellow change, and red clearance intervals. Splits are selected based on individual intersection phasing and expected demand. Therefore, splits may vary from intersection to intersection. Similarly to system cycle length determination, splits are determined using traffic signal timing software. When implementing splits on a traffic signal controller, the sum of the phase splits must be equal to or less than the programmed cycle length. Some traffic signal controllers will allow splits to be less than pedestrian requirements. This is intended for situations in which there are few pedestrian calls. The traffic signal controller may need to transition (See Section 7.6.4) after servicing a pedestrian call under this scenario.
- **Offsets:** Offset is the time that elapses between the master clock and the offset reference point at each local intersection included in the system. Therefore, each signalized intersection will also have a relative offset to each other. It is through this association that the coordinated phase is aligned between intersections to create the relationship for synchronized movements. The offset reference point is a user defined traffic signal controller parameter that helps structure the relationship between coordinated intersections by defining the point in time when the cycle begins timing. Offsets should be chosen based on the actual or desired travel speed between intersections, distance between signalized intersections, and traffic volumes. In an ideal coordinated system, offsets would allow platoons (leaving an upstream intersection at the start of green) to arrive at a downstream intersection near the start of green, or after the queue from minor streets or driveways discharged (green starts early enough to clear queued vehicles before the platoon arrives). Field observations and software outputs (time-space diagrams) should be used in combination to optimize the system. Figure 7.22 illustrates the relationship between cycle, split, and offset.
- **Force-offs:** Force-offs are used to enforce phase splits, making sure the traffic signal controller logic returns to serve the coordinated phases no later than the programmed time. There are two types of force-offs, fixed and floating, that determine how unused actuated green time on the non-coordinated phases is shared with subsequent phases. Under fixed force-off, when any non-coordinated phase gaps out, its remaining green time will be made available to the following phase in sequence to use. Under floating force-off, when any non-coordinated phase gaps out, its remaining green time will be transferred to the coordinated phase. The selection of force-off mode is related to operational objectives. Floating force-offs favor

the coordinated phases, as they do not allow non-coordinated phases to inherit time. Therefore, any unused time will always be transferred to the coordinated phase. Floating force-off is recommended if large queues remain at the start of green on coordinated phases or if minor movements have low traffic demand. Fixed force-offs can be beneficial when fluctuations in traffic demand exist and a non-coordinated phase needs more green time during a cycle to serve a surge in traffic. In this scenario, unused green time may be available to a subsequent phase, that in turn may not need all of the available time and “passes” it along to the next phase in sequence until any remaining green time is finally transferred to the coordinated phase. Fixed force-offs can also help to prevent the early return to green on the coordinated phases, reducing perceived delay along the corridor. Early return to green is a term used to describe the servicing of a coordinated phase in advance of its programmed begin time as a result of unused time from non-coordinated phases.

Figure 7.22 – Cycle, Split, and Offset Relationships

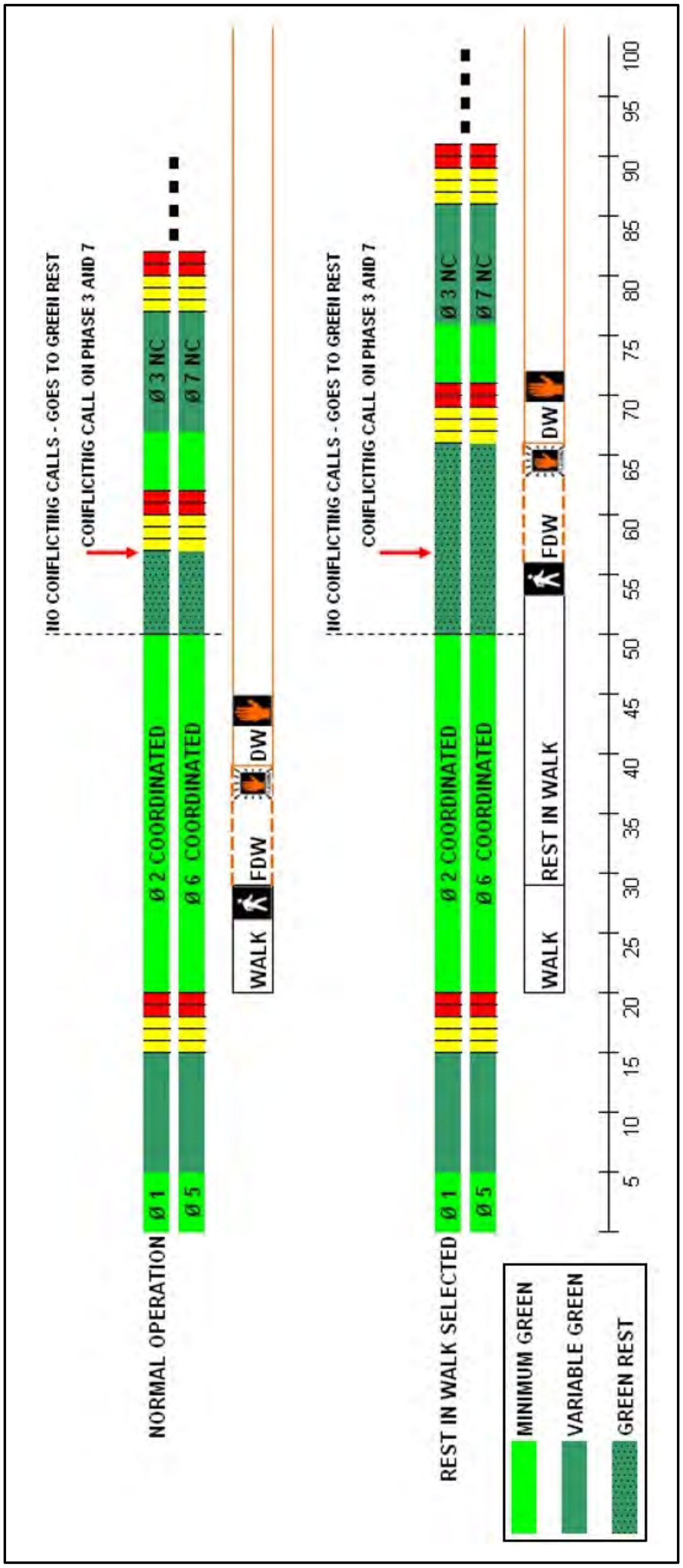


- **Pedestrian Timing and Walk Modes:** Pedestrians can have a direct impact on coordination along a corridor when the time required to serve them is larger than the green time needed for servicing vehicles. When pedestrian service is actuated and demand is relatively low, it may be desirable to allocate a split time that is less than the time required to serve a pedestrian. This scenario would require the traffic signal controller logic to be shifted out of coordination, but nevertheless, it may be more effective to transition (See Section 7.6.4) back for the occasional pedestrian, than to serve pedestrian timing every cycle. As a general rule, pedestrian crossing time should be provided within the split time for the phase whenever pedestrian volume is enough that it can repeatedly cause disruption to coordination (goes into transition). It can vary on different timing plans. This strategy is typically used when a pedestrian call occurs more than 20 percent of the cycles. Practitioners can select pedestrian parameters to accommodate different operational objectives. The rest in walk parameter makes the traffic signal controller logic dwell in the pedestrian walk interval while the coordinated phase is green. This mode is often used when there are high pedestrian volumes (downtown areas, schools, etc), during appropriate times of the day (when pedestrians are present) providing better service to pedestrians. However, this walk mode may delay the minor street movement's vehicular service because the traffic signal controller still has to time the flashing don't walk interval when a conflicting call comes in. Figure 7.23 illustrates the rest in walk parameter.

7.6.4 Traffic Signal Coordination Complexities

The spacing between signalized intersections is critical for achieving appropriate coordination. Evenly spaced intersections provide a better environment for two-way coordination than intersections that don't present consistent spacing. Furthermore, access management takes an important role in coordination as a designed bandwidth may be seriously compromised with the addition of a signalized intersection in an existing system. Also, corridor operations are improved when driveway connections (from parking lots, etc.) are managed and kept to a minimum, providing less platoon disruption. Turn-bay interactions can impact the effective capacity of an intersection. Turn-bay overflows can adversely impact progression by disrupting through traffic from proceeding to downstream intersections. Conversely, queued vehicles on the through movement may block access to the turn-bay causing operational issues as well. See Table 7.3 for left-turn phase sequence strategies to minimize turn-bay challenges. Heavy volumes from minor streets, interchanges, or driveways can affect the ability to progress through movements along a corridor. These surplus demands often enter the system outside the band established for through movements and disrupt operations. Downstream intersection timing may need to be adjusted for this scenario.

Figure 7.23 – Rest-in-Walk Parameter



Another coordination issue is the early return to green (See Section 7.6.3) and selection of force-off modes is crucial for reducing perceived delay. Lastly, but potentially very disruptive to coordination, is when the traffic signal controller undergoes transition logic. Transition is the process of either entering into a coordinated timing plan from free operation or changing between two plans (potentially different cycle lengths, splits and offsets). Transition may also occur after preemption or due to a pedestrian actuation, where pedestrian timing requirements exceed the allocated split time for the concurrent phase. Technically, under any of these scenarios, the local offset reference point may be shifted, requiring an algorithm to adjust the cycle to synchronize the local clock with the master (system) clock. The process may take from one to five cycle lengths, a period of time where the system is not responding to coordination as designed. Practitioners should explore appropriate transition modes for the traffic signal controller in use at the intersection according to system objectives. It is best practice to avoid frequent changes to timing plans, minimizing the chance for transition to happen and allowing a coordinated pattern to be running in a specific timing plan for at least 30 minutes. Similarly, a timing plan should be implemented before the start (5-10 minutes earlier) of the traffic demand period for which it was developed, especially if it is a peak period, to minimize the disruption that transition can cause at such critical time.

7.7 Traffic Signal Timing Plans

A traffic signal timing plan is a unique set of signal timing parameters (See Section 7.5) that can be scheduled to run at specific periods of the day, week, month, or year. In addition, signal timing plans can be customized to weekdays, weekends, or specific days (i.e. holidays, special events, etc.). Typically, signalized intersections experience a peak period during the morning, mid-day, and evening, warranting different signal timing plans. Practitioners should develop signal timing plans based on specific outcomes to help agencies meet operational objectives during different time periods (e.g. minimize delay vs. control queue spillbacks vs. maximize throughput, etc). For coordination (See Section 7.6), specific patterns should be developed, including cycle length, split, offset, etc., that will integrate with signal timing plans. Signal timing plans should always be monitored after installation and field adjustments performed (fine-tuned) to ensure safe and efficient operations.

7.7.1 Timing Software

Computer-based tools are available to calculate and evaluate traffic signal timing, but software capabilities and limitations need to be recognized. A good rule of thumb is for practitioners to have a sense for the expected answer (based on field knowledge or a quick critical movement analysis) to check if the software results are reasonable. Typical traffic signal timing software includes: Synchro, PASSER, Transit 7F, TEAPAC, Tru-Traffic, etc. Simulation models may be of great benefit for practitioners to evaluate signal timing alternatives, explore features, and demonstrate potential operational improvements to public officials. Similar to traffic signal timing software, simulation capabilities and limitations need to be recognized.

7.8 Advanced Traffic Signal Operations

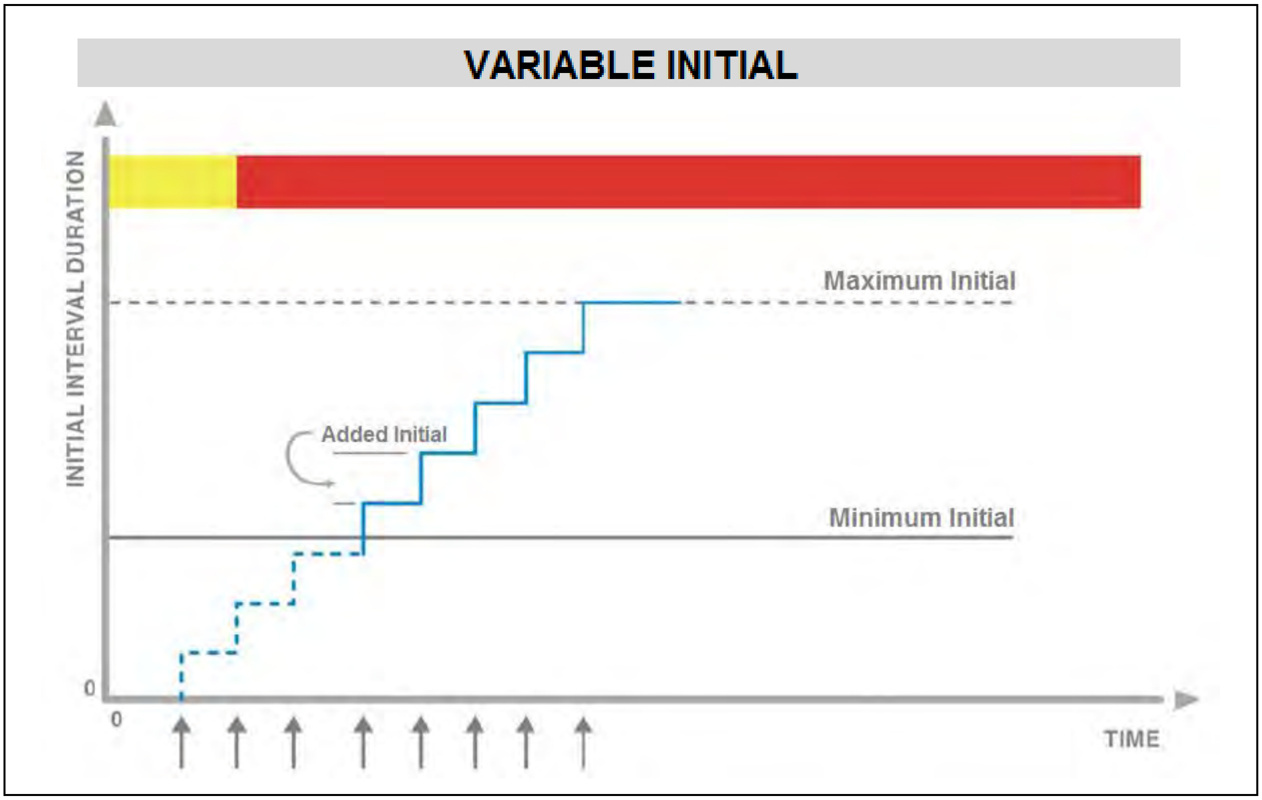
Advanced traffic signal systems rely on dynamic signal timing adjustments to enhance traffic operations. Most advanced systems require considerable investment from local agencies for equipment and maintenance. Therefore, a SEA report is recommended to determine if a system is appropriate for a given location based on local needs and requirements. For additional information on SEA requirements, see *TDOT's ITS Project Development Guidelines*. The following information explores volume density, traffic responsive, and adaptive signal control technology systems.

7.8.1 Volume Density

Volume density (also known as density timing) is an enhanced actuated operation where actuated controller parameters (minimum green and passage time) are automatically adjusted to improve intersection efficiency according to varying traffic demand. Variable initial modifies the minimum green parameter while gap reduction modifies the passage time parameter functionality.

- **Variable Initial:** Section 7.5.8 provided guidelines for setting the minimum green parameter for actuated operation. It mentioned that when detection design consists of no stop line detection and only advance detectors are present, the minimum green needs to be long enough to allow all vehicles queued between the stop line and the nearest advance detector to clear the intersection. This scenario may lead to a very long minimum green (inefficient operation with low traffic volumes) due to long detector advance distances (typically beyond 140 feet). Here is where the use of variable initial becomes beneficial. The variable initial allows the minimum green to be automatically calculated by the traffic signal controller based on the number of detection actuations placed during the yellow change and the red intervals. Therefore, the amount of minimum green is tailored to existing traffic demand, providing more efficient operations. This operation requires the programming of three traffic signal controller parameters (minimum initial, added initial, and maximum initial) and appropriate detection settings. Due to non-standard traffic signal terminology, practitioners should refer to traffic signal controller manuals to determine the appropriate parameters to be programmed. Figure 7.24 illustrates variable initial operation.

Figure 7.24 – Volume Density (Variable Initial)
Source: Traffic Signal Timing Manual



- **Minimum Initial:** The minimum initial is the shortest amount of time that the green interval will be active during volume density operation. Its setting is based on the lower range value for minimum green time to satisfy driver expectancy. The minimum initial is intended to allow time for motorists to respond to the onset of the green indication. If pedestrian timing requirements are a concern, the minimum initial timing should follow the guidelines presented for minimum green timing in Section 7.5.8. Table 7.15 provides typical values for minimum initial settings under volume density operations.

Table 7.15 – Volume Density Typical Values for Minimum Initial Settings

Facility Type	Time (Seconds)
Major Arterial (Speed Limit > 40 mph)	10
Major Arterial (Speed Limit > 40 mph)	7
Minor Arterial, Collector	5

- **Added Initial:** Because the minimum initial is set to low values, additional time may be needed to clear the queue of vehicles which arrived during the yellow change and red intervals. Therefore, the added initial is the incremental amount of time (in seconds) that accumulates for every vehicle actuation received during the associated phase yellow change and red intervals. The cumulative value for added initial becomes the active amount of time for the green interval once it exceeds the minimum initial value. Because vehicles can drive through the intersection side by side, the setting of the added initial parameter is dependent on the number of lanes on the approach. Table 7.16 provides typical values for added initial settings under volume density operations.

Table 7.16 – Volume Density Typical Values for Added Initial Settings

Number of Lanes Served by Phase	Time (Seconds)
1	2
2	1.5
3 or More	1.2

Note: Slightly larger values can be used if the approach has a significant upgrade, has significant number of trucks, or the intersection width is an issue for bicycles.

- **Maximum Initial:** The maximum initial is the longest amount of time that the added initial cumulative value can be extended. Typically, the maximum initial is set according to the minimum green for queue clearance guidelines. The maximum initial cannot exceed the maximum green for a phase. Table 7.17 provides typical values for maximum initial settings under volume density operations.

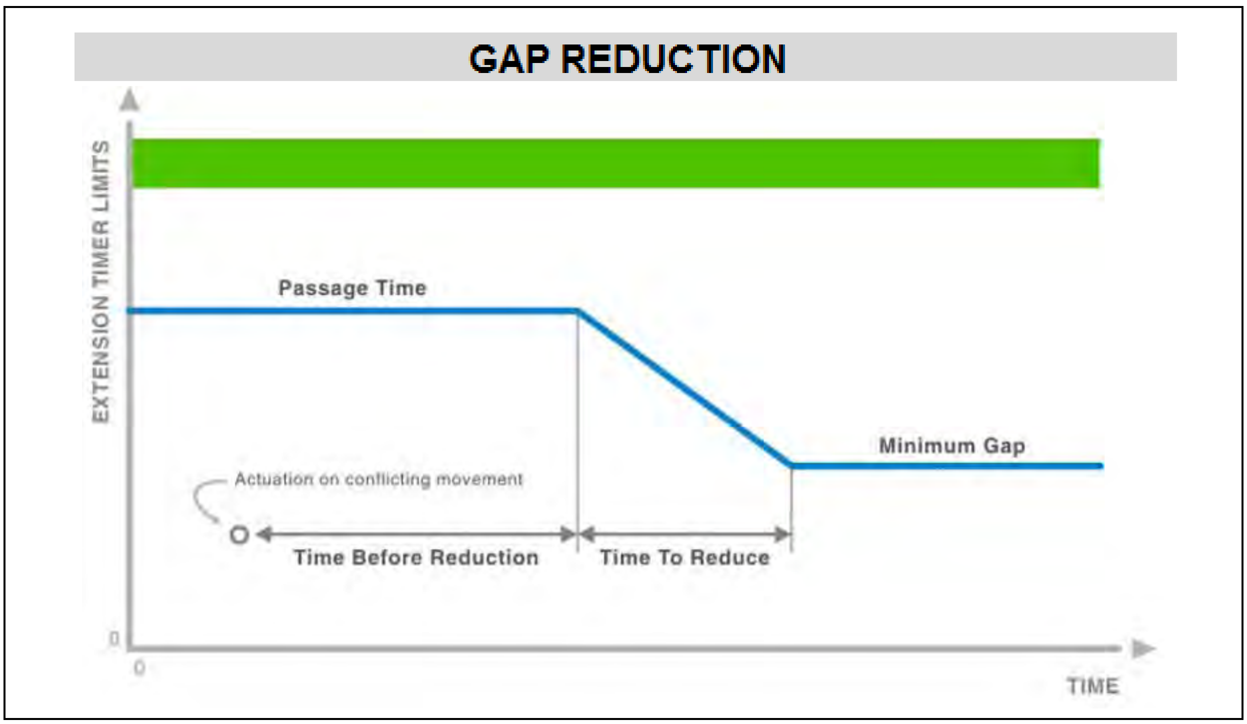
Table 7.17 – Volume Density Typical Values for Maximum Initial Settings

Setback Detector Placement Distance from Stop Line (Feet)	Time (Seconds)
285	25
325	29
365	32
405	35
445	38
485	41

➢ **Gap Reduction:** In certain locations and traffic conditions, it may be desirable to have a higher passage time initially to prevent a premature gap out when vehicles are slowly clearing the intersection. Then, as the green phase elapses and is continuously extended, it may be desirable to have a shorter passage time as vehicular flow decreases, allowing the phase to gap out more efficiently, potentially minimizing the delay for conflicting movements. This can be accomplished by the gap reduction feature of volume density operation. Signalized intersections with upgrade approaches, high traffic volumes, or considerable heavy vehicle volume may benefit from gap reduction. This operation requires the programming of four traffic signal controller parameters (passage time, time before reduction, time to reduce, and minimum gap). Gap reduction can be used with stop line detection and advance detection. Due to non-standard traffic signal terminology, practitioners should refer to traffic signal controller manuals to determine the appropriate parameters to be programmed. Figure 7.25 illustrates gap reduction operation.

Figure 7.25 – Volume Density (Gap Reduction)

Source: Traffic Signal Timing Manual



- **Passage Time:** For stop line detection, the passage time should be set using Equation 7.11 (See Section 7.5.8), but a maximum allowable headway of four seconds should be used. Table 7.18 provides typical passage time values for stop line detection. For advance detection, the passage time should be calculated as the time it takes a vehicle to travel from the nearest advance detector to the stop line (distance from the detector/approach speed). When indecision zone protection is provided (See Section 8.5.2), the use of gap reduction is not recommended.

Table 7.18 – Volume Density Gap Reduction Settings for Passage Time (Stop Line Detection)

Detection Zone Length (Feet)	Passage Time (Seconds) for Approach Speed (mph)								
	25	30	35	40	45	50	55	60	65
20	2.9	3.1	3.2	3.3	3.4	3.5	3.5	3.5	3.6
25	2.8	3.0	3.1	3.2	3.3	3.4	3.4	3.5	3.5
30	2.6	2.9	3.0	3.1	3.2	3.3	3.4	3.4	3.5
35	2.5	2.8	2.9	3.1	3.2	3.3	3.3	3.4	3.4
40	2.4	2.6	2.8	3.0	3.1	3.2	3.3	3.3	3.4
45	2.2	2.5	2.7	2.9	3.0	3.1	3.2	3.3	3.3
50	2.1	2.4	2.6	2.8	2.9	3.0	3.1	3.2	3.3
55	2.0	2.3	2.5	2.7	2.9	3.0	3.1	3.1	3.2
60	1.8	2.2	2.4	2.6	2.8	2.9	3.0	3.1	3.2
65	1.7	2.1	2.3	2.6	2.7	2.8	2.9	3.0	3.1
70	1.5	2.0	2.2	2.5	2.6	2.8	2.9	3.0	3.1
75	1.4	1.8	2.1	2.4	2.6	2.7	2.8	2.9	3.0
80	1.3	1.7	2.1	2.3	2.5	2.6	2.8	2.9	3.0

*The passage time may be increased by up to 1.0 second if the approach is on a steep upgrade and/or there is a large percentage of heavy vehicles.

- **Time Before Reduction:** The time before reduction determines the amount of time to be elapsed after a conflicting call is received and before the passage time is allowed to be reduced. In most cases, it should equal the minimum green setting (See Section 7.5.8). Table 7.19 provides typical time before reduction values.

Table 7.19 – Volume Density Gap Reduction Settings for Time Before Reduction

Minimum Green (Seconds)	Time (Seconds)
5	10
10	10
15	15
20	20

- **Time to Reduce:** The time to reduce determines the amount of time to be elapsed during the linear reduction of the passage time to the minimum gap value. It should equal one-half of the difference between the maximum green and the minimum green setting. Table 7.20 lists typical values for the time to reduce parameter.

Table 7.20 – Volume Density Gap Reduction Settings for Time to Reduce (Stop Line Detection)

Minimum Green (Seconds)	Maximum Green (Seconds) for Approach Speed (mph)										
	20	25	30	35	40	45	50	55	60	65	70
5	8	10	13	15	18	20	23	25	28	30	33
10	5	8	10	13	15	18	20	23	25	28	30
15	N/A	5	8	10	13	15	18	20	23	25	28
20	N/A	N/A	5	8	10	13	15	18	20	23	25

- **Minimum Gap:** The minimum gap determines the minimum value for the passage time to be reduced to. For stop line detection, the minimum gap should be set using Equation 7.11 (See Section 7.5.8), but a maximum allowable headway of two seconds should be used. Table 7.21 provides typical minimum gap values for stop line detection. For advance detection, the minimum gap should be set to two seconds with pulse mode detection. Again, when indecision zone protection is provided (See Section 8.5.2), the use of gap reduction is not recommended.

Table 7.21 – Volume Density Gap Reduction Settings for Minimum Gap (Stop Line Detection)

Detection Zone Length (Feet)	Passage Time (Seconds) for Approach Speed (mph)								
	25	30	35	40	45	50	55	60	65
20	0.9	1.1	1.2	1.3	1.4	1.5	1.5	1.5	1.6
25	0.8	1.0	1.1	1.2	1.3	1.4	1.4	1.5	1.5
30	0.6	0.9	1.0	1.1	1.2	1.3	1.4	1.4	1.5
35	0.5	0.8	0.9	1.1	1.2	1.3	1.3	1.4	1.4
40	0.4	0.6	0.8	1.0	1.1	1.2	1.3	1.3	1.4
45	0.2	0.5	0.7	0.9	1.0	1.1	1.2	1.3	1.3
50	0.1	0.4	0.6	0.8	0.9	1.0	1.1	1.2	1.3
55	0.0	0.3	0.5	0.7	0.9	1.0	1.1	1.1	1.2
60	0.0	0.2	0.4	0.6	0.8	0.9	1.0	1.1	1.2
65	0.0	0.1	0.3	0.6	0.7	0.8	0.9	1.0	1.1
70	0.0	0.0	0.2	0.5	0.6	0.8	0.9	1.0	1.1
75	0.0	0.0	0.1	0.4	0.6	0.7	0.8	0.9	1.0
80	0.0	0.0	0.1	0.3	0.5	0.6	0.8	0.9	1.0

*The passage time may be increased by up to 1.0 second if the approach is on a steep upgrade and/or there is a large percentage of heavy vehicles.

7.8.2 Traffic Responsive Plan Selection Systems

A TOD plan selection works well when traffic conditions are consistent and predictable – that is, similar traffic patterns generally occur during the same times each day. When an incident, a planned event (e.g., construction, county fair, football game, etc.), extreme weather, or any other unusual occurrence causes a significant change in the normal traffic conditions, the timing plan selected by the TOD method may not be the plan best suited to current conditions. To address this situation, the TRPS uses data from traffic detectors, rather than TOD, to automatically select the coordinated timing plan best suited to current conditions. Plan selection for responsive operations may also be invoked manually. Agencies operating traffic signals from their traffic management centers have the ability to use predetermined plans for planned special events or recurring congestion on an as-needed basis. TRPS normally takes place on a field master or central system. Considerable effort may be needed to:

- Identify vehicle detectors that will provide adequate representation of traffic conditions;
- Establish appropriate parameter values associated with detectors;
- Establish appropriate threshold values to trigger the implementation of new timing plans;
- Fine-tune once TRPS is implemented.

Historical traffic count data is necessary before the detector selection and setup begins. Furthermore, transition (See Section 7.6.4) may become a problem due to frequent changes in the timing plan. Therefore, it is recommended that the current timing plan be running for a minimum amount of time before a new plan can be implemented, and the new timing plan must typically be a certain percentage improvement over the current running plan. Traffic responsive plan selection systems merely select a timing plan to operate, but do not make changes to the timings specified in the timing plan. That is the role of adaptive traffic signal control. For additional information regarding TRPS systems, refer to the *Traffic Signal Timing Manual*.

7.8.3 Adaptive Signal Control Technology Systems

ASCT systems are a concept where vehicular traffic in a network is detected at an upstream and/or downstream point. A model is used to predict where the detected vehicular traffic will be and an algorithm makes signal adjustments at the downstream intersections based on those predictions. The signal controller utilizes these algorithms to compute optimal signal timings based on detected traffic volume and simultaneously implements the timings in real-time. This real-time optimization allows a signal system to react to traffic volume variations, resulting in potential reduced system user delay, shorter queues, and decreased travel times. Adaptive systems are critically linked to good, reliable detection systems. ASCT systems will provide the best operational improvements where:

- Traffic conditions fluctuate randomly on a day-to-day basis;

- Traffic conditions change rapidly due to new developments in land use;
- Incidents, crashes, or other events result in unexpected changes to traffic demand;
- Other disruptive events, such as preemption, require a response;
- Under-saturated conditions exist.

It is important to understand that ASCT systems are not set-and-forget systems. They require ongoing fine-tuning and higher levels of maintenance than traditional systems, in order to keep the detection and communications infrastructure working at a high level of performance. For additional information regarding ASCT systems, refer to the *Traffic Signal Timing Manual.*

7.9 Traffic Signal Priority

TSP is a type of preferential treatment based on an operational strategy communicated between vehicles and traffic signals (or through detection vehicle type classification) to alter the signal timing for the benefit or priority of those vehicles (mostly transit and heavy trucks). Coordination will not be affected by priority. Service is not guaranteed during a priority request. TSP may be accomplished through the following methods:

- **Green/Phase Extension:** Involves the extension of the preferred phase green interval past its normal termination point to prevent long delays for preferred vehicles that are anticipated to arrive near the end of the green interval (transit and heavy trucks);
- **Red Truncation/Early Green:** Involves shortening the duration of non-preferred phases in order to return earlier than normal to the green interval of the preferred phase, preventing additional delays to preferred vehicles (transit and heavy trucks);
- **Phase Insertion:** Involves the activation of a special, dedicated phase that is not served during normal (non-preferred) operations, and is only displayed when a preferred vehicle has been detected at the intersection. It is typically used to provide service to lanes dedicated to preferred vehicles or to support queue jumps, allowing preferred vehicles to enter a downstream link ahead of the normal traffic stream;
- **Phase Sequence Change:** Involves changing the sequence of phases to provide more immediate service to the preferred vehicle;
- **Phase Skipping:** Involves skipping service for non-preferred phases that would normally be served, in order to expedite service to preferred phases.

The *MUTCD Section 4D.27* requires that during priority control and during the transition into or out of priority control:

- The shortening or omission of any yellow change interval, and of any red clearance interval that follows, shall not be permitted;

- The shortening of any pedestrian walk interval below that time described in *MUTCD Section 4E.06* shall not be permitted;
- The omission of a pedestrian walk interval and its associated change interval shall not be permitted, unless the associated vehicular phase is also omitted or the pedestrian phase is exclusive;
- The shortening or omission of any pedestrian change interval shall not be permitted;
- A signal indication sequence from a steady yellow signal indication to a green signal indication shall not be permitted.

For additional information on traffic signal priority, refer to the *Traffic Signal Timing Manual* and to the *Transit Signal Priority Handbook.*

7.10 Traffic Signal Preemption

Traffic signal preemption is a type of preferential treatment that involves the transfer of normal operation of a traffic control signal to a special control mode of operation, typically including trains and emergency vehicles. Coordination will be affected by preemption and a service is guaranteed during a preemption request. The *MUTCD Section 4D.27* requires that during the transition into preemption control:

- The yellow change interval, and any red clearance interval that follows, shall not be shortened or omitted;
- The shortening or omission of any pedestrian walk interval and/or pedestrian change interval shall be permitted;
- The return to the previous green signal indication shall be permitted following a steady yellow signal indication in the same signal face, omitting the red clearance interval, if any.

The *MUTCD Section 4D.27* further requires that during preemption control and during the transition out of preemption control:

- The shortening or omission of any yellow change interval, and of any red clearance interval that follows, shall not be permitted;
- A signal indication sequence from a steady yellow signal indication to a green signal indication shall not be permitted.

The following describes emergency vehicle preemption and railroad preemption.

7.10.1 Emergency Vehicle Preemption

Various mechanisms can be used to preempt traffic signals so that emergency vehicles are provided with safe right-of-way as soon as practical. Emergency preemption systems allow emergency vehicles to interrupt the normal sequence of traffic signal phasing and provide preferential treatment to the approach with the emergency vehicle. To accomplish the operation, a flexible response system is deployed using either a light emitter or siren in the vehicle and a receiver connected to the traffic signal controller at various intersections. The receiver sends a message to the signal controller, which terminates the current phase and skips to the green interval on the required approach. Emergency vehicle preemption should be considered at signalized intersections along key roadways and routes to and from hospitals, fire stations, and police stations. Figure 7.26 shows an emergency vehicle preemption sequence. TDOT will normally install emergency vehicle preemption detection devices (optical or siren activated priority control systems) as a part of a traffic signal installation or upgrade project, upon request of the local governing agency. TDOT will normally not provide emitter/transponders unless the project's purpose is to provide a city-wide or area-wide preemption system and conforms with the area-wide or regional ITS architecture. The typical information to be shown on traffic signal construction plans for emergency vehicle preemption is shown in Figure 7.27.

- **Methods of Emergency Vehicle Preemption** - Several methods of traffic signal preemption are typically utilized for emergency vehicles:
  - **Hardwired from Source:** A connection between the traffic signal controller and the source of an emergency call (e.g. fire station) allows preemption.
  - **Optically Activated:** Optical preemption systems consist of an emitter mounted on a vehicle, detectors mounted above the intersection, and a phase selector and other equipment in the traffic signal controller cabinet. The detector senses the optical pulses emitted by properly equipped emergency vehicles and informs the traffic signal controller of the presence of designated vehicles.
  - **Siren Activated:** Siren preemption systems consist of detectors mounted above the intersection and a phase selector and other equipment in the traffic signal controller cabinet. The system is activated by a Class A electronic siren.
  - **GPS Activated:** GPS preemption systems consist of a GPS receiver and a radio antenna at the intersection to receive a coded signal with approach information from the emergency vehicle equipped to send preemption GPS coded information to the intersection.

Figure 7.26 – Emergency Vehicle Preemption Sequence

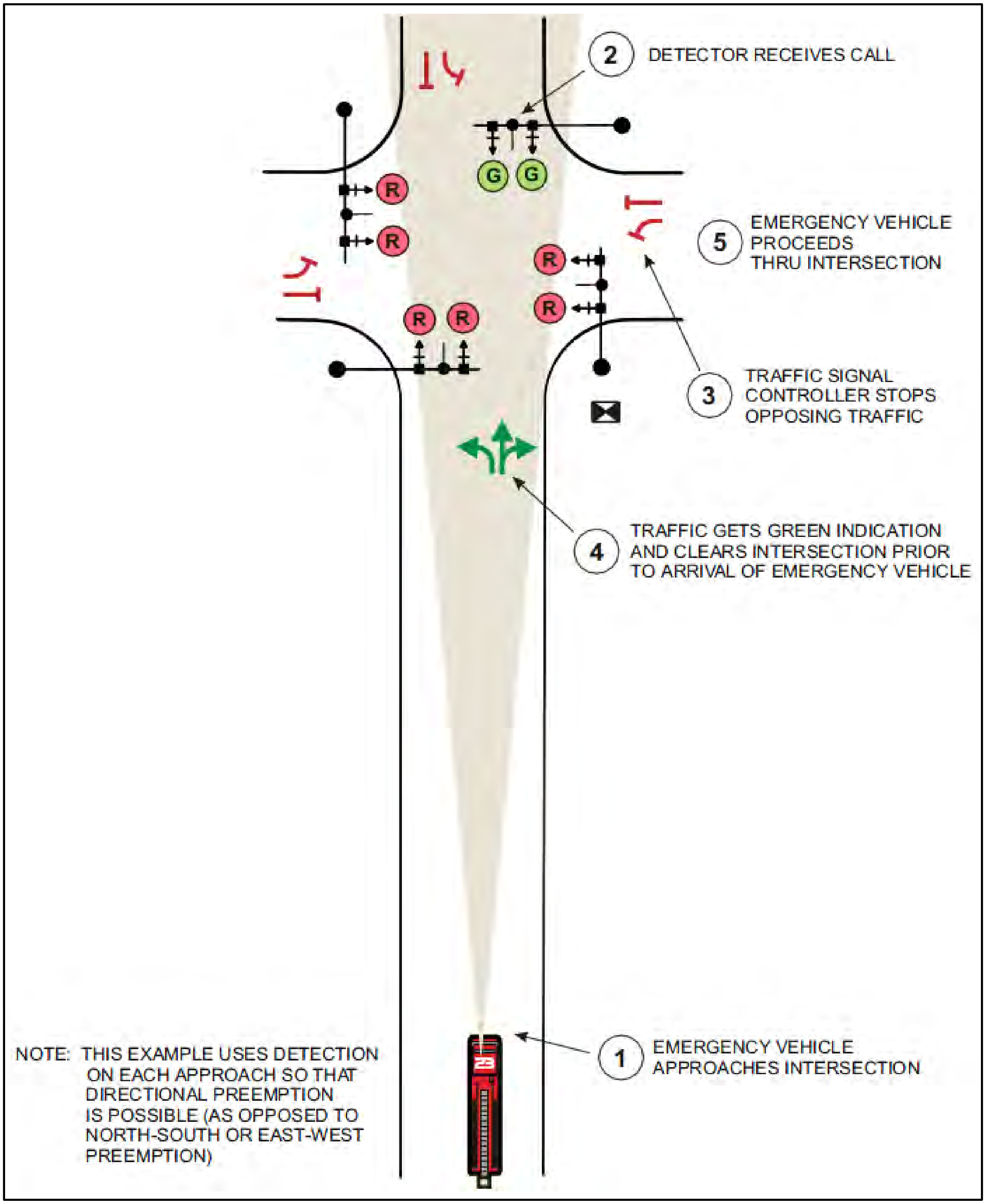
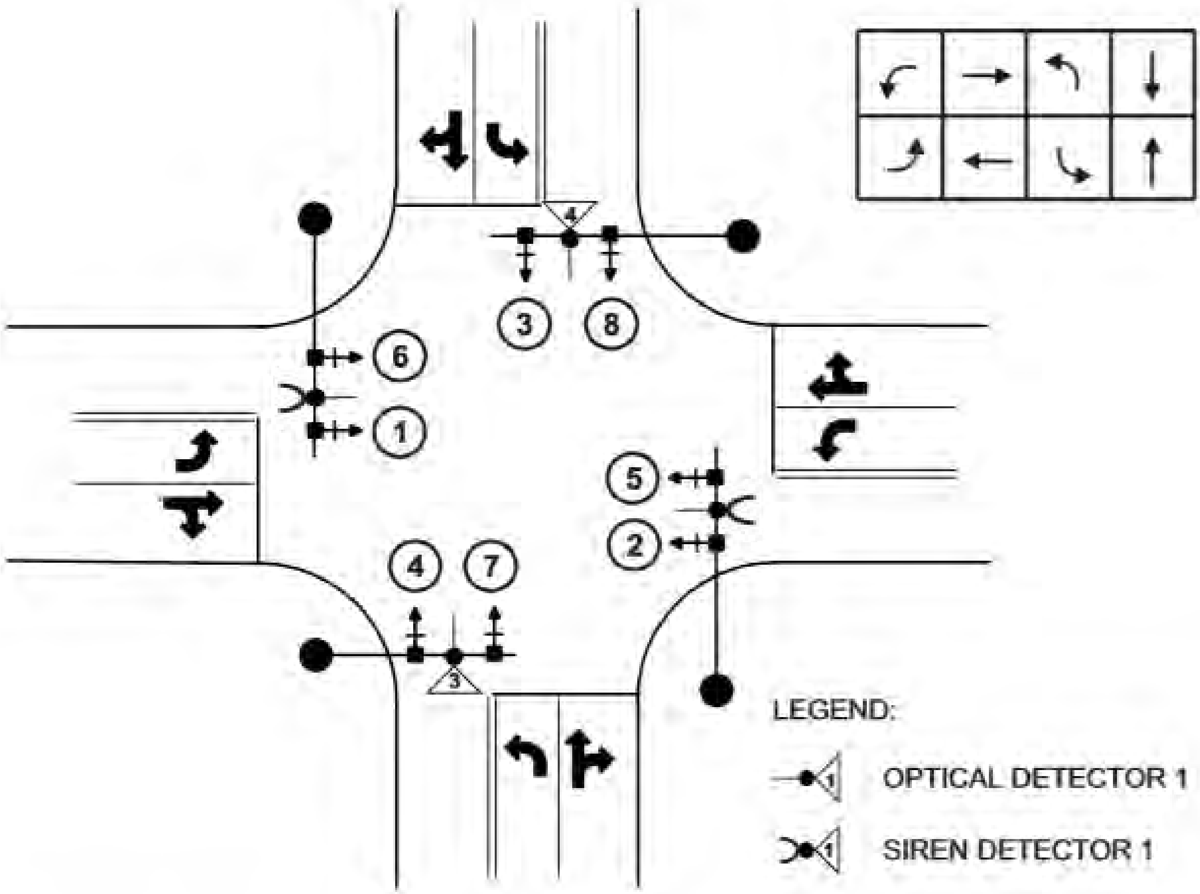


Figure 7.27 – Emergency Vehicle Preemption Design Example



EXAMPLE CHART TO
BE INCLUDED IN PLANS

PREEMPTION ASSIGNMENTS		
DETECTOR 1	PREEMPT 1	Ø 2 AND Ø 5
DETECTOR 2	PREEMPT 3	Ø 1 AND Ø 6
DETECTOR 3	PREEMPT 3	Ø 4 AND Ø 7
DETECTOR 4	PREEMPT 4	Ø 3 AND Ø 8

7.10.2 Railroad Preemption

Railroad preemption is a special signal phasing sequence which is actuated upon the detection of a train and is designed to clear traffic off the railroad tracks prior to the arrival of the train at the highway-rail grade crossing. Furthermore, railroad preemption shall inhibit movements that cross the railroad tracks until the train has cleared the crossing. It results in a special traffic signal operation, depending on the relation of the railroad tracks to the intersection, the number of phases of the traffic signal, and other traffic conditions. Railroad preemption is normally controlled by the highway-rail grade crossing warning equipment, which sends a signal to the traffic signal controller to initiate preemption of the traffic signal. Traffic signal preemption at a railroad crossing requires a permit with the railroad authority. The highway agency and railroad authority should coordinate to understand the operation of each other's system(s). In order to determine the minimum preemption warning time, factors such as equipment response and programmed delay times, minimum green signal time, vehicular and pedestrian clearances, queue clearances, and the train/vehicle separation times should be considered.

- **Railroad Preemption Warrant:** The *MUTCD Section 4C.10* presents the standards and guidelines to determine if a traffic signal is warranted near a highway-rail crossing. If warranted, preemption control shall be provided in accordance to the *MUTCD Sections 4D.27, 8C.09 and 8C.10*.
- **Railroad Preemption Pre-Signals:** Pre-signals are traffic control signal faces that control traffic approaching a highway-rail crossing, in conjunction with the traffic control signal faces that control traffic approaching an intersection beyond the tracks. Pre-signals are typically used where the clear storage distance is insufficient to store one or more design vehicles. The clear storage distance is the distance available for vehicle storage, measured between six feet from the rail nearest the intersection to the intersection stop line or the normal stopping point on the highway. The *MUTCD Section 8C.09* presents the standards and guidelines regarding the use of pre-signals.
- **Railroad Preemption Sequence:** The preemption sequencing of two-phase and three-phase traffic signals are shown in Figure 7.28. Railroad preemption for an eight-phase intersection is shown in Figure 7.29. As the figures show, the basic phases of the sequence are a right-of-way change interval, a clear track interval, and preemption hold phasing (while the train is occupying the highway-rail grade crossing).

Figure 7.28 – Railroad Preemption Sequence (2 or 3-Phase Operation)

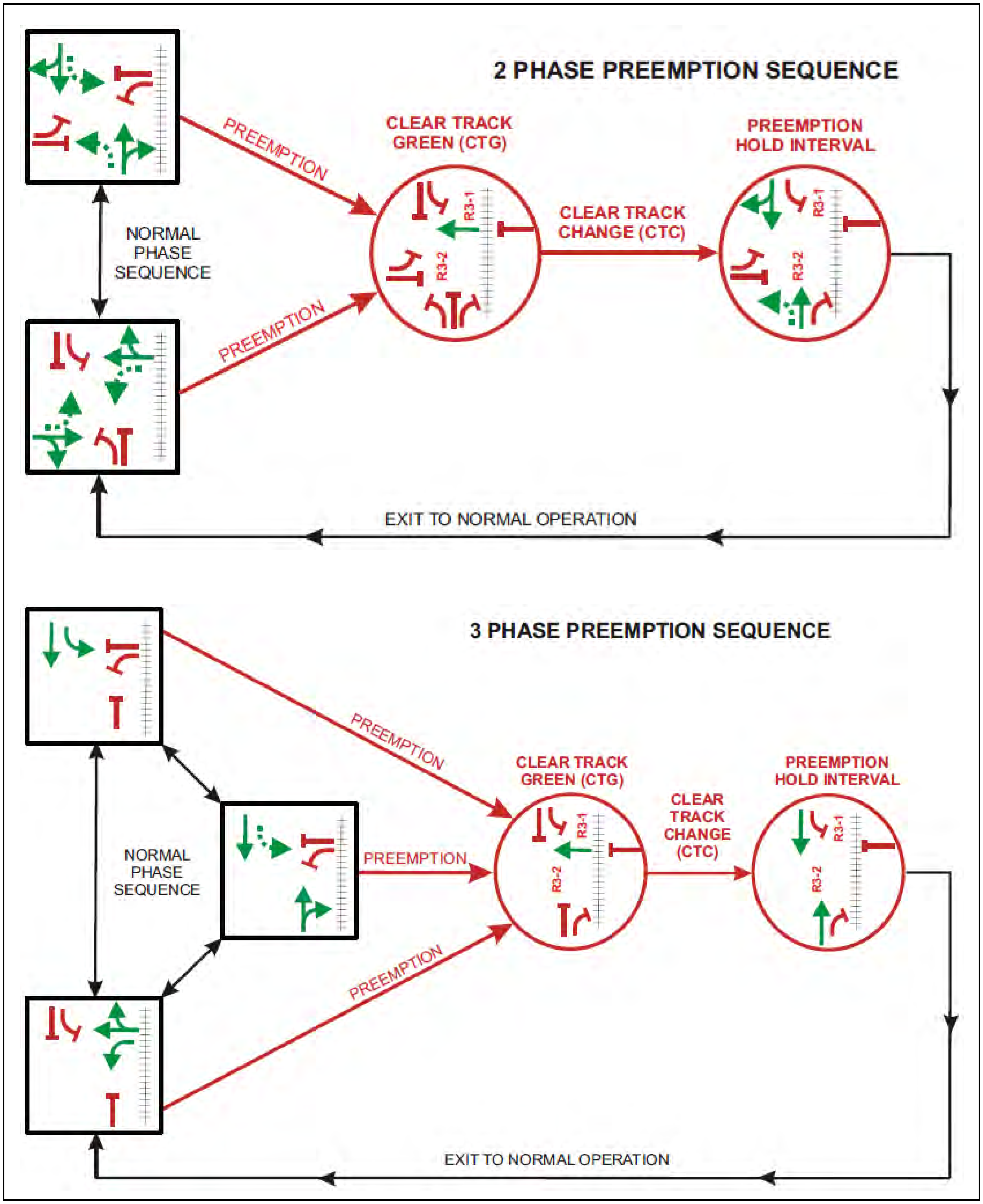
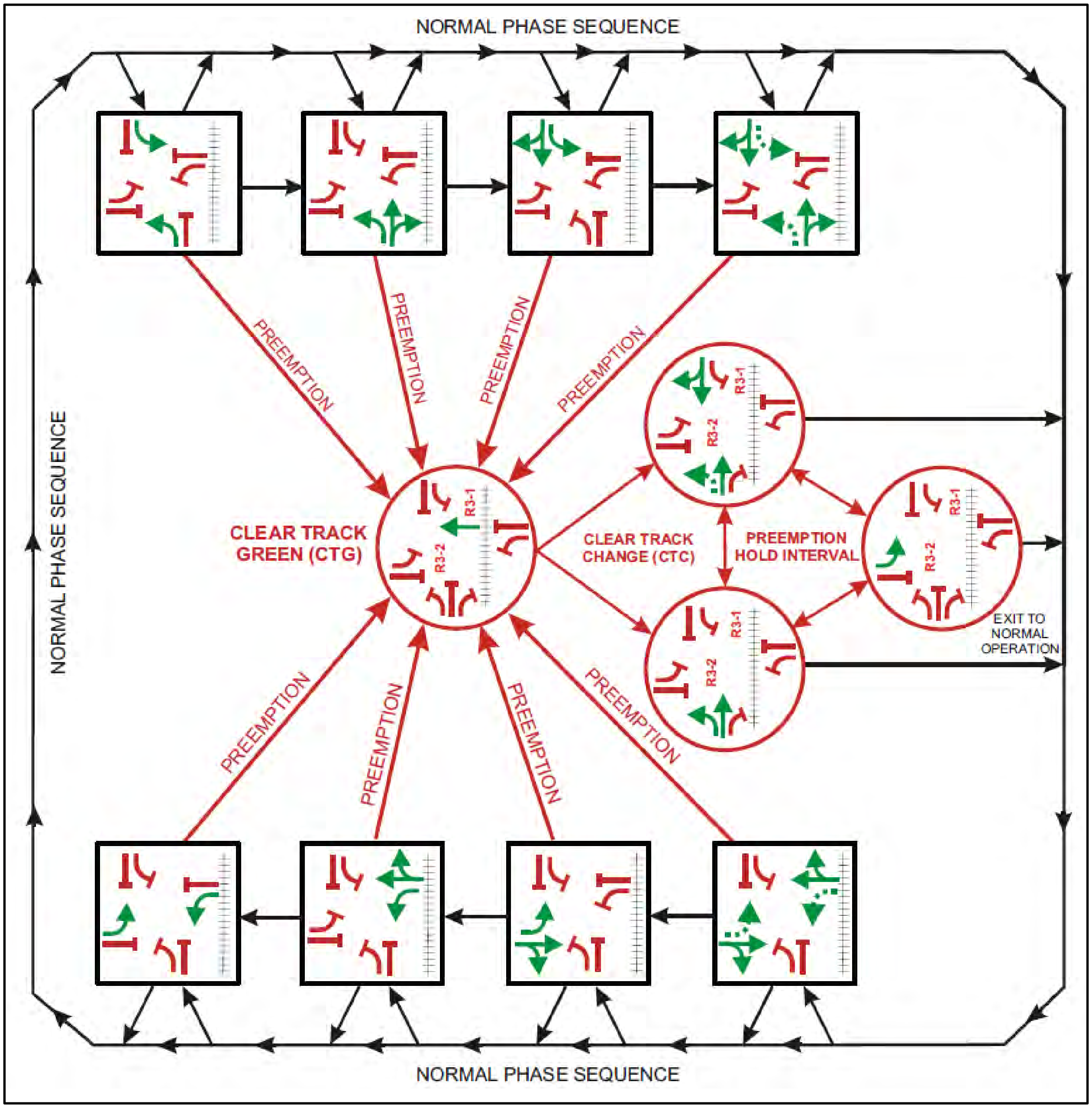


Figure 7.29 – Railroad Preemption Sequence (8-Phase Operation)



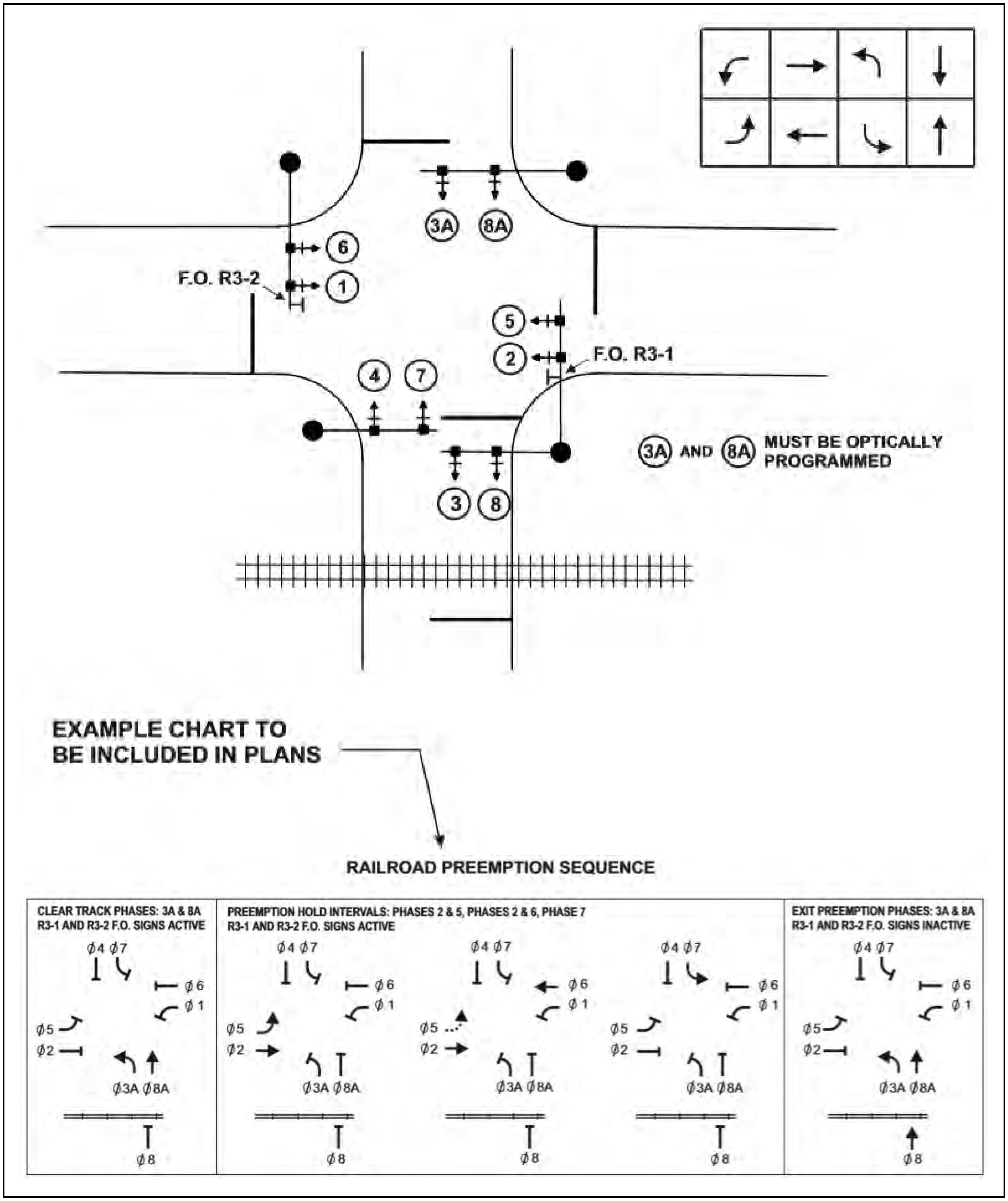
Railroad preemption of the traffic signal should have the following sequence:

1. A yellow change interval and any required all-red clearance interval for any signal phase that is green or yellow when preemption is initiated and which will be red during the track clearance interval. The length of yellow change and all-red clearance intervals shall not be altered by preemption. Phases which will be green during the track clearance interval and which are already green when preemption is initiated, shall remain green. Any pedestrian walk or pedestrian change interval, in effect when preemption is initiated, shall immediately be terminated and all pedestrian signal faces shall display steady don't walk indication;
2. A track clearance interval for the traffic signal phase or phases controlling the approach which crosses the railroad tracks;
3. Depending on traffic requirements and phasing of the traffic signal controller, the traffic signal may then do one of the following:
    - Go into flashing operation, with flashing red or flashing yellow signal indications for the approaches parallel to the railroad tracks and flashing red signal indications for all other approaches. Pedestrian signals shall be inactive;
    - Revert to limited operation with those signal indications controlling through and left turn approaches towards the railroad tracks displaying steady red. Permitted pedestrian signal phases shall operate normally;
4. The traffic signal shall return to normal operation following the release of preemption control.

The typical information to be shown on traffic signal construction plans for railroad preemption is shown in Figure 7.30.

- **Railroad Preemption Turn Restrictions:** According to the *MUTCD Section 8B.08***,** a blank-out sign, changeable message sign, other similar type sign, and/or appropriate highway traffic signal indication may be used to prohibit turning movements toward the highway-rail grade crossing during preemption. A blank-out sign displays a blank face unless internally illuminated upon activation, showing the message/symbol No Left Turn (R3-2) or No Right Turn (R3-1). Blank-out signs are useful as part of the railroad preemption sequence at signalized intersections immediately adjacent to grade crossing. At these locations, turn prohibition blank-out signs can prevent traffic from turning into and occupying the limited storage area between the tracks and the intersection, and eventually blocking the intersection itself. These signs are activated upon initiation of the railroad preemption and deactivated after the preemption is completed.

Figure 7.30 – Railroad Preemption Design Example



- **Railroad Preemption Terminology:** Railroad preemption signal timing design includes the calculation and programming of minimum warning time, constant warning time, equipment response time, minimum time, clearance time, buffer time, advance preemption time, total approach time, etc. For additional information regarding railroad preemption, refer to the *Traffic Signal Timing Manual*.

7.10.3 Multiple Preemption

A combination of railroad, emergency preemption, and priority control is allowed at an intersection. There is usually a hierarchy in determining which preemption and/or priority occurs first when more than one is received by the traffic signal controller. The traffic signal controller preemption priority hierarchy shall be as follows:

1. Railroad Train Preemption; over
2. Boat Preemption; over
3. Heavy Vehicle Emergency Vehicle Preemption (Fire, Rescue, or Ambulance); over
4. Light Vehicle Emergency Vehicle Preemption (Law Enforcement); over
5. Light Rail Transit Priority; over
6. Rubber Tire Transit Priority.

7.11 Flashing Operations

All traffic signals are programmed to operate in the flash mode for emergencies. Signals may also operate in maintenance flash, railroad preemption flash, or scheduled operational flash modes. The type of flash used (all-red or yellow-red) must be considered carefully. Driver expectation is an important factor. Drivers are conditioned to react to situations through their experiences. Mixing the types of flash can confuse drivers if they are accustomed to the all-red flash. The benefits of operating a mixed-color flash must be weighed against the disadvantages. Violation of driver expectation can be a disadvantage of a mixed-color flash. Flashing operations of a traffic signal shall comply with *MUTCD Sections 4D.28, 4D.29, 4D.30 and 4D.31*.

7.11.1 Types of Flashing Operation

Flashing mode operation can be characterized by planned and unplanned operation. More specifically:

- **Emergency Flash:** Emergency flash mode is used when the conflict monitor (malfunction management unit) senses a malfunction. Emergency flash shall use all-red flash exclusively.

- **Maintenance Flash:** Maintenance flash mode can be programmed for the operation of the intersection during routine maintenance. Yellow-red flash can be used if the main street traffic is significantly more than the minor street traffic.
- **Scheduled Flash:** Traffic signals can operate in scheduled flash mode as a time-of-day operation (e.g. nighttime flash). Nighttime flash can reduce delay at intersections operating in the fixed time mode. Scheduled flash mode typically uses the yellow-red flash type operation. Nighttime flash should not be used at fully actuated intersections unless all other intersections in the area operate nighttime flash. Again, driver expectation is a major factor in this decision. Isolated actuated traffic signals do not normally have a programmed flash mode operation. If a traffic signal using LED indications is placed in an automatic flashing mode during the night, the LED signal indications should be dimmed to reduce the brightness of the indications.
- **Railroad Preemption Flash:** When a traffic signal is preempted by a train, flashing operation may be used while the train is going through the crossing. Either all-red flash or yellow-red flash can be used.

7.11.2 Flashing Operation Signal Display

The following describes the all-red and the yellow-red flashing operation:

- **All-Red Flash:** This type of flashing operation flashes red to all intersection approaches. It may be used under the following conditions:
  - **Traffic Volumes:** Traffic volumes on the two intersecting streets are approximately equal.
  - **Minor Street Delay:** Minor street traffic would experience excessive delays and/or hazard in trying to cross the major street with yellow flashing signal indications. Engineering judgment must be used to balance this benefit against the delay that will be experienced by the major street traffic.
  - **Minor Street Sight Distance:** Minor street traffic has insufficient sight distance to safely enter or cross the major street with yellow flashing signal indications.
- **Yellow-Red Flash:** This type of flashing operation is the most common and flashes yellow to the major street and red to the minor street. Minor street sight distance, as well as the difficulty the minor street traffic will have crossing the major street, must be considered.

[This page intentionally left blank.]

CHAPTER 8

TRAFFIC SIGNAL DESIGN – DETECTION

8.1 Detection

Detection is a critical component of traffic signal design. Detectors provide the traffic signal controller with the information necessary to determine the servicing of roadway users. The sections below explore detection objectives and location. Furthermore, guidelines on detection parameters and phase recalls are presented. Lastly, guidelines for detection design of low-speed and high-speed approaches are discussed in addition to pedestrian detection design and types of detection.

8.1.1 Detection Objectives

Enhancing intersection safety and efficiency are the overall goals of traffic signal detection design. The following items characterize specific detection objectives:

- Identify user presence for a movement and call its phase when the phase is red;
- Extend a phase when the phase is green;
- Identify gaps in traffic where a phase should end due to no traffic or inefficient flow;
- Provide safe phase termination at the onset of the yellow indication for high-speed vehicle movements;
- Monitor intersection performance using measure of effectiveness logs.

8.1.2 Detection Location

Detection can be located at the stop line or upstream from an intersection. Typically, stop line detection addresses intersection efficiency issues while upstream detection addresses intersection safety issues. See Sections 8.4 and 8.5 for specific detection design guidelines.

- **Stop line Detection:** Stop line detection is used for approaches below 35 mph on through lanes, exclusive left-turn lanes and exclusive right-turn lanes. Stop line detection may also be used in conjunction with upstream detection for high-speed approaches. Stop line detection is located where vehicles are anticipated to stop, but should be extended a minimum of three feet and not more than five feet beyond the stop line.
- **Advance Detection:** Advance detection is used for approaches 35 mph or higher typically located in the path of vehicles on through lanes, and in advance of the stop line (see Section 8.5). Advance detection provides information on vehicles approaching the intersection that can be used to safely terminate a phase on the onset of the yellow indication.

8.2 Detection Parameters

Several detection settings will influence intersection operation. The following modes will provide information on the typical detection parameters: presence and pulse, locking and non-locking, delay, extend, call, queue, and detector switching. *Note: The terminology of detection parameters is not consistent between vendors; therefore, specific vendor manuals should be consulted for appropriate parameter selection and settings.*

8.2.1 Detection Operating Modes

The detector's operating mode influences the duration of the actuation submitted to the traffic signal controller by the detector unit. One of two modes (presence or pulse) can be used.

- **Presence:** Presence mode is used to measure occupancy. The actuation starts with the arrival of the vehicle to the detection zone and ends only when the vehicle leaves the detection zone. The actuation time duration depends on vehicle length, detection zone length, and speed. Presence mode is typically the default mode and is typically associated with stop line detection.
- **Pulse:** Pulse mode is used to count vehicles. The actuation starts with the arrival of the vehicle to the detection zone and ends after the pulse activation (usually 0.10 to 0.15 seconds). Pulse mode is typically associated with advance detection.

8.2.2 Detection Memory Modes

The detector's memory modes affects the ability of the traffic signal controller to remember an actuation received during a red interval. It can be set to locking or non-locking mode.

- **Locking:** In the locking mode, the first actuation received by the traffic signal controller on a specified channel during the red interval is used to trigger a continuous call for service. This call is retained until the assigned phase is serviced, regardless of whether or not any vehicles are waiting to be served. Locking mode is usually associated with advance detection. Locking mode will prevent the ability of permissive movements (Right-turning vehicles) to be completed without invoking a phase change.
- **Non-Locking:** In the non-locking mode, an actuation received from a detector is not retained by the traffic signal controller after the actuation is dropped by the detection unit. The traffic signal controller recognizes the actuation only during the time when there is a vehicle in the detection zone. Non-locking mode is usually associated with stop line detection. When coupled with the delay parameter (See Section 8.2.3), non-locking mode allows permissive movements to be completed without invoking a phase change, potentially improving intersection efficiency (e.g. RTOR scenario).

All actuations received during a green interval are treated as non-locking by the traffic signal controller.

8.2.3 Detection Modifiers

Detector modifiers have the ability to alter the actuations received by the traffic signal controller to improve intersection operations.

- **Delay:** Delay is used to temporarily disable the detector output for a phase, essentially preventing vehicle actuations from being recognized right away by the signal controller. An actuation is not made available unless the delay timer has expired and the detection zone is still occupied. The delay parameter should be considered for RTOR scenarios. Its use is recommended for exclusive right-turn lanes on minor streets operating with stop line detection, presence mode detection, or adjacent through movement phases not on recall (See Section 8.3). An analysis of the number of gaps available on the major road is necessary to make sure that right-turning vehicles will not be further delayed when the delay parameter is in use. The delay setting could range from eight to twelve seconds, but should be fine-tuned for each individual location. The delay parameter should also be considered to prevent erroneous calls from being registered in the traffic signal controller if vehicles tend to traverse over another phase's detection zone. For example, left-turning vehicles often cut across the perpendicular left-turn lane at the end of their turning movement. A detector delay, coupled with non-locking memory, would prevent a call from being placed for the unoccupied detector. The delay setting could range from two to five seconds, but should be fine-tuned for each individual location.
- **Extend:** Extend is used to temporarily increase the duration of a detection actuation. An actuation continues to be made available to the traffic signal controller as the detection zone becomes unoccupied, and the call is retained until the extension timer expires. The extend parameter is typically used with detection designs that combine multiple advance detectors on high-speed intersection approaches. It is applied to advance detectors that extend the green interval to ensure that a vehicle approaching the intersection at design speed has sufficient time to reach the next downstream detector. The extend parameter setting is dependent on the approach speed, detector size; and distance between detectors. Typical values range up to two seconds.
- **Call:** The call parameter allows the traffic signal controller to receive actuations only when it is not timing a green interval. Therefore, actuations received during the green interval are ignored (no extension of the phase is possible). The call parameter is typically used with detection designs that combine advance detection and stop line detection. Here, the call parameter is set to the stop line detection to ignore the actuation these detectors receive during the green interval. Advance detection would be

used to ensure safe and efficient operation during the green interval. Locations where detection design uses only advance detection, but where a driveway exists between the stop line and the advance detection, can also benefit from a call detector. It would be placed on the driveway to ensure service to vehicles that have not crossed the advance detection.

- **Queue:** The queue parameter allows the traffic signal controller to receive actuations for a determined amount of time to service the initial queue, at which time it is deactivated until the start of the next conflicting phase. The call parameter is typically used with detection designs that combine advance detection and stop line detection. Here, the queue parameter is set to the stop line detection and practitioners would determine the amount of time necessary to serve the typical queue. Once that time is elapsed, the stop line detection is deactivated and the advance detection would be used to ensure safe operation during the remainder of the green interval.
- **Detector Switching:** Detector switching allows detectors to extend a call for one phase and then send calls to another phase (switch phase) once the extend phase ends. Detector switching is commonly used on left-turn lane detectors under protected/permissive operations. Vehicles detected on left-turn lanes are switched to extend the through phase during the permitted portion of the phase to provide more time for vehicles making left-turn movements. Detector switching is a recommended operational strategy when coordinated operation constrains and pedestrian timing requirements limit the ability of providing additional time to protected left-turn movements. Table 8.1 provides a summary of the typical settings for detector switching at a standard eight-phase intersection with protected/ permissive operation on all approaches.

Table 8.1 – Typical Detector Switching Settings

Phase	Extend Phase	Switch Phase	
		Five-Section Signal Head Protected/Permissive Operation	Flashing Yellow Arrow Protected/Permissive Operation
1	1	6	2
3	3	8	4
5	5	2	6
7	7	4	8

8.3 Phase Recalls

A phase recall causes the traffic signal controller to place a call automatically for a specified phase, regardless of the presence of any detector-actuated calls (vehicular or pedestrian). Phase recalls are most commonly used on major road through phases, causing the signal indication to rest in green on the main street in the absence of demand on other phases. There are four types of phase recalls: minimum recall, maximum recall, soft recall, and pedestrian recall. Table 8.2 provides typical phase recall settings assuming a single detector per lane.

8.3.1 Minimum Recall

The minimum recall parameter causes the traffic signal controller to place a call for vehicle service on a phase in order to serve at least its minimum green duration.

8.3.2 Maximum Recall

The maximum recall parameter causes the traffic signal controller to place a continuous call for vehicle service on a phase in order to run its maximum green duration every cycle.

8.3.3 Soft Recall

The soft recall parameter causes the traffic signal controller to place a call for vehicle service on a phase in the absence of a serviceable conflicting call.

8.3.4 Pedestrian Recall

The pedestrian recall parameter causes the traffic signal controller to place a continuous call for pedestrian service on a phase.

Table 8.2 – Typical Phase Recall Settings

<table>
<tr><th rowspan="2">Recall Mode</th><th colspan="2">Detection Location</th><th colspan="2">Memory Mode</th><th rowspan="2">Recommended Use</th></tr>
<tr><th>Stop Bar</th><th>Setback</th><th>Locking</th><th>Non-Locking</th></tr>
<tr><td rowspan="3">Minimum Recall</td><td>●</td><td></td><td></td><td>●</td><td rowspan="3">• Major road through movement phases; semi-actuated, non-coordinated intersections.
• Ensures that traffic signal controller will return to major road through movement phases regardless of demand, where it will rest in green until a conflicting call comes in. Phase green time is extended based on vehicle actuations.</td></tr>
<tr><td colspan="2">or</td><td colspan="2"></td></tr>
<tr><td></td><td>●</td><td></td><td>●</td></tr>
<tr><td>Maximum Recall</td><td colspan="2">No Detectors</td><td colspan="2">Not Applicable</td><td>• When fixed time operation is desired.
• When detection is temporarily out of service.
• Note: May result in inefficient operation.</td></tr>
<tr><td rowspan="3">Soft Recall</td><td>●</td><td></td><td></td><td>●</td><td rowspan="3">• Major road through movement phases; fully-actuated, non-coordinated intersections.
• Ensures that traffic signal controller will rest on these phases’ green in the absence of calls on conflicting phases, and allow major road through movement phases to be skipped in the absence of major street phase calls when calls exist on other phases.</td></tr>
<tr><td colspan="2">or</td><td colspan="2"></td></tr>
<tr><td></td><td>●</td><td>●</td><td></td></tr>
<tr><td>Pedestrian Recall</td><td colspan="2">Not Applicable</td><td colspan="2">Not Applicable</td><td>• Pedestrian detection is not present or out of service.
• High pedestrian demand on specific locations and/or at times of the day (downtown areas, schools, etc.).</td></tr>
</table>

8.4 Detection Design for Approaches Below 35 MPH

Providing efficient operations is the main objective when designing detection for approaches with a posted speed limit below 35 mph. Basically, the goal is to call the low-speed approach phases and clear the standing queue while minimizing delay. The use of only stop line detection is typical practice. The length of the detection zone and its parameter settings is dependent on the type of detection used. The use of large detection zones (either through a single larger detection zone or multiple smaller detectors) allows practitioners to reduce the passage time parameter (See Section 7.5.8), thus preventing premature termination of the phase due to sluggish traffic, yet allowing for snappy termination when the last vehicle passes the stop line. Fundamentally, the length of the detection zone provides the ability for the extension of the green interval, thereby improving intersection efficiency, since there is no need to time a larger passage time once the detection zone is not occupied. Figure 8.1 illustrates schematics for typical detection design for approaches below 35 mph. Figure 8.2 provides typical inductive loop (See Section 8.8.1) design for approaches below 35 mph.

Figure 8.1 – Typical Detection Design Schematics (< 35 MPH)

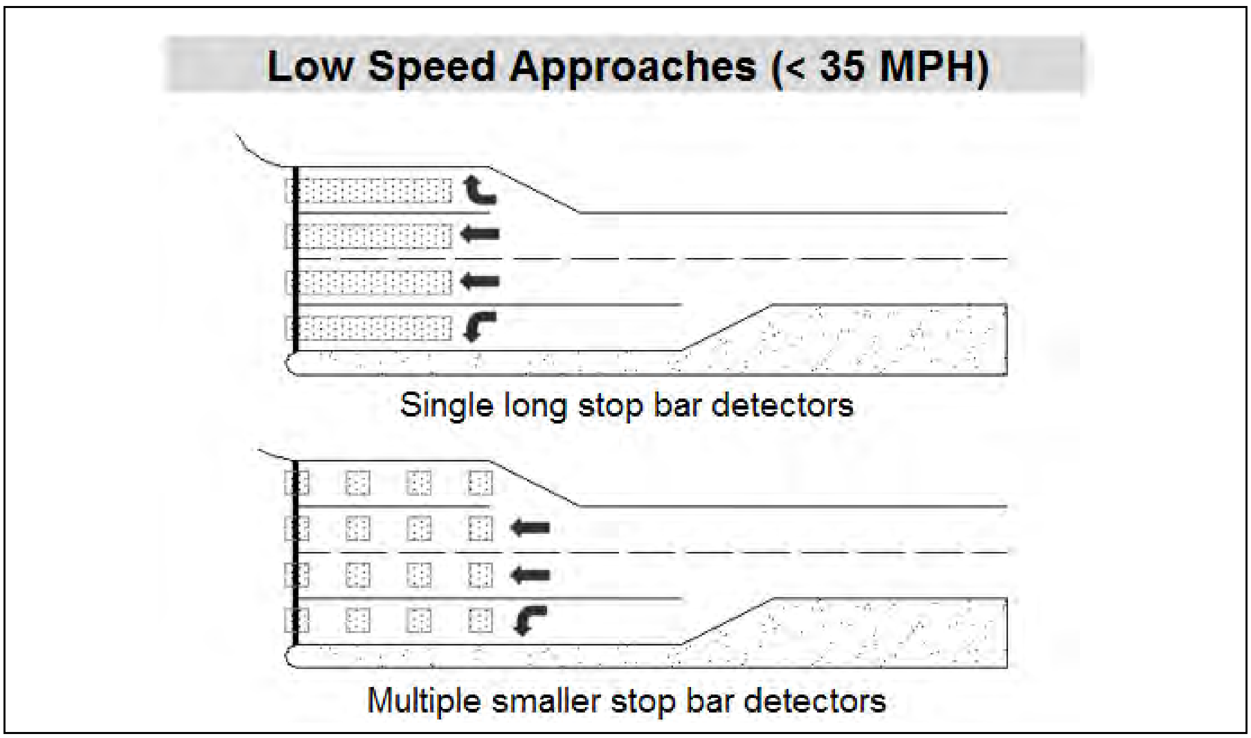
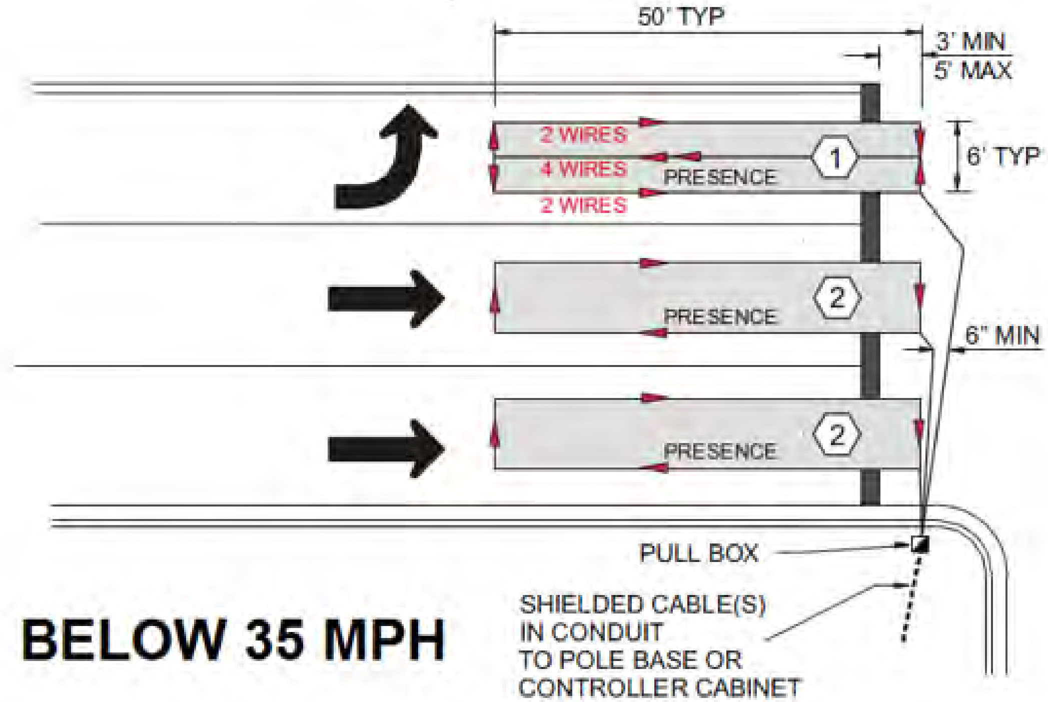


Figure 8.2 – Inductive Loop Detection (< 35 MPH)



Legend:

(2) Detector numbers

Settings:

Presence, Non-Locking

Notes:

- Loops with the same number indicate wired in series;

- Quadrupole design recommended for all lanes on major road if phases are not on recall.
- Quadrupole design recommended for all lanes on minor road.

8.5 Detection Design for Approaches 35 MPH or Above

Detection design on approaches with a posted speed limit 35 mph or above should focus on serving the queue at the beginning of green and safely terminate the phase once there is a conflicting call. The design of advance detection on approaches 35 mph or above requires special attention. Drivers, when faced with the onset of the yellow indication, may have problems deciding whether to stop or to proceed through the intersection. This scenario is related to two issues that are often confused:

8.5.1 Timing of the Yellow Change Interval

Incorrect timing of the yellow change interval will lead to a dilemma zone situation where a yellow is too short for a vehicle to safely enter the intersection, but the vehicle is too close to the stop line to safely stop. See Section 7.5.5 for recommendation on the appropriate timing of the yellow change interval. It is important to note that even with well-designed yellow change intervals, drivers will still experience the dilemma zone when driving above the design speed limit.

8.5.2 Driver Behavior

The human factors of driver perception, reaction, and judgment lead to an indecision zone where each individual driver makes a different decision upon seeing the yellow signal indication; some drivers may stop and others may go. Research has shown that the limits of the indecision zone tend to be between 5.5 (beginning) and 2.5 (end) seconds of travel time from the stop line. To minimize the effects of the indecision zone, advance detection should be located at the beginning of the indecision zone and settings (passage time, extension, or a combination of both parameters) programmed to prevent a phase from terminating before a vehicle clears the indecision zone. Once the vehicle has cleared the indecision zone, the onset of the yellow takes place. Appropriate yellow change and red clearance (See Section 7.5.5) should provide enough time for the vehicle to navigate safely through the intersection. Table 8.3 provides recommended advance detection location.

Table 8.3 – Typical Advance Detection Placement

Approach Vehicular Speed (MPH)	Begin of Indecision Zone (5.5 Seconds from Stop Line) (Feet)	End of Indecision Zone (2.5 Seconds from Stop Line) (Feet)	Setback Detection Placement Distance from Stop Line (Feet)
35	285	125	285
40	325	145	325
45	365	165	365
50	405	180	405
55	445	200	445
60	485	220	485

In summary, appropriate timing of the yellow change interval for the design speed, coupled with detection and settings that minimize the chance for a vehicle to be in the indecision zone on the onset of the yellow signal display, will provide acceptable approach detection design. Detection design for approaches 35 mph or above varies from simple advance detection designs to more complex designs using two or three advance detectors, with some designs incorporating stop line detection and advance detection together. When a phase maxes out (See Section 7.5.8) or is forced off by coordination (See Section 7.6), there is no indecision zone protection. Figure 8.3 illustrates schematics for typical detection designs for approaches 35 mph or above. Figure 8.4 provides typical inductive loop (See Section 8.8.1) design for approaches 35 mph or above. The FHWA *Traffic Detector Handbook Volumes 1 and 2* provides additional information on detection designs for all approaches.

Figure 8.3 – Typical Detection Design Schematics (≥ 35 MPH)

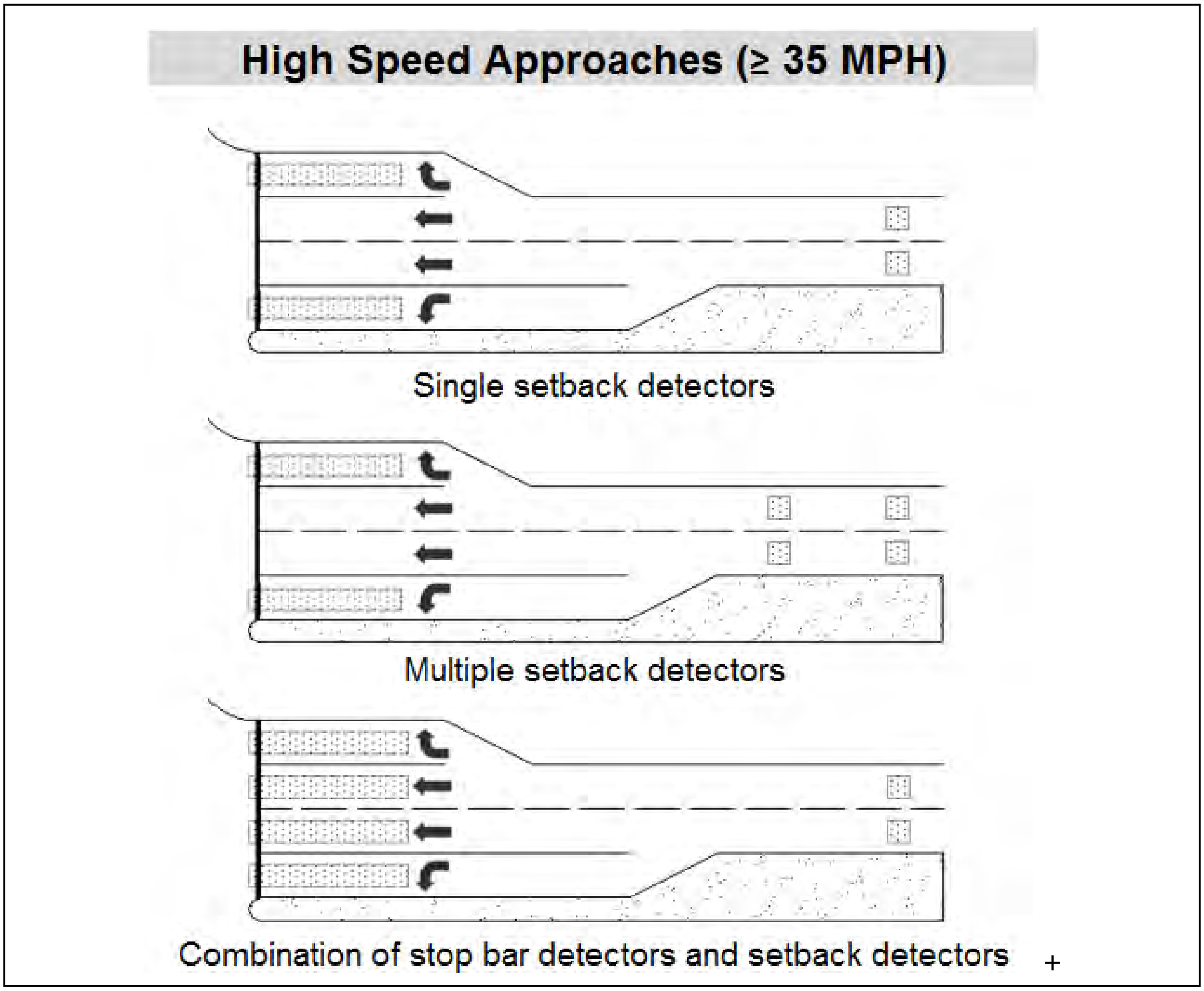
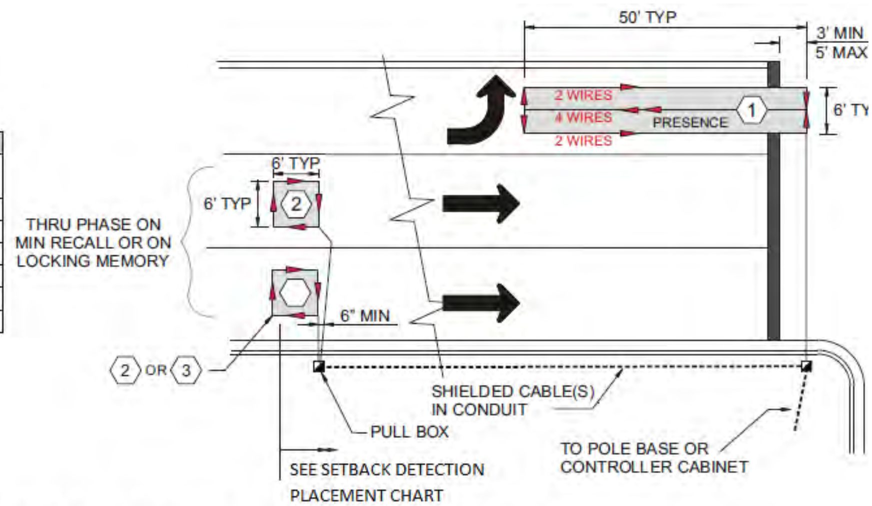


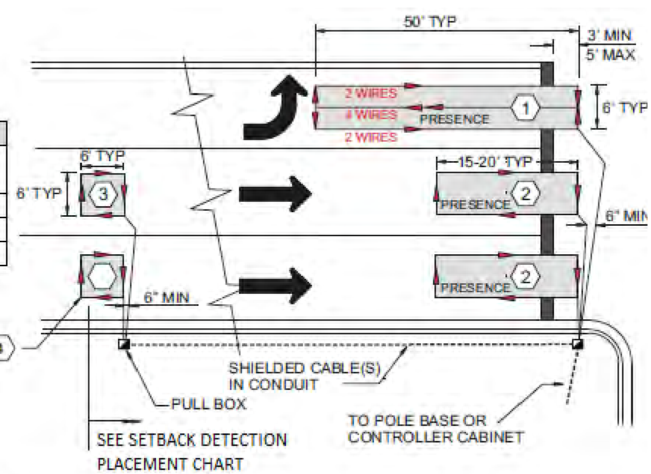
Figure 8.4 – Inductive Loop Detection (≥ 35 MPH)

SETBACK DETECTION PLACEMENT	
APPROACH SPEED (MPH)	DISTANCE TO STOP BAR (FT)
35	285
40	325
45	365
50	405
55	445
60	485



TYPICAL HIGH SPEED APPROACH

LOOP TURNS		
LOOP LENGTH	NO. TURNS IN ASPHALT	NO. TURNS IN CONCRETE
6 - 24'	3	4
24 - 50'	2	3
QUADRUPOLE	2-4-2	3-6-3



ALTERNATE HIGH SPEED APPROACH

8.6 Detection Design for Coordinated Systems

In coordination (See Section 7.6), the coordinated phases (typically major road through movements) are guaranteed their split time every cycle. Therefore, it is common practice to have no detectors for the major road through phases. However, practitioners should plan for adequate serving of major road through phases during times that the intersection is not operating in a coordinated system. This can be accomplished with the use of detection or a maximum recall (efficiency issues). Especially in the case of video detection, there is usually no additional cost for setting up detection zones on the major road through movements, and practitioners should take advantage of traffic signal controller features that may improve intersection operational efficiency by monitoring the end of the coordinated phases.

8.7 Pedestrian Detection

When an intersection provides pedestrian signal phasing (See Section 7.4), the servicing of pedestrians shall be accomplished by the use of pushbuttons, passive detection devices, or a pedestrian recall (See Section 8.3.4). Passive detection devices register the presence of a pedestrian in a position indicative of a desire to cross without requiring the pedestrian to push a button. Some passive detection devices are capable of tracking the progress of a pedestrian as the pedestrian crosses the roadway for the purpose of extending or shortening the duration of certain pedestrian intervals. When a pedestrian recall is used, its associated vehicular green phase time shall accommodate, at a minimum, the required pedestrian interval timings. Pedestrian pushbuttons should be located within easy reach of pedestrians and should be positioned in such a way to make it obvious which pushbutton is associated with each crosswalk. Practitioners shall refer to the *MUTCD Section 4E.08* for requirements and guidance on pushbutton locations and related signs. Consideration should be given to the use of additional pedestrian pushbuttons on islands or medians and the use of pilot lights.

8.7.1 Accessible Pedestrian Signals

Practitioners shall refer to the *MUTCD Sections 4E.09 through 4E.13* for accessible pedestrian signals. The ADA requires access to the public right-of-way for people with disabilities. Access to traffic and signal information is an important feature of accessible sidewalks and street crossings for pedestrians who have vision impairments. While most intersections pose little difficulty for independent travelers who are blind or have low vision, there are some situations in which the information provided by an accessible pedestrian signal is necessary for independent and safe crossing. The primary technique that pedestrians who have visual disabilities use to cross streets at signalized locations is to initiate their crossing when they hear the traffic in front of them stop and the traffic alongside them begin to move, which often corresponds to the onset of the green interval. The existing environment is often not sufficient to provide the information that pedestrians who have visual disabilities need to cross a roadway at a signalized location as referred to in the *MUTCD Section 4E.09*. If a particular signalized location presents difficulties for pedestrians who have visual disabilities to cross the roadway, an engineering study should be conducted that considers the needs of pedestrians in general, as well as the needs of pedestrians with visual disabilities. The engineering study should consider the following factors:

- Potential demand for accessible pedestrian signals;
- A request for accessible pedestrian signals;
- Traffic volumes during times when pedestrians might be present, including periods of low traffic volumes or high RTOR volumes;
- The complexity of traffic signal phasing (such as split phases, protected turn phases, leading pedestrian intervals, and exclusive pedestrian phases); and
- The complexity of intersection geometry.

The FHWA recommends that jurisdictions have a policy on accessibility including the use of accessible pedestrian signals on new construction projects, as well as a transition plan to retrofit established locations.

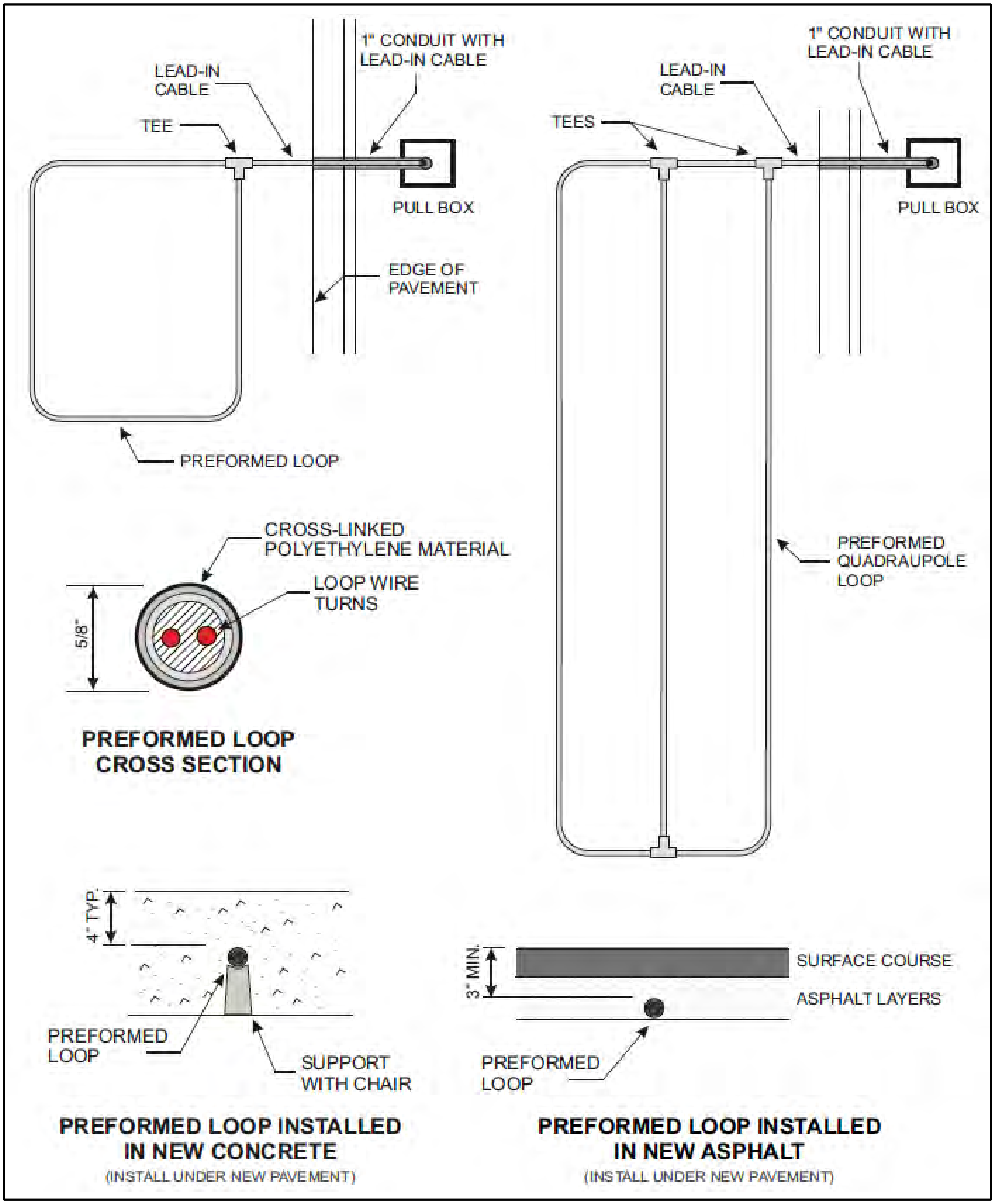
8.8 Types of Detection

Many different technologies exist to enable detection of vehicles at an intersection. These can be categorized by in-ground and above-ground detection. Inductive loops and magnetometers are in-ground types of detection and, due to the necessity of pavement cutting for installation, they are also considered intrusive detection. Video, radar (microwave), and thermal are types of above-ground detection and are considered non-intrusive detection. Pushbuttons are the most appropriate type of detection for pedestrians, while for bicycles, inductive loops are typical. Detection is also necessary for vehicles receiving preferential treatment at intersections, such as emergency vehicles, buses, light rail transit, and trains. Types of preferential treatment detection typically include GPS, hard-wired loop, light-based, radio-based, sound-based, and station pushbutton. Detailed information on types of detection can be found in the FHWA *Traffic Detector Handbook Volumes 1 and 2*. The following provides information on typical vehicular detection used in Tennessee.

8.8.1 Inductive Loop Detection

The inductive loop detects vehicles by sensing a change of inductance caused by the passage or presence of a vehicle over the loop. Inductive loops are placed in the pavement by saw cutting a slot, installing loop wire, and encapsulating the wire by filling the saw cut with sealant. The induction detector is made up of three components: a loop of wire, a lead-in (shielded) cable, and a detector processing unit (detector amplifier) in the controller cabinet. The life of a regular inductive loop which is saw cut into the pavement is dependent on the condition of the pavement and it must be replaced each time a road is milled and resurfaced. When long term maintenance is a concern, an alternative to the traditional saw cut inductive loop (other than video, radar, etc.) for new construction projects is the preformed inductive loop. Preformed inductive loops function similarly to a regular saw cut loop; however, the conductor is encased in a heavy duty plastic housing. The loops are placed within concrete or in the lower lifts of asphalt prior to final paving (See Figure 8.5). Preformed loops can last longer than traditional saw cut loops and should be strongly considered on new construction projects where maintenance of saw cut loops is an issue. While they can be installed in existing pavement, preformed loops are not recommended due to the size of the saw cut required. A presence detector should be able to detect all licensed motor vehicles, including a small motorcycle. A conventional long rectangular inductive loop may not detect a small motorcycle. A common inductive loop configuration that provides greater detection capabilities is the quadrupole loop. Quadrupole loops also provide more accuracy in vehicle detection and minimize false detections from adjacent through lanes. Figures 8.2 and 8.4 illustrate typical inductive loop layout recommended by TDOT. Refer to TDOT *Standard Drawing T-SG-3* for additional information on inductive loop detection.

Figure 8.5 – Preformed Inductive Loop



8.8.2 Video Detection

Video detection detects vehicles by sensing a change in the properties of image pixels caused by the passage or presence of a vehicle over user-defined virtual detection zones. Video detection is provided by cameras mounted above the ground on stable fixtures, typically on mast arms, poles, or luminaire arms. Video detection can be considered for a signalized intersection or interchange when one or more of the following conditions are present:

- When a large number of detectors is needed at the location (twelve or more);
- When inductive loop life is short due to poor pavement conditions;
- When extensive intersection reconstruction will last for one or more years;
- When inductive loop installation is physically impractical due to the presence of a bridge deck, railroad tracks, or underground utilities;
- When the pavement in which the inductive loop is placed will be reconstructed in less than three years or during overlay projects at large intersections where the cost of replacing all inductive loops exceeds the cost of installing video detection.

Camera position is the primary factor for successful video detection operation. The optimal camera location maximizes detection accuracy by being stable, by having an unobstructed view of each traffic lane on the approach, and by excluding the horizon. Consideration should also be given to sight lines affected by sun glare, shadows, and headlight glare during different times of the day, or by moving power lines, utility cables, or any light-generating source that may trigger unnecessary calls. Fog, snow, and heavy rain may also be a problem for video detection and practitioners should explore equipment failsafe operation. Cameras should not be mounted below 24 feet in height to minimize equipment maintenance (dirt, spray, and mist on lenses). Detection zone layout varies by equipment vendor, but due to its ease and flexibility, the use of longer detection zones (greater than 60 feet) and low passage time (close to zero seconds) is recommended for intersection efficiency. Typically, an additional camera (located upstream from the intersection) is needed for advance detection. Refer to TDOT *Standard Drawing T-SG-3A* for additional information on video detection.

8.8.3 Radar Detection

Radar detection detects and tracks vehicles by sensing a change in the influence area of the radar transmitter caused by the passage or presence of vehicles over user-defined virtual detection zones. Radar detection continuously tracks vehicles in the influence area and is provided by corner fire and/or forward fire units. To capture true presence detection where vehicles are continually tracked throughout the presence detection phase, a second radar unit may be necessary for the mainline approaches (one unit for the stop bar detection and one unit for the advanced detection). Multiple detection zones can be designed at the stop line and vehicles can be detected and tracked as far as 600 feet upstream, providing better indecision zone protection. Radar detection should be considered for a signalized intersection or interchange for the same reasons mentioned for video detection (See Section 8.8.2). Radar detection is not influenced by obstructions and is not affected by sun glare, shadows, headlight glare, light sources, and weather-related issues, which provides very low maintenance needs. Refer to TDOT *Standard Drawing T-SG-3A* for additional information on radar detection.

[This page intentionally left blank.]

CHAPTER 9

TRAFFIC SIGNAL DESIGN – SUPPORTS AND SIGNAL HEADS

9.1 Traffic Signal Supports

The two basic types of traffic signal supports are strain poles and mast arm poles. Traffic signal supports shall be in accordance with current TDOT standards and specifications and the AASHTO *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. In addition, traffic signal supports shall be in accordance with the NEC and the NESC. Adjacent utility poles shall not be used for traffic signal supports in new installations, unless physical conditions preclude the installation of separate traffic signal supports. In these cases, it is important to coordinate the traffic signal design and installation with the affected utility company. TDOT no longer supports the utilization of its Intersection Pole Designer Software for use in the design of traffic signal pole foundations. Based on the traffic signal layout and other information provided in the bid documents, the traffic signal contractor shall be responsible for the design and installation of traffic signal poles and their associated foundations.

9.1.1 Traffic Signal Strain Poles

A traffic signal strain pole is a pole (wood, steel, or concrete) to which span wire is attached for the purpose of supporting the signal wiring and signal faces (See TDOT *Standard Drawings T-SG-1, T-SG-4, and T-SG-8*). Wood poles should only be used for temporary traffic signal installations. Steel or concrete strain poles should be considered when span lengths exceed 90 feet or easements/right-of-way will be required for guy wires. Traffic signal strain poles should also be considered when a box span arrangement is used to provide additional strength.

- **Span Length:** Strain poles should be located so as to limit the distance between the stop line and the signal heads to a maximum of 180 feet. The minimum breaking strength for span wires shall be noted in the plans. Each span wire shall be grounded.
- **Strain Pole Height Determination:** The height of a strain pole is determined by Equation 9.1. When providing a pole height on signal plans, it is important to specify that the top of the pole foundation should usually be at the same elevation as the roadway crown. In cut areas, fill may be required to prevent the foundation from protruding out of the ground. An exception is on high-fill roadway sections where the pole must be located outside of the fill area. Consideration must be made to ensure an adequate pole length is specified in such a situation.

$$PH = 2 + L_sS + c + H + d$$

Equation 9.1 – Pole Height

Where:

PH = Pole Height (feet)
L_s = Maximum Span Length (feet)
S = Design Sag (typically 5%)
c = Clearance above Road (17.5 feet typical)
H = Height of Signal Head with Backplate (usually 4.5 feet)
d = Side-slope Drop-off (feet from crown of road)

Where two span wires attach to the same strain pole, the pole height will be determined by using the longer of the two span wires. Pole heights shall be rounded up where necessary to be specified in even number feet (i.e. 26, 28, 30, etc.).

- **Strain Pole Location:** Generally, strain poles should be located outside of the clear zone, inside the right-of-way.
  - **Signal Location:** Strain poles should be located so that signal faces hung on their span wire are located between 40 to 180 feet from the approach stop line.
  - **Minimum Horizontal Clearances:** On curbed roadways, poles shall be located no closer than two feet to the front of curb. In all cases, traffic signal poles should be located as far as practical from the edge of the travel lane without adversely affecting signal visibility.
  - **Pedestrian Considerations:** When installing a pedestrian pushbutton, poles should be located adjacent to the sidewalk within reach of pedestrians in accordance with the *MUTCD*.
- **Luminaires:** Where street lights are installed on traffic signal poles, their design shall be integrated with the pole and they shall be mounted at a minimum height of 30 feet above the roadway. Actual mounting height shall be determined by the luminaire photometrics.
- **Tether Wires:** Tether wires shall be installed on all span wire assemblies to minimize traffic signal face movement due to wind effects. Tether wires must be able to breakaway from poles when hit or snagged.
- **Span Wire Layouts:** Span wire layouts in general allow for further pole placement from the roadway than do mast arm installations. In addition, they eliminate the need for boring under the roadway by allowing signal and detector cables to be run overhead on the signal span wire. If possible, diagonal span wire layouts should always be avoided. Typical strain pole span wire layouts are shown in Figure 9.1. The following are the most common span wire arrangements:

- **Box Span Arrangement:** This signal arrangement is the most common and places strain poles on each of the four corners of the intersection.

  Advantages:

  - Allows good alignment of signal heads;
  - Provides the required minimum 40-foot distance between the signal heads and stop line on all approaches;
  - Provides shorter span wire lengths and sag than diagonal spans;
  - Provides locations for pedestrian signals.

  Disadvantages:

  - Requires four poles;
  - Could require supplemental signal faces if the signal faces are more than 180 feet beyond the approach stop line.

- **Suspended Box Arrangement:** This signal arrangement is a box span arrangement, but the box is connected to the poles by diagonal spans. This is typically used at large intersections in order to minimize the distance between signal faces and the stop line. A variation where two corners of the box are connected by diagonal spans and the other two corners are connected directly to the poles is often used for skewed intersections. The suspended box arrangement should be avoided, if possible, due to potential issues maintaining the height of traffic signal faces.

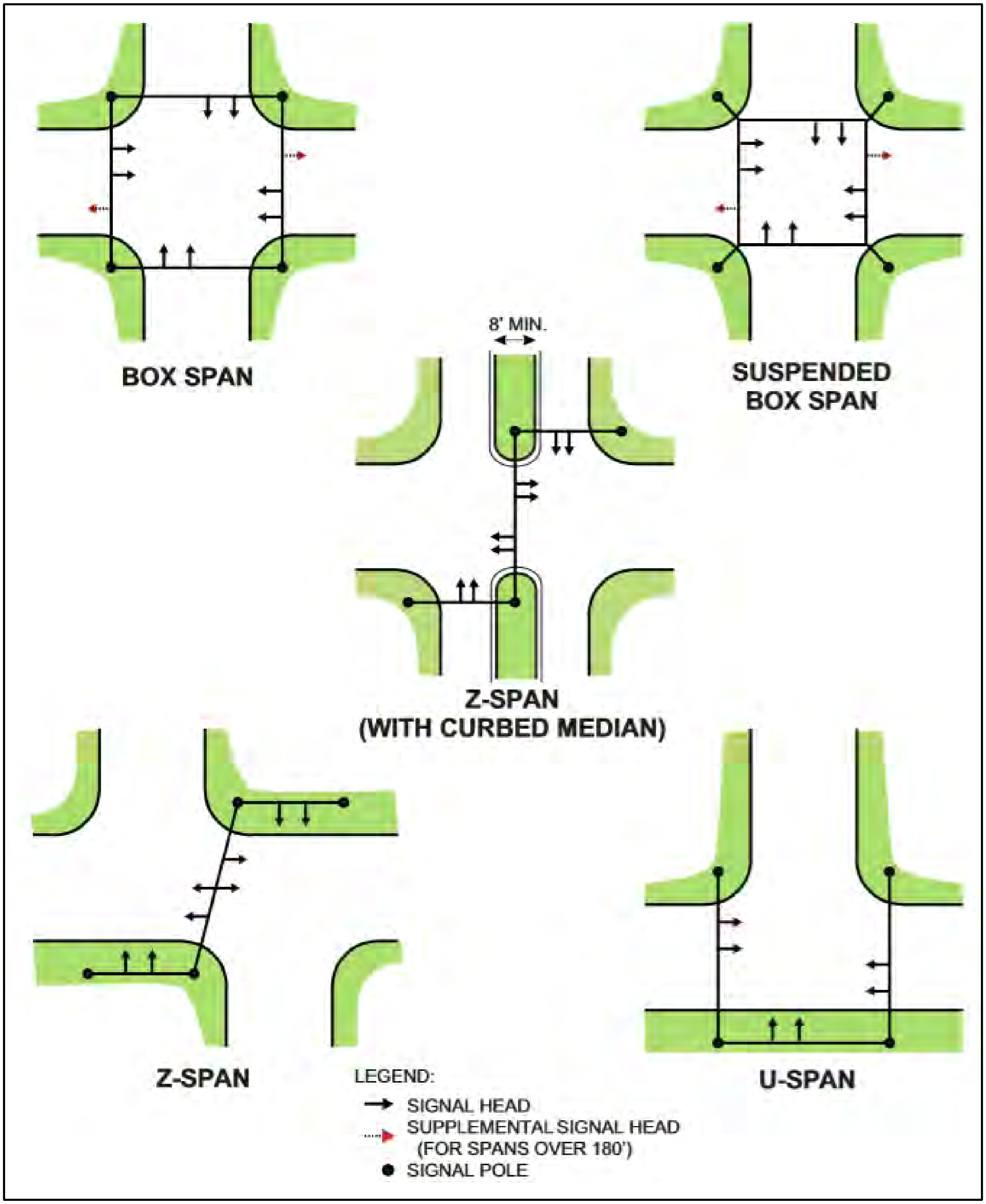
  Advantages:

  - Same advantages as box arrangements, plus;
  - Decreased distance between the signal heads and stop line.

  Disadvantages:

  - Same as box span arrangement but more difficult to install.

Figure 9.1 – Typical Strain Pole Span Wire Layouts



- **Z-Span Arrangement:** Z-spans are applicable at offset intersections. Z-span installations may be applicable on divided roadways where median clear zone requirements can be met.

  Advantages:

  - On divided roadways, shorter span wires are required across the street with the median;
  - Provides good signal face placement for offset intersections.

  Disadvantages:

  - On divided roadways, it places traffic signal poles in median areas, where they are more likely to be struck by vehicles. Check clear zone requirements;
  - On divided roadways, additional pedestal poles may be needed if pedestrian signals and detectors are required;
  - On divided roadways, pedestrians cannot see the parallel signal indications once they get to the median area.

- **U-Span Arrangement:** U-spans are applicable at T-intersections.

  Advantages:

  - Reduces the span wire length needed.

  Disadvantages:

  - Adds signal cable length;
  - Depending upon the surrounding terrain, guy wires may be needed to support the strain poles.

9.1.2 Traffic Signal Mast Arm Poles

A mast arm pole is a cantilever structure that permits the overhead installation of the signal faces without overhead messenger cables and signal wiring, which is run inside the arm structure (See TDOT *Standard Drawing T-SG-9*). Mast arm supports provide a more rigid mounting for signal heads and overhead signs than do span wire installations. They also require less maintenance because signal faces and signs are less likely to rotate or turn around in the wind. Mast arm installations are more aesthetically pleasing than span wire installations, since there is no overhead span wire or visible signal wiring. Mast arm supports are considered when they would result in fewer overall poles, when utilities are underground, or when aesthetics are a concern. Generally, mast arm layouts are more expensive than strain pole layouts. However, through the use of dual mast arm poles, mast arm layouts can reduce foundation and mast arm support costs, and they can become cost comparable to strain pole layouts. The installations of traffic signal mast arms are also more expensive then strain poles because they require boring under the roadway to route signal and detector cables to the controller cabinet.

- **Traffic Signal Mast Arm Length:** Mast arm length must be specified on signal plan sheets. The arm length is determined by taking into account signal face placement in relation to the approach travel lanes and the pole distance off the edge of the travel way. Mast arm lengths shall be limited to 90 feet or less. In mast arm lengths ranging from 50 to 90 feet, the last signal head on a mast arm is located at least seven feet from the end of the mast arm due to a damper plate installation being required. In addition, mast arms with at least one mast arm greater than 60 feet shall require a 4-foot diameter width for the foundation. When twin mast arms are utilized, the combined length between the two mast arms shall not exceed 120 total feet.
- **Traffic Signal Mast Arm Height:** Typical mast arm poles have a 22-foot shaft, unless street lighting is integrated with the traffic signal pole. Refer to TDOT *Standard Drawing T-SG-9* for additional information on street lighting supports.
- **Traffic Signal Mast Arm Pole Location:** The requirements are the same as those listed for the location of strain poles (See Section 9.1.1).
- **Luminaires:** The requirements are the same as those listed for the location of strain poles (See Section 9.1.1).
- **Traffic Signal Mast Arm Pole Layouts:** The following describes the two layouts of traffic signal mast arm poles, single and dual, and shown in Figure 9.2.
  - **Single Mast Arm Layout:** A typical single mast arm installation can be used at the intersection of two undivided roadways.

    Advantages:

    - Provides the required minimum 40-foot distance between the signal heads and stop line of all approaches;
    - Provides good far-side signal face visibility for pedestrians;
    - Provides locations for pedestrian signal indications and pedestrian detectors where needed.

    Disadvantages:

    - Requires four mast arm poles and foundations for a typical four-leg intersection.

- **Dual Mast Arms Layout:** The dual mast arm arrangement is often applicable at offset intersections and at T-intersections.

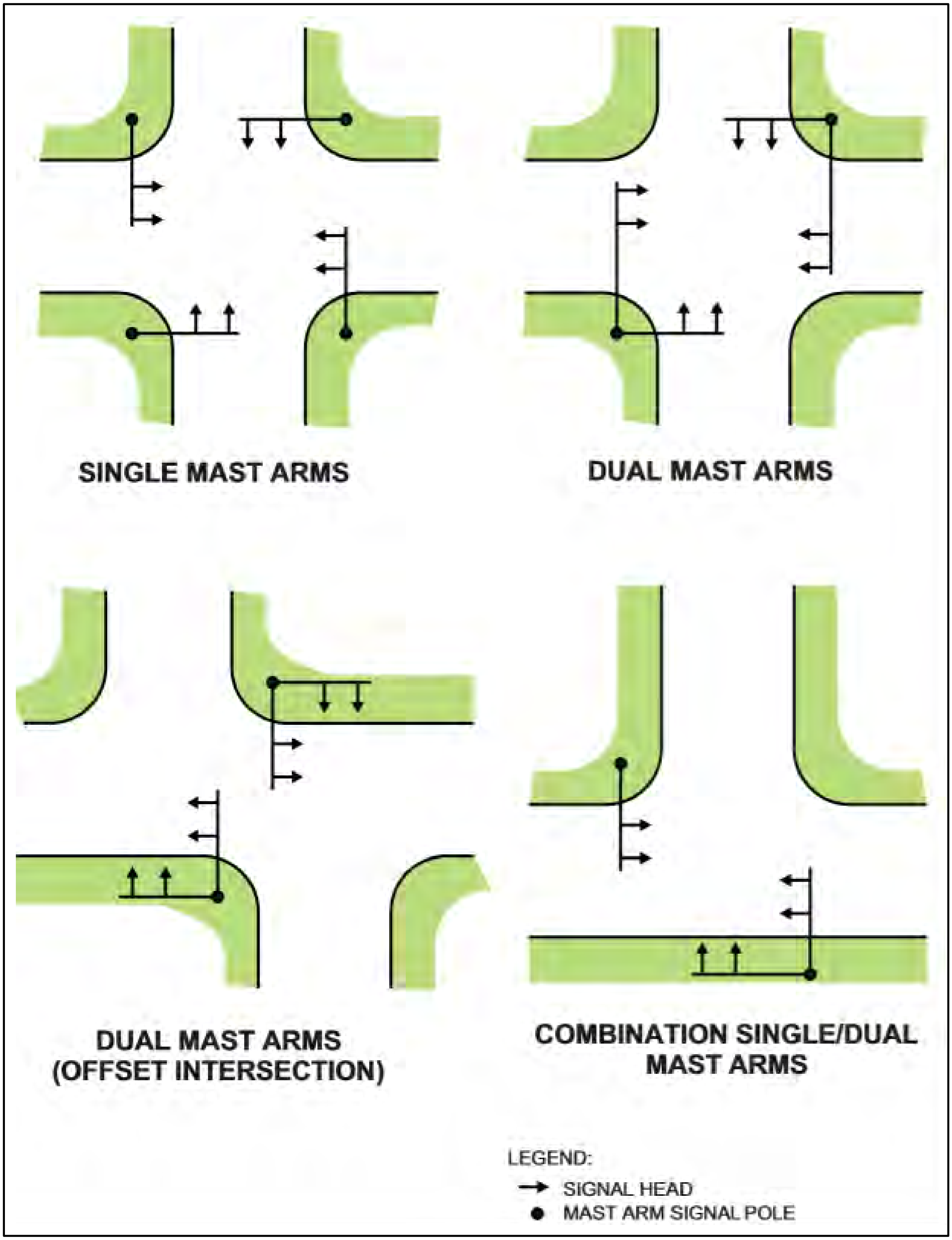
  Advantages:

  - Uses fewer poles than a strain pole or single mast arm arrangement;
  - Provides good signal face placement for offset intersections;
  - Good for locations with corners lacking right-of-way for poles.

  Disadvantages:

  - Additional traffic signal poles may be needed if pedestrian signals and detectors are required;
  - Sight lines to the signal faces may be obscured.

Figure 9.2 – Typical Mast Arm Pole Layouts



9.2 Traffic Signal Indications

Traffic signal indication design shall comply with the *MUTCD Sections 4D.04 through 4D.25*. In addition, the following information should be considered.

9.2.1 Lens Size, Illumination and Shielding

All new traffic signal vehicular indications should be 12-inch diameter LED lenses (See TDOT *Standard Drawing T-SG-7*). The use of LED lights conserves energy and reduces maintenance requirements. As a minimum, all signal indications shall be equipped with cut away or tunnel visors (See Section 9.2.12). Signal visors exceeding twelve inches in length shall not be used on free-swinging signal faces.

9.2.2 Traffic Signal Housing

Aluminum or polycarbonate traffic signal housings are recommended for traffic signal indications. Due to its light weight, polycarbonate traffic signal housing must either be tethered or rigidly mounted to minimize wind sway. Tethered traffic signal housing must have break-away clamps to allow it to swing free during heavy wind conditions. Aluminum traffic signal housing weigh more, but require less maintenance and is more durable than polycarbonate traffic signal housing. Traffic signal housing should have a black or yellow finish. The inside of signal visors and the entire surface of louvers and fins shall have a dull black finish.

9.2.3 Traffic Signal Backplates

Traffic signal backplates increase the contrast between the signal indications and the signal background. Backplates shall be used at all rural locations, on approaches 45 mph or greater, and at urban locations where glare or other visual distractions are present which include a rising/setting sun or intensive advertising signing along the roadway. Where used, backplates shall have a dull black finish along with a retro-reflective strip around the border of the backplate (See TDOT *Standard Drawing T-SG-9A*).

9.2.4 Strobe Lights

The use of strobe lights within or adjacent to any traffic signal indication is prohibited.

9.2.5 Countdown Displays

The use of countdown displays as part of a vehicular traffic signal indication is prohibited.

9.2.6 Number of Signal Faces and Arrangement on an Approach

The number of primary signal faces and the need for supplemental signal faces is determined by the following criteria:

- **Primary Signal Faces:** If a signalized through movement exists on an approach, a minimum of two primary signal faces shall be provided for the through movement. If a signalized through movement does not exist on an approach, a minimum of two primary signal faces shall be provided for the signalized turning movement that is considered to be the major movement from the approach. Where two or more left-turn lanes are provided for a separately controlled protected only left-turn movement, a separate primary left-turn face shall be provided for each lane. The same applies for right-turn lanes.
- **Supplemental Signal Faces:** Supplemental signal faces are used to maximize visibility of traffic signal indications, to minimize issues of approaching vehicles traveling behind large vehicles (trucks, buses, etc), or in locations where sun glare is problematic. A supplemental near-side signal face is required where primary signal faces are located more than 180 feet beyond the stop line. A supplemental near-side signal face may be beneficial where primary signal faces are located between 150 feet and 180 feet from the stop line. A supplemental near-side or far-side signal face may also be beneficial where approaching speeds are 45 mph or greater.

Typically, traffic signal faces should be centered over the lanes to which they apply or positioned over lane lines between lanes (shared signal faces). Depending upon the number of approach lanes to the intersection and the traffic signal phasing operation for that approach, the number and type of traffic signal faces will vary. Refer to TDOT *Standard Drawing Series T-SG-7A to T-SG-7S* for additional information regarding typical signal head placement on intersection approaches. For additional information regarding specific lane configurations or for alternative arrangements of signal faces, refer to the *MUTCD*.

9.2.7 Visibility of Signal Faces on an Approach

The two primary signal faces required as a minimum for each approach should be continuously visible to traffic approaching the traffic control signal, from a point at least the minimum sight distance provided in Table 9.2 in advance of and measured to the stop line. This range of continuous visibility should be provided unless precluded by a physical obstruction or unless another signalized location is within this range. If approaching traffic does not have a continuous view of at least two signal faces for at least the minimum sight distance shown in Table 9.1, a sign (two signs in case of a median) shall be installed to warn approaching traffic of the traffic control signal and a warning beacon may be used.

Table 9.1 – Minimum Sight Distance for Signal Visibility

Approach Speed (mph)	Minimum Sight Distance for Signal Visibility (Feet)
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

Note: Distances in this table are derived from stopping sight distance plus an assumed queue length for shorter cycle lengths (60 to 75 seconds).

9.2.8 Mounting Height of Signal Faces

Table 9.2 provides the minimum vertical clearance (from the bottom of the signal housing to the roadway, sidewalk, or median) and the maximum mounting height (from the roadway, sidewalk, or median to the top of the signal housing) for vertical and horizontal mounting of traffic signal faces. It is good practice to align red signal indications at the same height. Table 9.3 provides the maximum mounting height to the top of the signal housing for overhead signals located between 40 feet and 53 feet from the stop line (See Figure 9.3). Individual signal sections shall be mounted vertically rather than horizontally, unless sight distance or vertical clearance concerns dictate.

Table 9.2 – Mounting Height of Signal Faces

<table>
<tr><th>Mounting</th><th>Location</th><th>Minimum Height to Bottom (Feet)</th><th>Maximum Height to Top (Feet)</th></tr>
<tr><td rowspan="4">Vertical</td><td rowspan="2">Roadway</td><td>17.5 (Recommended)</td><td rowspan="2">25.6</td></tr>
<tr><td>16.5 (Minimum)</td></tr>
<tr><td>Sidewalk</td><td>8</td><td>19</td></tr>
<tr><td>Median</td><td>4.5</td><td>19</td></tr>
<tr><td rowspan="4">Left-Turn</td><td rowspan="2">Roadway</td><td>17.5 (Recommended)</td><td rowspan="2">25.6</td></tr>
<tr><td>16.5 (Minimum)</td></tr>
<tr><td>Sidewalk</td><td>8</td><td>22</td></tr>
<tr><td>Median</td><td>4.5</td><td>22</td></tr>
</table>

Table 9.3 – Mounting Height to Top of Signal Housing (40-53 Feet)

Horizontal Distance from Stop Line (Feet)	Height to Top of Signal Housing Above Pavement (Feet)
40	21.0
41	21.3
42	21.7
43	22.1
44	22.4
45	22.7
46	23.2
47	23.5
48	23.8
49	24.2
50	24.5
51	24.9
52	25.3
53	25.6

Note: Distances in this table are derived from stopping sight distance plus an assumed queue length for shorter cycle lengths (60 to 75 seconds).

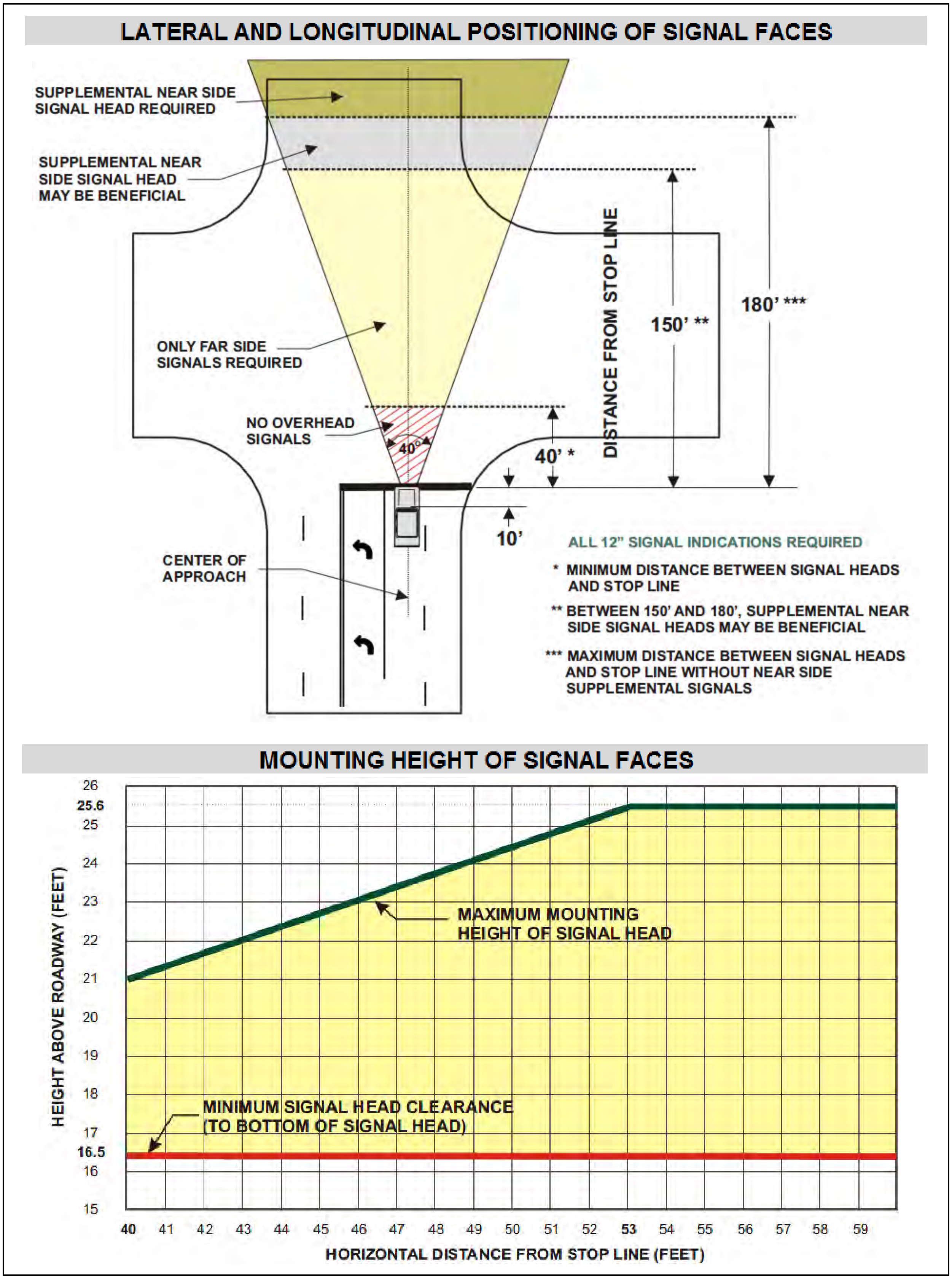
9.2.9 Lateral and Longitudinal Positioning of Signal Faces

At least one and preferably both of the two minimum primary signal faces required in Section 9.2.6 shall be located within the cone of vision illustrated in Figure 9.3. Signal faces on the same span wire or mast arm are typically placed twelve feet apart and shall be placed no closer than eight feet of horizontal separation between faces on the same movement (measured from center to center).

9.2.10 Shared and Separate Signal Faces

A shared signal face controls both a turn movement and the adjacent through movement, always displaying the same color of circular signal indication as the adjacent through signal face. A shared signal face can serve as one of the two required primary signal faces for the through movement (See Section 9.2.6). A separate signal face exclusively controls a turn movement and displays indications that are applicable only to the turn movement. A separate signal face cannot serve as one of the two required primary signal faces for the through movement.

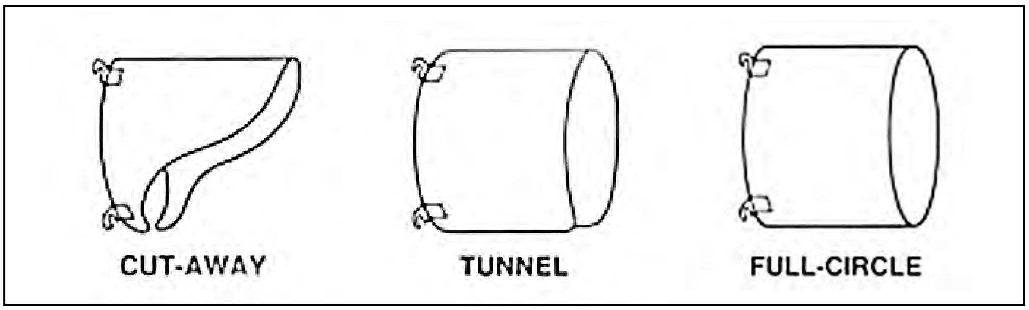
Figure 9.3 – Positioning of Signal Faces



9.2.11 Signal Head Visors

A signal head visor shall be in accordance with the *MUTCD* and should be used to direct the signal indication to the appropriate approaching traffic, especially if conflicting signal faces are readily visible, and to reduce sun phantom which can result when external light enters the lens. A signal head visor should be used with each lens on the signal head face and are made of the same material as the housing. The rear of the signal head visor must have four, slotted mounting tabs for easy attachment and for securing the visor to the signal housing door. The signal head visor mounting method must permit the signal head visor to be rotated and secured at 90 degrees for horizontal signal head installations. The signal head visor shall have a minimum length of 9.5 inches and a minimum downward tilt of 3.5 degrees measured from the center of the lens. There are three types of signal head visors: cut-away, tunnel, and full-circle visors as shown in Figure 9.4.

Figure 9.4 – Types of Signal Head Visors



Cutaway visors, sometimes referred to as a cap or partial visors, are signal head visors with the bottom cut away. This type of signal head visor reduces water and snow accumulation and does not let birds build nests within the visor.

Tunnel visors reduce the signal visibility from other approach directions by providing an almost complete circle around the lens. Tunnel visors look like an inverted "U" that encircles and shields the lens from a minimum 300 degrees with the opening at the most bottom of the lens. This type of signal head visor reduces water and snow accumulation and does not let birds build nests within the visor.

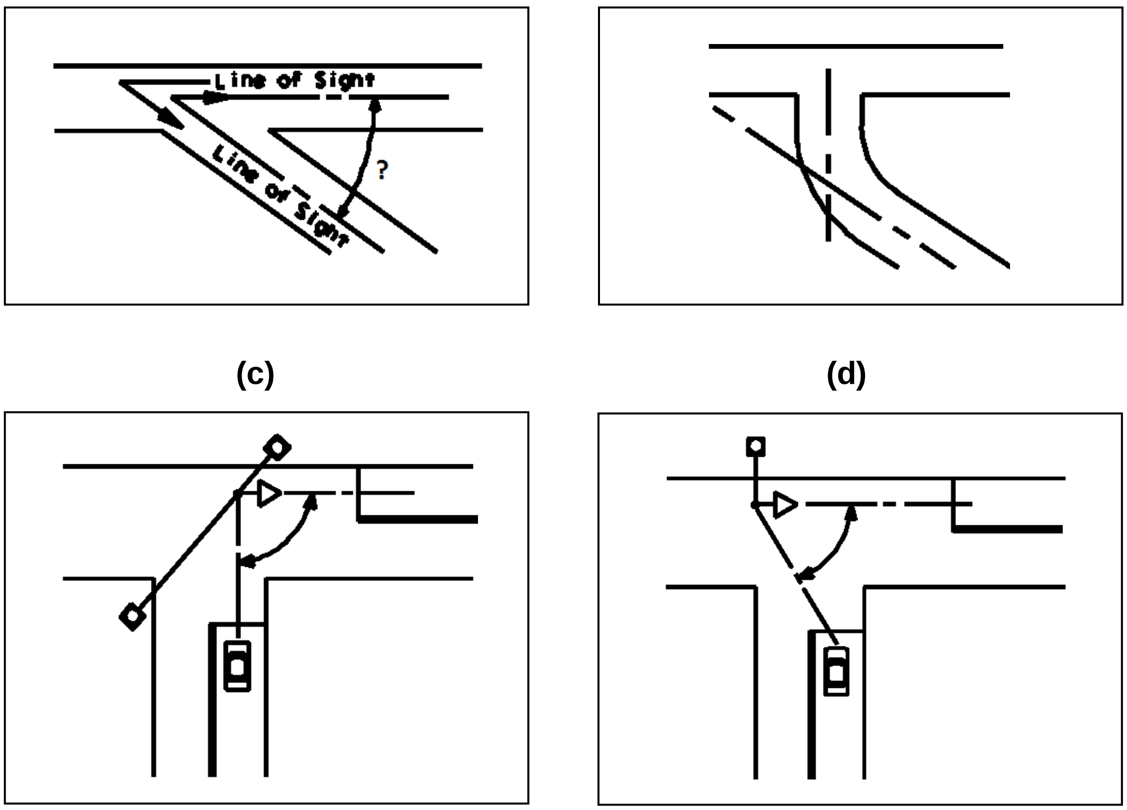
Full-circle visors are similar to tunnel visors with the exception that it provides a complete circle around the lens. Full-circle visors have a sharp angular beam cut off for signal installations where highly directional beam characteristics are necessary to prevent driver confusion, such as streets intersecting at a very sharp angle of 35 degrees or less. Full-circle visors should only be considered when using visibility-limited traffic signal devices (See Section 9.2.13). This type of signal head visor has a drawback in that it inherently has possibility of snow accumulation and bird nests built that can block the lens.

Cut-away and tunnel visors are normally used on projects, but the decision on which signal head visor type should be determined using engineering judgment on a site-by-site basis. To assist in this determination, first measure the angle between the lines of sight for approaching vehicles as shown in Figure 9.5(a). If the approach bends to a near 90 degree angle as shown in Figure 9.5(b), then use engineering judgment to determine the line of sight angle. Consideration of the line of sight angle should also be given for vehicles at the stop lines as shown for diagonal spans in Figure 9.5(c) and for mast arms in Figure 9.5(d).

Figure 9.5 – Line of Sight Angle Measurements

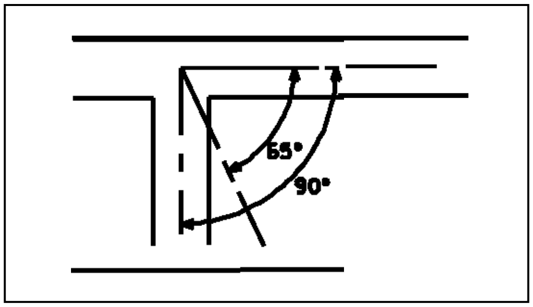
(a) **(b)**

(c) **(d)**

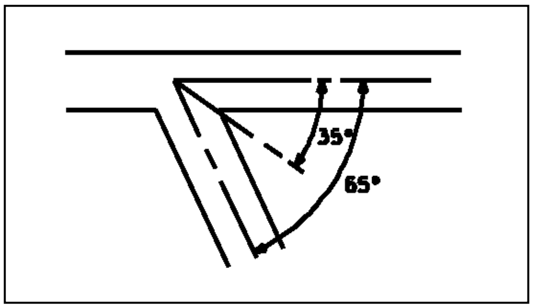


After determining the line of sight angle for approaching vehicles as shown in Figure 9.5, the recommended signal head visor type should be determined using Figure 9.6.

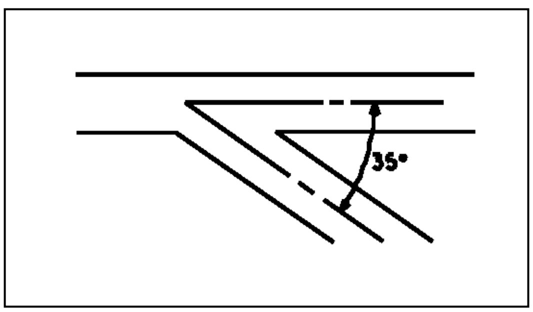
Figure 9.6 – Recommended Signal Head Screening Types



For roadway approaches with line of sight angles between 65 degrees and 90 degrees line of sight angles, use cut-away or tunnel signal head visors.



For roadway approaches with line of sight angles between 35 degrees and 65 degrees, use tunnel signal head visors or full-circle signal head visors.

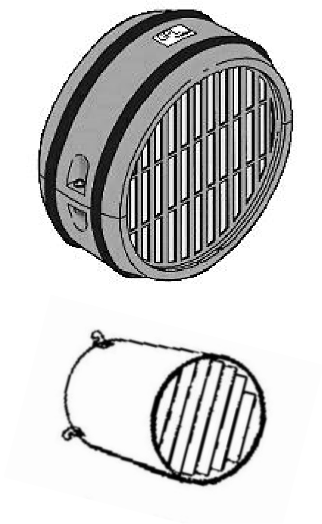


For roadway approaches with line of sight angles less than 35 degrees, use full-circle signal head visors with visibility-limited signal devices.

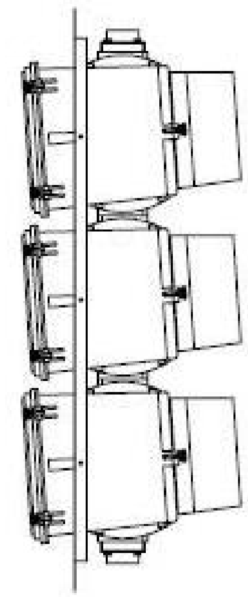
9.2.12 Visibility-Limited Traffic Signal Devices

Visibility-limited traffic signal devices shall be in accordance with the *MUTCD* and are an acceptable method of screening the view of motorists by restricting the signal indication visibility to a specific lane. When considered for installation, visibility-limited traffic signal devices should be reviewed by the TDOT Traffic Engineering Office. Besides roadway approaches with line of sight angles less than 35 degrees, another situation to consider visibility-limited traffic signal devices is where traffic signal heads along a corridor are placed very close to one another such as offset intersections. The conflicting signal indications could be confusing to motorists because they could see both red and green signal indications at the same time. Visibility-limited traffic signal devices should be installed with full-circle visors (See Section 9.2.12) and mounted on a rigid traffic signal support such as a mast arm rather than on a span wire assembly. There are two types of visibility-limited traffic signal devices: geometrically programmed louvers and optically programmed traffic signal heads as shown in Figure 9.7.

Figure 9.7 – Types of Visibility-Limited Traffic Signal Devices



GEOMETRICALLY PROGRAMMED LOUVER (SHOWN ABOVE WITH AND WITHOUT A FULL-CIRCLE SIGNAL HEAD VISOR)



OPTICALLY PROGRAMMED TRAFFIC SIGNAL HEAD

Geometrically programmed louvers, provide a sharp cut off through the use of a series of louvers, which are full-circle vertical slats, sometimes referred to as fins, fitted to the full-circle visor designed to restrict lateral (side-to-side) visibility. When considered for installation, the designer should specify and detail on the traffic signal plans: 1) a sight triangle to show the cone of visibility to the signal indication; and 2) clearly delineate the degree of horizontal cut-off and which side the cut-off is to occur, left or right, as viewed by the intended user.

Optically programmed traffic signal heads should be mounted in a manner permitting very little or no motion because they are intended to direct the signal indication to a specific approach lane and for a specific longitudinal distance. Optically programmed traffic signal heads do not reduce the light intensity of the display and their optically directed lenses provide an optical cut-off of the indication, both horizontally and longitudinal distances as needed. Optically programmed traffic signal heads should include a night time automatic dimming circuit to adjust light output according to ambient light conditions. When considered for installation, the designer should specify and detail on the traffic signal plans: 1) a sight triangle to show the cone of visibility to the signal indication; and 2) clearly delineate the degree of horizontal cut-off and the longitudinal distance view limits, as viewed by the intended user. The designer should also consider that because optically programmed traffic signal heads can restrict visibility distance, there is a possibility that they can severely restrict stopping sight distance. Therefore, signal phasing operation should be carefully chosen so that the proposed signal phasing operation does not create a situation where motorists have inadequate warning of a red signal indication.

The satisfactory operation of visibility limiting signal devices is dependent on correct alignment. Geometrically programmed louvers are typically less expensive than optically programmed heads, however geometrically programmed louvers have limited applications since they can only restrict horizontal visibility, whereas optically programmed traffic signal heads can restrict both horizontal and longitudinal distance visibility. The decision on whether to use visibility limiting signal devices and which type to use should be determined using engineering judgment on a site-by-site basis.

9.2.13 Use of Signs at Signalized Intersections

The *MUTCD Section 4D.34* and the sections listed below provide standards and guidelines regarding the use of signs at signalized intersections.

- Section 2B.18 – Movement prohibition signs;
- Sections 2B.19 to 2B.22 – Lane control signs;
- Section 2B.51 – Pedestrian crossing signs;
- Section 2B.52 – Pedestrian and bicycle actuation signs;
- Section 2B.53 and 2C.48 – Traffic signal signs;
- Section 2C.36 – Signal ahead warning signs;
- Section 2D.43 – Street name signs;
- Section 2D.44 – Advanced street name signs.

9.2.14 Use of Stop Signs at Signalized Intersections

The *MUTCD Section 4D.34* mentions that STOP signs shall not be used in conjunction with any traffic signal operation, except when:

- The signal indication for an approach is a flashing red at all times;
- A minor street or driveway is located within or adjacent to the area controlled by the traffic signal, but does not require separate traffic signal control because an extremely low potential for conflict exists.

9.2.15 Pedestrian Signal Indications

Pedestrian signal indications consist of illuminated symbols of a WALKING PERSON (symbolizing WALK) and an UPRAISED HAND (symbolizing DON'T WALK when steady). When the UPRAISED HAND pedestrian signal indication is flashing it means that a pedestrian shall not start to cross the roadway, but any pedestrian who has already started to cross shall proceed to the other side of the traveled way or to the median. The *MUTCD Chapter 4E* provides standards and guidelines regarding pedestrian control features. All new pedestrian signal indications shall be displayed within a rectangular background and shall consist of symbolized messages. TDOT requires the use of a one-section integrated pedestrian head on new signal installations with the countdown display. Symbol designs shall follow the *Standard Highway Signs and Markings* and colors shall be consistent with the *Pedestrian Traffic Control Signal Indications*. TDOT requires the symbols on the pedestrian signal indication to be a minimum of twelve inches high. A pedestrian change interval countdown display (*MUTCD Section 4E.07*) shall be used where the calculated pedestrian change interval is more than seven seconds to inform pedestrians of the number of seconds remaining in the pedestrian change interval. The countdown display shall be displayed simultaneously with the flashing UPRAISED HAND signal indication. TDOT requires the numbers (digits) on the countdown display to be a minimum of nine inches. The bottom of the pedestrian signal housing (including brackets) shall be mounted between eight and ten feet above the sidewalk level. See *TDOT Standard Drawing T-SG-6* for typical pedestrian signal indication design guidelines.

[This page intentionally left blank.]

CHAPTER 10

TRAFFIC SIGNAL DESIGN – PULL BOXES, CONDUITS, AND WIRING

10.1 Pull Boxes

A pull box is an underground compartment made of various materials, such as pre-cast concrete or polymer concrete (composite). When possible, pull boxes should be located adjacent to the sidewalk rather than in the sidewalk. Pull boxes used in traffic signal installations shall meet current TDOT standards and specifications (See TDOT *Standard Drawing T-SG-2*). The purpose of pull boxes is:

- To provide access to underground detectors and interconnect cables;
- To provide locations to consolidate separate runs of signal and detector cables;
- To provide locations to facilitate the pulling of long runs of detector or interconnect cables;
- To provide locations to store spare lengths of signal detector or interconnect cables.

10.1.1 Type/Size/Use of Pull Boxes

TDOT *Standard Drawing T-SG-2* shows the various pull box sizes and their normal application or use. Type A Pull Boxes should be used exclusively for splicing loop wires to shielded cable only. Type B Pull Boxes should be used for all other traffic signal cable applications. To eliminate multiple types of pull box quantities, Type B Pull Boxes can be used in lieu of Type A Pull Boxes. Pull boxes for fiber optic cable should be larger than standard pull boxes due to the large bending requirements of fiber optic cable (See TDOT *Fiber Optic Standard Drawings*).

10.1.2 Spacing of Pull Boxes

Pull boxes shall be located at 150-foot intervals for signal cable and detector cable runs. Pull boxes for interconnect cable runs shall be located at 300-foot intervals. Pull boxes for fiber optic cable runs shall be placed every 1,000 feet.

10.1.3 Pull Box Material

Pull boxes and covers are to be of load-bearing design in accordance with current TDOT standards and specifications.

10.2 Traffic Signal Conduits

All underground signal wiring shall be encased in conduit to protect the cables or conductors and facilitate maintenance. All signal wiring above ground shall be installed in conduit (e.g. risers), unless the wiring is inside of a pole or attached to a span wire or a messenger cable. Traffic signal conduits shall be in accordance with current TDOT standards and specifications (See TDOT *Standard Drawing T-SG-2*), the NEC and the NESC. Conduit used for traffic signal installation shall have the following characteristics:

10.2.1 Conduit Material Type

- **Underground:** In general, typical conduit placed below ground should be PVC Schedule 40 conduit except for the following locations:
  - **Under Roadways and Public Driveways:** When conduit is shown on the plans in areas which are subjected to heavier vehicular traffic, such as under roadways and public driveways, RGS conduit should be used;
  - **Under Private Driveways:** When conduit is shown on the plans in areas which are subjected to lighter vehicular traffic, such as under private driveways, PVC Schedule 80 conduit should be used. However, HDPE conduit can be substituted in lieu of the PVC Schedule 80 conduit.

  PVC Schedule 40 and Schedule 80 conduits shall not be used together on the same conduit run (different inside diameter).
- **Risers:** All risers shall be RGS conduits. When transitioning from overhead to underground or vice versa on a utility pole, a 2-inch diameter RGS riser must be specified for signal and interconnect cables.

10.2.2 Conduit Installation Methods

There are three typical construction techniques used to install underground conduits for traffic signals. The standard technique used by contractors is the open cutting (or trenching) method. When there are restrictions to using the open cut method, the conduit must be installed by either the directional bore method or the jacking method.

- **Open Cut Method:** The open cut method is generally permitted when the conduit is being installed in areas that will not affect traffic, such as grass medians, or within existing roadways when the existing pavement will be replaced upon project completion;

- **Directional Bore Method:** The directional bore method is generally used when the open cut method is not feasible. The directional bore method installs conduits by boring along a prescribed route under the roadway, driveway, or railroad track. The directional bore method requires an 8-foot by 8-foot staging area to install conduits less than six inches in diameter;
- **Jacking Method:** The jacking method pushes a pipe sleeve that is two inches larger in diameter than the conduit(s) that it will be conveying under a roadway, driveway, or railroad track. This method requires a jacking pit, which must be within the right-of-way. For 20-foot pipe sleeve sections, the jacking pit is typically 32-foot long and 6-foot wide. For 10-foot pipe sleeve sections, the jacking pit is typically 22-foot long and 6-foot wide.

10.2.3 Depth Installed Underground

Conduit is placed 18 inches to 50 inches below the finished grade, typically as follows:

- **Conduit Underground (Sidewalks, Medians, etc.):** Minimum of 18 inches between the top of the conduit and the finished grade;
- **Conduit under any Roadway Surface:** Minimum of 24 inches between the top of the conduit and the driving surface;
- **Conduit under Ditches:** Minimum of 24 inches of cover;
- **Conduit under Railroad Tracks:** Minimum of 50 inches between the top of the conduit and the top of the rails, or as required by the railroad company;
- **Communication/Interconnect Cables:** Minimum of 30 inches of cover between the top of the conduit and the finished grade.

10.2.4 Conduit Sizing

The maximum size conduit to be used on traffic signal installations shall be three inches. Where larger conduit capacity is required, multiple conduit runs will be used. The sizing of conduit(s) should be such as to not fill over 40% of the internal area of the conduit, as shown in Table 10.1. Typical traffic signal conduit shall be 2-inch diameter and detector loop conduit shall be 1-inch diameter, unless otherwise indicated. Conduits smaller than 1-inch diameter shall not be used. The only exception being that grounding conductors at service points shall be enclosed in 3/4-inch diameter conduit. No reducing couplings will be permitted. The conduit between a saw cut and a pull box for loop lead-ins shall be minimum 1-inch diameter. To determine the proper number and size of the conduits needed for the traffic signal layout, combine the number and wire size requirements for each conduit run using the cable/wire size requirements listed in Table 10.2.

Table 10.1 – Conduit Size Requirements

Conduit Diameter (Inches)	Conduit Area	
	Area (Square Inches)	Maximum Usable Area, 40% of Total Area (Square Inches)
0.75	0.44	0.176
1.00	0.77	0.308
1.50	1.77	0.708
2.00	3.14	1.256
2.50	4.91	1.964
3.00	7.07	2.828

10.2.5 Communications Cable Conduit

All communications cables shall be run in a separate conduit from shielded cable, signal cable, and power cable. Conduit for communications interconnect cable should be 2-inch diameter.

10.2.6 Power Cable Conduit

Conduit for power supply shall be run in a separate, 1-inch diameter conduit.

10.2.7 Jacked and Bored Conduit

All jacked and bored conduit shall be RGS or HDPE. The estimation of the amount of boring is critical. Care should be taken for a realistic estimate.

10.2.8 Conduit Radii

All conduit bends shall be large radius to facilitate cable pulling (6” minimum radius).

10.2.9 Spare Conduit

Spare conduit stubs for future use shall always be installed in all new controller cabinet bases and pole foundations.

10.2.10 Conduit for Road Widening Projects

Conduit and pull boxes should be considered for installation on collector and arterial street widening projects where there is a potential for future interconnect needs.

10.3 Traffic Signal Wiring

All conductors shall be run inside conduit, except loop conductors in the pavement, cables run along messenger or span wire, or cables run inside poles. All new cable runs shall be continuous and free of splices. All signal cables shall be in accordance with current TDOT standards and specifications (See TDOT *Standard Drawing T-SG-2*), and shall meet the applicable requirements of IMSA, AWG, and NEC.

10.3.1 Signal Control Cable

All signal control cables shall conform to applicable IMSA Specification No. 19-1 or 20-1. Stranded cable color-coded AWG No. 14 shall be used for all signal and accessory circuits. All signal control cables shall be labeled in the cabinet.

10.3.2 Inductive Loop Wire

Conductors for traffic loops and home runs shall be continuous cross-linked polyethylene-insulated AWG No. 14 wire, conforming to IMSA Specification No. 51-1, 51-3, or 51-7, connected to the detector terminals or spliced with shielded detector cable within a pull box, conduit, or pole base (See TDOT *Standard Drawing T-SG-3*).

10.3.3 Loop Detector Lead-In Cable Wire

Loop detector lead-in cable wire shall be continuous AWG No. 14 wire conforming to the requirements of IMSA Specification No. 50-2, polyethylene-insulated, polyethylene-jacketed shielded cable (See TDOT *Standard Drawing T-SG-2*).

10.3.4 Preformed Loop Detector Wire

Preformed loop assemblies are suitable for placement under new asphalt or concrete pavement. Preformed loop detector wire shall consist of a minimum of four turns of No. 18 AWG wire or larger, not to exceed No. 14 AWG wire. The loop wires shall be installed in protective tubing with a diameter of less than 5/8 inch. The home run cable shall be installed inside conduit or the manufacturer's recommended enclosure between the pavement and the pull box to prevent damage in the ground (See TDOT *Standard Drawing T-SG-3A*).

10.3.5 Coordinated Systems Communications

The following are typical guidelines for coordinated systems communication:

- **Copper Communications Cable (Hard Wire):** Copper communications cable shall be 6-pair, AWG No. 19 polyethylene-insulated, polyethylene-jacketed cable with electrical shielding meeting the requirements of IMSA Specification No. 40-2;

- **Fiber Optic Communications Cable:** Fiber optic communications cable shall be specifically selected to meet the individual needs of a specific project. All fiber optic cables should be designed with spare fibers for future use. A rule of thumb is to double the fibers that are needed today and round up to the nearest six (fiber optic cable is manufactured in multiples of six);
- **Spread Spectrum Radio:** Communication using spread spectrum radio may be carried between units in master and local controller cabinets. Omni-directional antennas are used at master cabinet locations and uni-directional (Yagi) antennas are used at local cabinet locations.

10.3.6 Cable Lashing

Cables shall be attached to span or messenger cable by means of non-corrosive lashing rods or stainless steel wire lashings (one 360-degree spiral of lashing wire per foot).

10.3.7 Cable/Wire Sizing and Measurements

After the signal face and signal detector arrangements/placements have been determined, the necessary signal wiring required involves the following steps:

- **Signal Face Requirements:** The typical wiring requirement of each individual signal face may be determined by using TDOT *Standard Drawing T-SG-12*;
- **Mast Arm/Span Wire Runs:** Determine the length of wiring required for the signal faces depending on whether span wire or mast arms are used. In addition to horizontal distances shown on the construction plans, the designer must account for the height of the signal poles and five feet extra inside each pull box;
- **Detectors, Power and Interconnect Cable:** Determine the wiring required for detectors, power, and interconnect cables where applicable. In addition to horizontal distances shown on the construction plans, the designer must account for the height of the signal poles and five feet extra inside each pull box;
- **Cable/Wire Sizes:** The typical cable/wire sizes are shown in Table 10.2.

Table 10.2 – Typical Cable/Wire Sizes

AWG 10			AWG 12		
Number of Conductors	Outside Diameter (Inches)	Area (Square Inches)	Number of Conductors	Outside Diameter (Inches)	Area (Square Inches)
1	-	-	1	-	-
2	0.511	0.205	2	0.466	0.171
3	0.542	0.231	3	0.492	0.190
4	0.623	0.305	4	0.552	0.239
5	0.695	0.379	5	0.590	0.273
6	-	-	6	-	-
7	0.756	0.449	7	0.677	0.360
8	-	-	8	-	-
9	N/A	N/A	9	0.834	0.546
10	N/A	N/A	10	0.854	0.573
11	-	-	11	-	-
12	0.946	0.703	12	0.881	0.610
AWG 14			AWG 16		
Number of Conductors	Outside Diameter (Inches)	Area (Square Inches)	Number of Conductors	Outside Diameter (Inches)	Area (Square Inches)
1	-	-	1	-	-
2	0.399	0.125	2	0.358	0.101
3	0.421	0.139	3	0.382	0.115
4	0.458	0.165	4	0.419	0.138
5	0.500	0.196	5	0.460	0.166
6	-	-	6	-	-
7	0.543	0.232	7	0.499	0.196
8	-	-	8	-	-
9	0.707	0.393	9	0.572	0.257
10	0.721	0.408	10	0.606	0.288
11	-	-	11	-	-
12	0.731	0.420	12	0.669	0.352

Note: 1, 6, 8, and 11 conductor cables are not recommended for installation.

Other Communication Cables		
Type	Outside Diameter (Inches)	Area (Square Inches)
6 Pair / 19	0.644	0.326

[This page intentionally left blank.]

CHAPTER 11

TRAFFIC SIGNAL DESIGN – MISCELLANEOUS INFORMATION

11.1 Signal Control for Private Driveways within Signalized Intersections

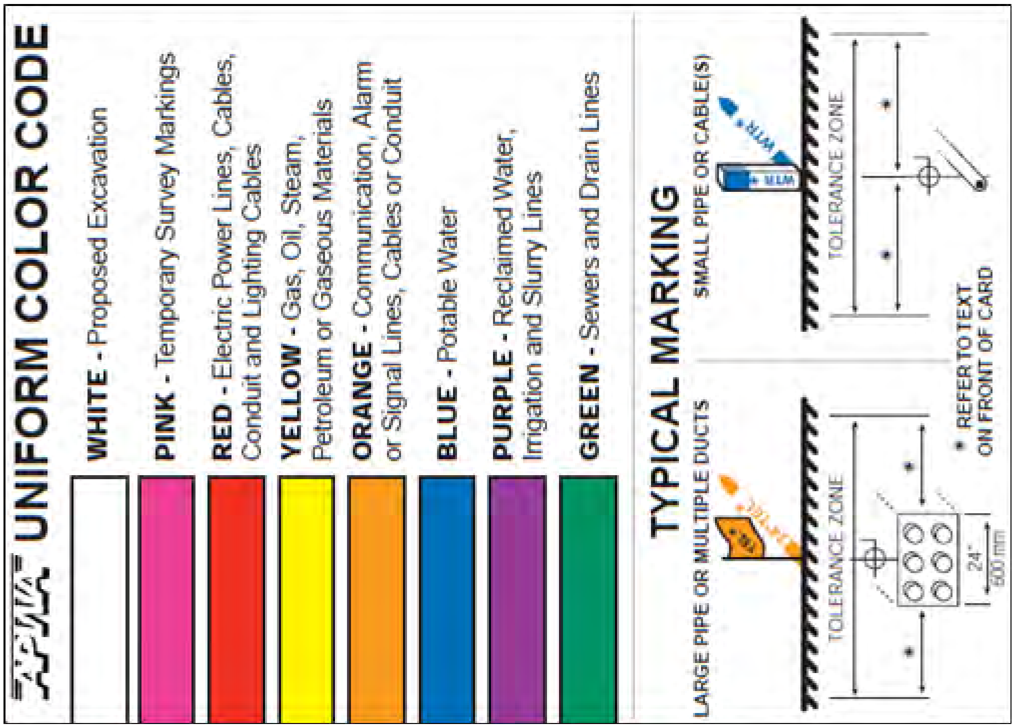
Traffic signal control for a private driveway should be considered if the private driveway is located within signalized intersections. When a traffic signal is installed based on the pedestrian or school crossing warrant (Warrants 4 or 5), pedestrian signals should control the private driveway. Split-phase operation for low-volume driveways should be considered and detection should always be provided for the approach to avoid unnecessary delays on other approaches. Engineering judgment should be used in all cases.

11.2 Utilities

The Tennessee One-Call System (also known as 811) should be contacted before work starts on any traffic signal installation. The following is relevant information regarding work with utility companies:

- Utility companies should expose/mark/relocate utilities;
- Check for any additional underground and overhead utilities;
- Check for required permits;
- Keep utility company’s contact information onsite for any emergencies;
- Keep authorization documents (eg. ticket number) at the worksite;
- Notify utility companies before starting to dig;
- When in doubt, hand dig or Hydro Vacuum should be utilized;
- Uniform color-coding is used to identify underground utilities (See Figure 11.1);
- For overhead utilities, proper insulation should be placed on signal poles and utility wires.

Figure 11.1 – Uniform Color Codes for Underground Utilities



GUIDELINES FOR UNIFORM TEMPORARY MARKING OF UNDERGROUND FACILITIES

This marking guide provides for universal use and understanding of the temporary marking of subsurface facilities to prevent accidents and damage or service interruption by contractors, excavators, utility companies, municipalities or any others working on or near underground facilities.

ONE-CALL SYSTEMS
The One-Call damage prevention system shall be contacted prior to excavation.

PROPOSED EXCAVATION
Use white marks to show the location, route or boundary of proposed excavation. Surface marks on roadways do not exceed 1.5" by 18" (40 mm by 450 mm). The facility color and facility owner identity may be added to white flags or stakes.

USE OF TEMPORARY MARKING
Use color-coded surface marks (i.e., paint or chalk) to indicate the location or route of active and out-of-service buried lines. To increase visibility, color coded vertical markers (i.e., stakes or flags) should supplement surface marks. Marks and markers indicate the name, initials or logo of the company that owns or operates the line, and width of the facility if it is greater than 2" (50 mm). Marks placed by other than line owner/operator or its agent indicate the identity of the designating firm. Multiple lines in joint trench are marked in tandem. If the surface over the buried line is to be removed, supplementary offset markings are used. Offset markings are on a uniform alignment and clearly indicate the actual facility is a specific distance away.

TOLERANCE ZONE
Any excavation within the tolerance zone is performed with non-powered hand tools or non-invasive method until the marked facility is exposed. The width of the tolerance zone may be specified in law or code. If not, a tolerance zone including the width of the facility plus 18" (450 mm) measured horizontally from each side of the facility is recommended.

ADOPT UNIFORM COLOR CODE
The American Public Works Association encourages public agencies, utilities, contractors, other associations, manufacturers and all others involved in excavation to adopt the APWA Uniform Color Code, using ANSI standard Z535.1 Safety Colors for temporary marking and facility identification.

Rev. 4/99

11.3 Street Lighting on Traffic Signal Supports at Intersections

See Chapter 15 in this manual for lighting design information. More specifically, street lighting may be justified at signalized intersections as follows:

- **Urban Locations:** In urban areas where street lighting already exists along the highway;
- **Rural Locations:** In rural locations where street lighting at the intersection would have a positive effect on the nighttime safety.

11.3.1 Street Light Support Design

Where used on mast arms or strain poles, the design of the street light support must be integrated with the traffic signal support. The pole manufacturer must provide an acceptable design for review by TDOT.

11.3.2 Luminaire Mounting Height

The luminaire for the street lighting is typically mounted a minimum of 30 feet above the roadway. The actual mounting height shall be determined by the luminaire photometrics.

11.3.3 Wiring Requirements

The following requirements should be observed:

- **Circuit Breaker:** A disconnect and fuse shall be located at the power pole location;
- **Wire Type:** 1-2 conductor, #6 AWG;
- **Conduit Size:** One inch diameter RGS;
- **Isolation:** Street light conductors shall not be routed through the controller cabinet and shall have separate conduits and pull boxes;
- **Pull Boxes:** Pull boxes used in lighting applications should be a maximum of 300 feet apart.

11.4 Traffic Signal Installation Inspection Guidelines

The primary goal of this section is to assist TDOT with the inspection guidelines of traffic signal installations by ensuring that construction is performed in accordance with the plans, specifications, and related contract provisions. Inspectors should be properly trained and be familiar with all the typical traffic signal construction activities.

11.4.1 Responsibilities of the Inspector

Some of the responsibilities of the inspectors are:

- Work with the contractor to make sure that construction of the traffic signal installation is completed safely with proper protection of the contractor's employees, the traveling public, and pedestrians in or adjacent to the work area;
- Verify that the items of work are done in accordance with the special provisions, the plans, Standard Drawings and in conformance with industry standards;
- Know the scheduling and status of construction activities, including the coordination of utility work that may affect the progress of construction;
- Coordinate with project engineer any necessary changes in the original project. Document any changes;
- Maintain a project diary, documenting construction activity, equipment test results, pay item measurements, etc. Taking pictures is recommended. These records will be the basis for final inspection and approval;
- Verify that materials installed are approved by the traffic signal owner's agency;
- Prior to turn-on, check traffic signal system in conjunction with project engineer that all components are operating properly according to the design plans;
- Follow traffic signal activation procedures in Section 11.5.

11.4.2 Preconstruction Activities

A preconstruction conference with the contractor and other interested parties (e.g. utilities, etc.) is normally conducted on traffic signal installations. The project engineer and inspector(s) should thoroughly review the plans and specifications and visit the project site, making special note of any potential conflicts or items that might require clarification or field modification. During the conference, the responsibilities of each party are determined as well as the establishment of safety procedures to be adopted throughout the construction process.

11.4.3 Sampling and Testing of Materials

Before construction, the contractor should submit a detailed list of suppliers and anticipated delivery dates for all materials to be used on the job. This list is commonly supplied and discussed at the preconstruction conference. Typically, the following materials require approval before installation:

- Traffic signal structural support;
- Traffic signal controllers;
- Flasher units;
- Signal heads (vehicular and pedestrian);
- Detection systems and detection amplifiers;
- Pedestrian pushbuttons and accessible pedestrian signals (APS) (if applicable);
- Preemption systems (if applicable);
- Wiring.

It is good practice to maintain documentation accepting the materials used in the project.

11.4.4 General Principles

The inspector should maintain a cooperative and positive attitude with the contractor while closely adhering to the contract documents. The inspector should work with the contractor and project engineer to resolve any issues that arise during the project. Nevertheless, the inspector does not work for the contractor, and should not direct any of the contractor's personnel in any facet of the construction activity. Providing direction or instruction assumes responsibility for the actions of the contractor and the outcome of the project. The inspector should maintain professional separation from the contractor and focus on documentation and reporting.

11.4.5 Inspection Activities

It is recommended for the inspector to regularly visit the project site to assure that all steps of the traffic signal installation have been closely monitored. The lack of regular inspection can lead to an agency experiencing operational problems soon after the work is completed and accepted. A high quality installation should provide years of reliable service. Moreover, proper documentation of inspection activities constitutes an essential part of the project records and may be subject to review during an audit, investigation, or litigation proceedings. Proper documentation should include project diaries, inspection and test reports, change orders, meeting notes, etc. There are several steps of the traffic signal installation process that cannot be simply visually inspected during a final inspection of the signal system. For example, placement, depth, slope and bonding of conduits, foundation excavation depth and type of steel reinforcement bars, number of turns of a loop detection wire, etc. Basically, the inspector should check and document all steps of the traffic signal installation, including the construction of underground facilities, according to the project design and standard specifications. Before the traffic signal system can be turned on, a final and thorough inspection of the installation should be performed. The use of the following checklist(s) is recommended for the inspection of traffic signal installations in the State of Tennessee:

- **Preliminary Hardware Inspection:** It is recommended that the inspector carefully complete this preliminary report before the traffic signal activation date. A representative of the contractor should be available for any necessary clarifications;
- **Activation Day Inspection:** It is recommended that the inspector and the project/traffic engineer complete this report to check for proper operation of the traffic signal system. The contractor should give a one week notice before requesting for signal activation assistance. A representative of the contractor should be available for any necessary clarifications.

The checklists may be tailored according to agency needs. Each item on the list should be checked with the plans provided. Consideration should be given to overall workmanship and quality of equipment installation. Notes should be specific, dated, and initialed. Appendix C provides additional guidelines and forms on inspection activities.

11.4.6 Final Acceptance and Notification

Upon satisfactory completion of the inspection activities, the contractor should be formally notified of final acceptance in writing.

11.5 Traffic Signal Activation Procedures

Activation of a new traffic signal is a critical part of the signal installation process. The traffic signal designer should consider the possible consequences of a change in traffic control and add any notes and items which may improve the safety of the transition period. When signalization is introduced at locations where a multi-way stop, flashing beacon operation exists, special measures may be required.

The following steps are recommended for the activation of a new traffic signal:

- **Advance Flash Period:** To make motorists aware of its presence, a new traffic signal installation should be put on flash operation for a minimum of seven calendar days up to a maximum of 14 calendar days prior to the activation of normal traffic signal operation. Other flash operation time periods can be considered upon written approval from the Regional Traffic Engineer;
- **Publicity:** The date and time of the activation of stop and go operation should be advertised in the local newspaper and on local radio stations both, prior to and on the date of activation;
- **Activation:** The actual activation of normal stop and go operation should be made during an off-peak traffic period (not on Fridays or before holidays);
- **Technical Support:** The contractor shall be on-hand for all new traffic signal activations to immediately troubleshoot or fix any problems that arise;
- **Signing Adjustments:** Once the traffic signal is turned on normal traffic signal operation, remove the stop signs that the traffic signal replaces;
- **Police Assistance:** Police assistance should be requested and be on site at the time of traffic signal activation to provide emergency traffic control in case of a malfunction and to help emphasize the new traffic control change to the motorists;
- **School Crossing:** Should the intersection include a school crossing with a crossing guard, the crossing guard should be familiarized with the operation of the new traffic signal;
- **Fine-Tuning:** Shortly after the traffic signal is turned on, the engineer should observe the signal’s operation during both peak and off-peak periods (AM and PM) to assure the adequacy of the signal’s timing parameters. Late night operation should also be checked.

[This page intentionally left blank.]

CHAPTER 12

TRAFFIC SIGNAL DESIGN – POST-INSTALLATION

12.1 Traffic Signal Maintenance Guidelines

The primary goal of this section is to provide effective maintenance guidelines to transportation agencies responsible for the operation of traffic signals in Tennessee. After activation, it is recommended that signalized intersections be routinely inspected by trained personnel in order to reduce agency exposure to liability and to provide safe operations to the public. Preventive Maintenance and Response Maintenance guidelines are detailed in the following sections. The ITE/IMSA *Traffic Signal Maintenance Handbook* was used as a Standard Reference in the development of these guidelines.

12.1.1 Reducing Agency Exposure to Liability

Most tort liability claims originate from negligent traffic signal installation and maintenance. In regards to maintenance, negligence is the failure to comply with the duty to maintain traffic signal equipment in a reasonably safe condition, through some act or omission on the part of the agency or its employees. Therefore, an agency should observe the following to reduce its exposure to liability:

- **Temporary Traffic Control Plans:** Agencies should conform to the specifications of the *MUTCD* when performing traffic signal maintenance tasks. Agencies should also inform local law enforcement and emergency services agencies of all lane closures, detours, and other changes in traffic control. Appropriate training should be provided for agency employees. Appendix D provides a table with recommended *MUTCD* temporary traffic control plans for typical maintenance tasks.
- **Routine Inspection:** Agencies should perform preventive maintenance and signal timing maintenance as described in these guidelines. In addition, maintenance records should be regularly reviewed to identify recurring problems with the signal equipment and appropriate actions should be taken. Crash records should also be reviewed to identify potential defects or hazards. Furthermore, it is recommended that all agency employees, such as police, roadway maintenance, utility, sanitation, etc. who regularly work on the street system be trained to look for and properly report any damaged or apparently defective traffic signal equipment to a pre-determined notification system.
- **Maintenance Practices:** Maintenance personnel should be trained in the proper actions to take in the case of traffic control system malfunction or loss of control. Temporary control by police should be sought in potentially dangerous situations until repairs can be completed or until adequate

interim warning measures can be implemented. Maintenance work should be performed by qualified personnel. Agencies should perform response maintenance as described in these guidelines.

- **Maintenance Records:** *A*dequate maintenance records are essential. Records may be in hardcopy or electronic format. Duplicate records should be stored at an offsite location.

12.1.2 Preventive Maintenance

The objective of preventive maintenance is to prevent the failure of traffic signal equipment before it actually occurs. Replacing worn components before they fail has the potential to preserve and enhance equipment reliability. Furthermore, a good preventive maintenance program can reduce agency liability, extend the life of the installation, reduce the frequency and severity of malfunctions, and make better use of manpower and resources. TDOT recommends that signal timing directives be checked during preventive maintenance for safe and efficient traffic signal operations.

- **Recommended Documentation:** The following documents should be available at each signalized intersection for reference by the technician (typically kept in the cabinet):
    - **Actual drawings:** A set of traffic signal plans with a record of necessary changes approved during construction.
    - **Approved timing directives:** Timing directives should contain the address of the intersection, date the directive was approved, name and signature of the person approving the directive, and all the parameter settings necessary for the designed operation. The parameters include, but are not limited to, phasing sequence, timing, signals displayed during each interval, signal head numbering, coordinated and non-coordinated phases, splits, cycles, offsets, pedestrian timings, preemption, volume density, detector plans, TOD operation, etc.
    - **Logbooks:** The logbook should contain the address of the intersection, make, model, and serial number of the controller components and the communication equipment. Technicians should, at a minimum, include their name, date, and time of the visit to the intersection, work performed (including parts that were replaced), condition on arrival, and condition when the technician left.

  A copy of actual drawings, approved timing directives, and logbooks should be stored in the agency office in a safe location. It is also recommended that user manuals for all of the equipment used at signalized intersections be available to technicians.

- **Frequency:** TDOT recommends that preventive maintenance be performed every six months, with a minimum of once a year. Agencies should review maintenance records and service calls, determine trends, and determine its appropriate preventive maintenance scheduling. TDOT also recommends that agencies inspect signals after severe weather to determine potential damage and ensure proper operation.
- **Recommended Tools, Equipment, and Supplies:** Agencies performing traffic signal maintenance should have the means of testing its traffic signal equipment routinely, using its own testing equipment or contracting it out. Typically, the following equipment is used for testing:
  - A certified CMU or MMU tester (printouts of system timing tests, voltage tests, power conflict, red fail conflict, short yellow indicator, AC power failure transfer, restore, power fluctuation, etc);
  - Loop detector analyzer and tester for testing loops and detector amplifiers (signal strength, inductance and change of inductance, resistance);
  - Video monitor to observe video detection operation;
  - Suitcase tester or test box for controller;
  - Load switch tester (verify current outputs);
  - BIU tester;
  - Earth ground clamp;
  - Power quality meter;
  - Digital multi-meter;
  - Test kits for communication.

  It is also recommended for agencies to have readily available spare parts for the proper maintenance of traffic signals. Examples of commonly used spare parts are the following:
  - Pushbuttons and accompanying signs;
  - Spare cabinet fans and thermostats;
  - Spare controller;
  - Signal and flash load switches;
  - Flash transfer relays;
  - Replacement air filters;
  - Spare controller cabinet bulbs;
  - Spare circuit breakers;
  - Spare ground fault circuit interrupter (GFCI) receptacles;
  - Spare detector panel relay sockets and relays;

- Spare preemption relay sockets and relays;
- Spare communication equipment;
- Spare gasket material for cabinets;
- Replacement LED modules;
- Spare UPS batteries;
- Spare loop detector amplifiers;
- Spare video detection card and camera interface panel;
- Spare power supply for detector cards.

➢ **Deficiencies Requiring Immediate Action:** Once a deficiency is found during an inspection of a traffic signal, agencies should take appropriate actions to preserve the safe and efficient operation of the intersection. The documentation of the problem and proper servicing action or communication to a supervisor is necessary. The following are examples of deficiencies requiring immediate action:

- A CMU or MMU that fails any of the tests performed by the tester;
- Bad load switches;
- Damaged signal heads;
- Damaged or missing traffic signal hardware;
- Broken or damaged doors for pole base or handhole access;
- Nonfunctioning pushbuttons;
- Missing ground wire, bushings or connectors;
- Damaged, frayed, or faulty cables;
- Non-functioning preemption;
- Faulty circuit breakers, GFCIs, or mercury switches;
- Missing junction or splice box covers;
- Bad controller.

➢ **Preventive Maintenance Checklists:** Appendix D contains recommended TDOT Traffic Signal Preventive Maintenance Checklist Forms. Technicians should initial all pages of the form once a job is finished.

12.1.3 Response Maintenance

Response maintenance is the type of maintenance required when one or more components of a traffic signal system fails, causing the traffic signal to malfunction or operate in a way that is not intended. Response maintenance will be required, for example, during knockdowns, when the signal is operating in flash mode due to faulty equipment, when wrong indications or multiple indications are displayed, when indications are dark, when signal heads are out of proper alignment, when the intersection is not resetting after a power loss, etc. Agencies with good preventive maintenance programs will significantly reduce the number of response calls.

- **Standard Operating Procedure:** Agencies should have a SOP to notify personnel when traffic signal response maintenance is required. A clear understanding of the actions to properly respond to service calls is necessary. Response maintenance may be performed by in-house staff or may be outsourced to a contractor. Response times may be established to different tasks, based on the urgency of the service to be performed. A two-hour response time is a widely accepted standard, but agencies should consider the geographic area that needs to be covered (larger cities may need additional time), traffic conditions (peak and off-peak periods), and weather-related conditions. Agencies should develop a plan to determine how the initial call will be serviced. First, a list of intersections that the agency will be servicing needs to be determined. The list should then be shared with authorities (police, 911 dispatchers, etc), signal technicians, and contractors (if necessary). Next, determine the number to be called in case a traffic signal needs to be serviced. It is important to recognize the potential need for a call tree (in-house and contractors) and also plan for off-hours, holidays, and weekends.
- **Recommended Documentation:** The following information should be included in the service call by the person receiving the complaint:
  - Name of caller;
  - Date and time the complaint was received;
  - Location and apparent problem as reported;
  - Name of receiver.

  The following information should be added to the initial service call by the person sent to the field:

  - Maintenance personnel, time dispatched, and time of arrival;
  - Trouble found (as reported by the maintenance crew), action taken, and time cleared.

  Once on location, the technician should assess the site conditions and confirm that the trouble reported represents what is being observed. A determination should be done if additional staff or equipment will be necessary to address the problem. It is highly recommended to take photos to document the time and date, site conditions upon arrival (include street name signs), temporary traffic control implemented, and conditions once service is restored to the traffic signal. It is also recommended for technicians not to direct traffic, asking for law enforcement assistance if necessary. Lastly, technicians should complete the traffic signal service call report immediately after the work is finished. Appendix D provides a recommended Traffic Signal Service Call Report.

12.2 Automated Traffic Signal Performance Measures

TDOT encourages maintaining agencies to collect performance measures, or MOE, to enhance traffic signal system operations. ATSPMs can easily be used to manage and optimize all modes of traffic signal operations. They can be monitored and/or reported via email alerts, and can be reported independent of central system software. The basic performance measures are proactive in monitoring traffic signals for impacts to the traffic signal operations, such as malfunctioning detection and troubleshooting complaints. Performance measures also allow a maintaining agency to be more efficient when creating work orders, such as:

- Diagnosing a problem and describing it to the technicians;
- Making sure the right technician is dispatched to the field;
- Correcting the problem remotely without having to dispatch a technician;
- Making sure the complaint is observed at the right time of day, if applicable.

Travel time, delay, and average speeds are also commonly used performance measures to evaluate the quality of traffic movements along a corridor. Current traffic signal technology provides the opportunity for practitioners to collect detailed information that could be used to fine-tune traffic signal timings and improve operational efficiency. In order to collect ATSPMs, traffic signal controllers must be able to meet the following requirements:

- Be able to collect high-resolution traffic data that is recording events at a rate of 0.1 seconds;
- Be compatible with the *Indiana Traffic Signal Hi-Resolution Data Logger Enumeration* software capabilities;
- The ATSPM source codes are free and available from the Utah DOT.
- Be able transfer data remotely to a server. This data transfer can be achieved using a variety of means, including wireless modems, Internet Protocol (IP) over radio, and fiber optic cable. One connection is needed at each isolated intersection or interconnected corridor.

The Indiana Traffic Signal Hi-Resolution Data Logger Enumeration software is free and is provided at no cost to maintaining agencies. Information Technology (IT) support will also be needed to set up the ATSPMs since they involve the transfer of data. Most ATCs are capable of reporting ATSPMs, but it is important for the designer to verify traffic signal controller requirements to ensure its compatibility for reporting these types of performance measures. There are currently more than 30 types of ATSPMs that can be reported from the traffic signal controllers: Table 12.1 shows some ATSPMs with the controller and detection requirements needed for each ATSPM.

Table 12.1 – Types of ATSPMs and Controller/Detection Requirements

Automated Traffic Signal Performance Metric	Controller with High-Resolution Data Capability	Type of Detection Needed(1)				
		Advanced Count Detection	Advanced Speed Detection (Radar Only)	Lane-by-Lane Count Detection	Lane-by-Lane Presence Detection	Probe Travel Time (GPS or Bluetooth)
Purdue Phase Termination	X					
Split Monitor	X					
Pedestrian Delay	X					
Preemption Details	X					
Transit Signal Priority Details(2)	X					
Purdue Coordination Diagram	X	X				
Approach Volume	X	X				
Platoon Ratio	X	X				
Arrivals on Red	X	X				
Approach Delay	X	X				
Approach Speed	X		X			
Turning Movement Counts	X			X		
Yellow and Red Actuations	X			X		
Purdue Split Failure	X				X	
Purdue Travel Time Diagram	X					X

- Any type of detectors (loops, radar, video, pucks, etc.) can be used to collect traffic data except for the Approach Speed metric which requires radar detection.
- The Transit Signal Priority Details ATSPM is currently under development.

The ATSPM reports are dependent upon adequate vehicle detection in the field. As shown in Table 12.1, many different types of detectors and configurations can be used. A couple of before and after examples using ATSPMs are shown in Figures 12.1 and 12.2, respectively. For additional information on ATSPM's, the designer should reference the *Traffic Signal Timing Manual*, the *FHWA Traffic Analysis Toolbox*, the *Performance Measurement Fundamentals*, and the Indiana Joint Research Program *Performance Measures for Traffic Signal Systems*.

Figure 12.1 – Automated Traffic Signal Performance Measure Before Example (Purdue Phase Termination and Split Monitor)
Source: Utah DOT

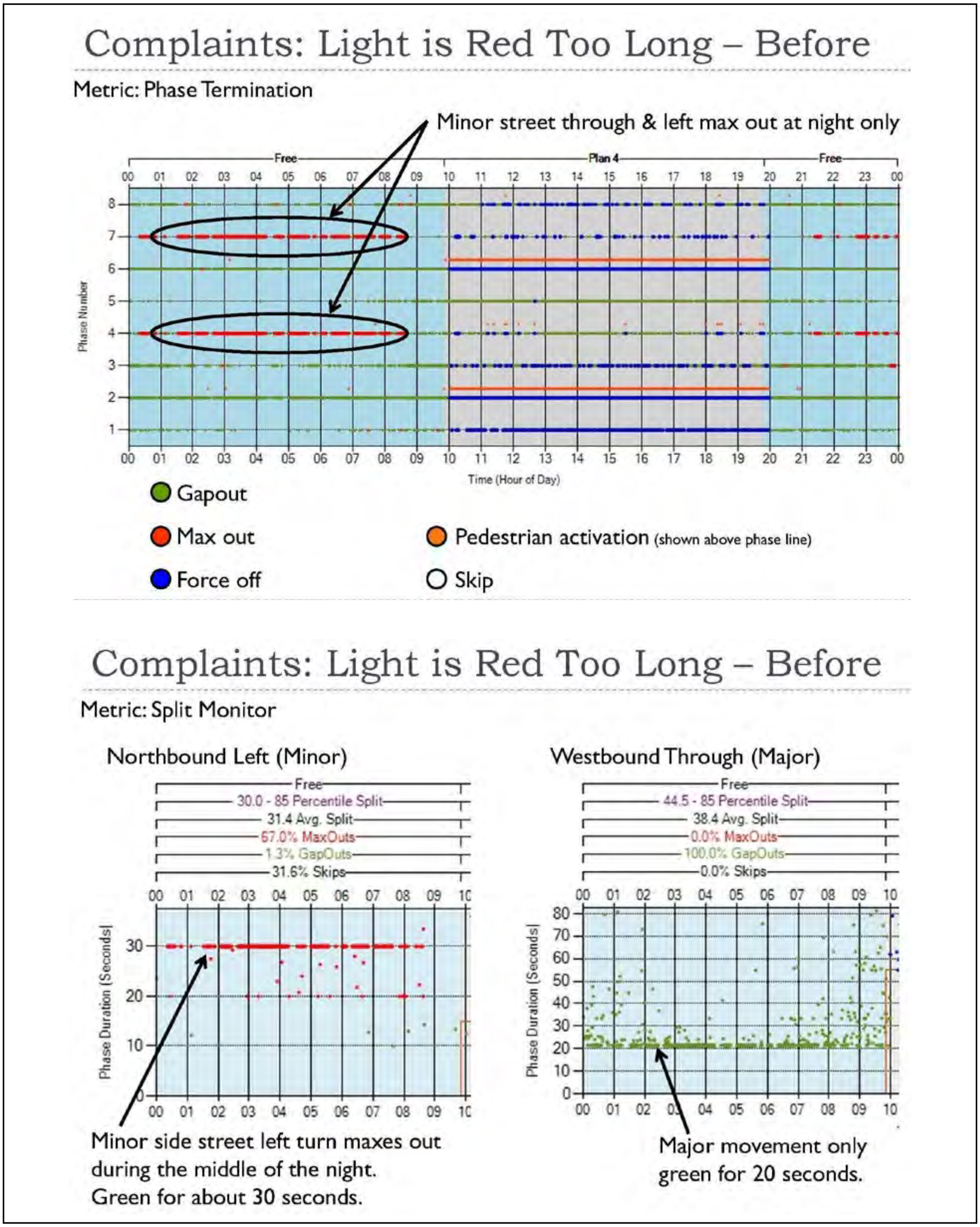
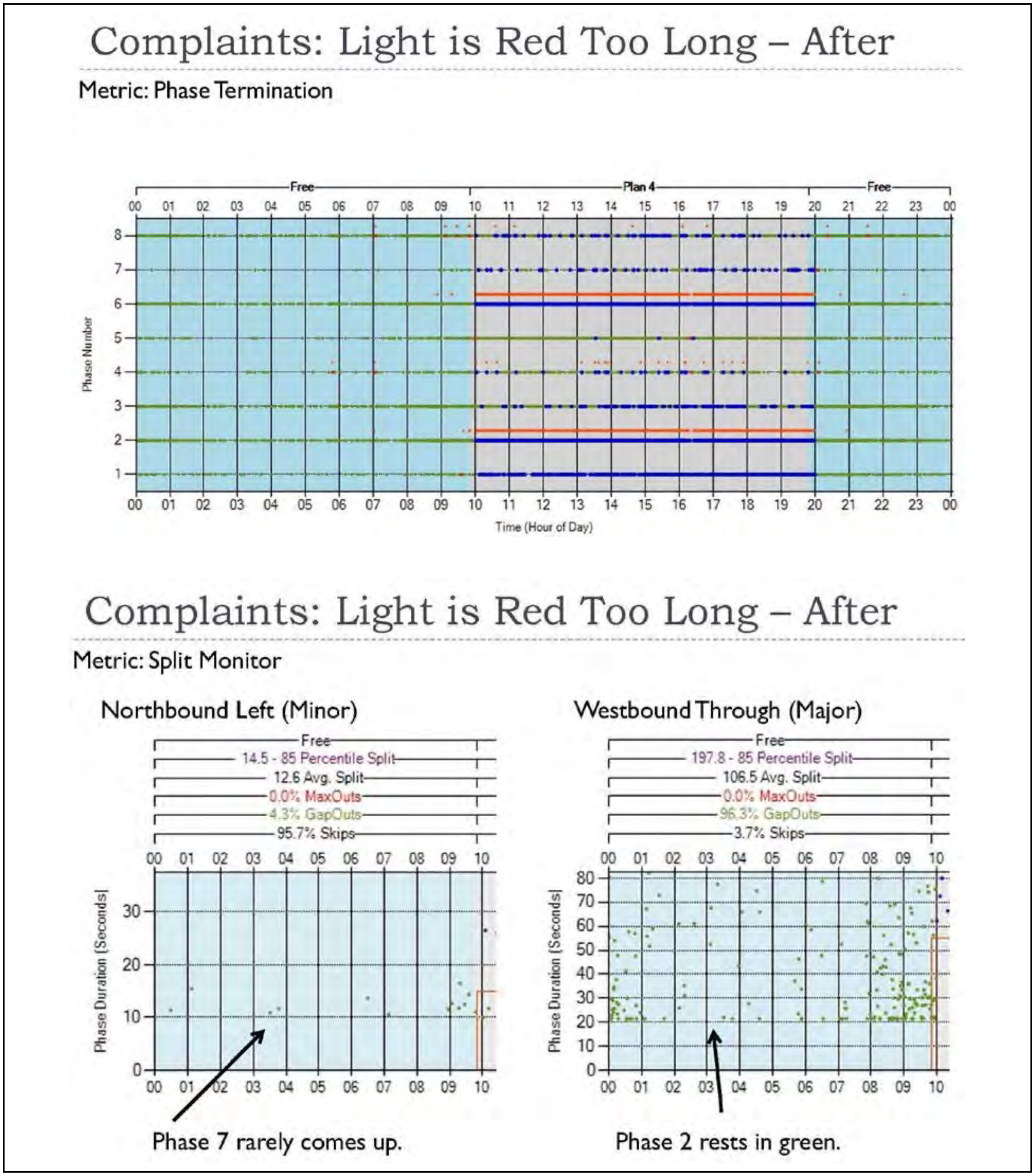


Figure 12.2 – Automated Traffic Signal Performance Measure After Example (Purdue Phase Termination and Split Monitor)
Source: Utah DOT



12.3 Removal of Traffic Signals

Although the original installation of a traffic signal may be based on the satisfaction of one or more traffic signal warrants and other factors, changes in traffic flow over time may reduce the effectiveness of traffic signal control. When this occurs, it may be appropriate to remove a traffic signal. The ***MUTCD*** does not contain specific traffic signal warrants for the removal of traffic signals. A general rule of thumb is that if a traffic signal does not meet at least 50% of the values of any of the traffic signal warrants, the traffic signal should be analyzed for removal. Even though traffic volumes may have decreased, the removal of a traffic signal requires engineering judgment, because removal of the traffic signal may or may not be appropriate. If the engineering study indicates that the traffic control signal is no longer justified, removal should be accomplished using the following steps:

- Determine the appropriate traffic control to be used after removal of the traffic signal;
- Remove any sight-distance restrictions as necessary;
- Flash or cover the traffic signal heads for a minimum of 90 days, and install the appropriate stop control or other traffic control devices;
- Remove the signal if the engineering data collected during the removal study period confirms that the traffic signal is no longer needed.

As a step down, replace the traffic signal with an all-way stop. If an all-way stop is not warranted, then remove the stop signs on the major approaches. Instead of total removal of the traffic control signal, the poles and cables may remain in place after removal of the signal heads for continued analysis. Remove all traffic signal equipment if the continued analysis finds that the traffic signal is no longer needed. See Appendix B for an example traffic signal removal form.

CHAPTER 13

OTHER TYPES OF TRAFFIC SIGNALS

13.1 Highway Traffic Signals

The primary type of traffic signal device in use is the traditional traffic control signal at an intersection (See Chapters 5-12 in this manual for details on traditional traffic control signals). However, a traffic signal can be a device other than a traditional traffic control signal. The following are additional types of traffic signals:

- **Pedestrian Hybrid Beacons (*MUTCD Chapter 4F*):** A pedestrian hybrid beacon is a special type of hybrid beacon used to warn and control traffic at an unsignalized location, in order to assist pedestrians in crossing a street or highway at a marked crosswalk. Pedestrian hybrid beacons are also known as "HAWK Signals".
- **Emergency Vehicle Traffic Control Signals (*MUTCD Chapter 4G*):** A special traffic control signal that assigns the right-of-way to an authorized emergency vehicle.
- **Traffic Control Signal for One-Lane, Two-Way Facilities (*MUTCD Chapter 4H*):** A traffic control signal for one-lane, two-way facilities, such as a narrow bridge, tunnel, or roadway section, and is a special signal that assigns the right-of-way for vehicles passing over a bridge or through a tunnel or roadway section that is not of sufficient width for two opposing vehicles to pass.
- **Ramp Control Signal (*MUTCD Chapter 4I*):** A highway traffic signal installed to control the flow of traffic entering the freeway facility. This is often referred to as "ramp metering".
- **Traffic Control for Movable Bridges (*MUTCD Chapter 4J*)**: A special type of highway traffic signal installed at movable bridges to notify road users to stop because of a road closure rather than alternately giving the right-of-way to conflicting traffic movements.
- **Traffic Signals at Toll Plazas (*MUTCD, Chapter 4K*):** Traffic control signals used at toll booth plazas.
- **Flashing Beacons (*MUTCD Chapter 4L*):** A highway traffic signal with one or more signal sections that operates in a flashing mode.
- **Lane-Use Control Signals (*MUTCD Chapter 4M*):** A signal face displaying signal indications to permit or prohibit the use of specific lanes of a roadway or to indicate the impending prohibition of such use.
- **In-Roadway Lights (*MUTCD Chapter 4N*):** In-roadway lights are special types of highway traffic signals installed in the roadway surface to warn road users that they are approaching a condition on or adjacent to the roadway that might not be readily apparent and might require the road users to slow down and/or come to a stop. This includes situations warning of marked school crosswalks, marked midblock crosswalks, marked crosswalks on uncontrolled approaches, marked

crosswalks in advance of roundabouts, and other roadway situations involving pedestrian crossings.

The next sections summarize important information on the other types of traffic signals listed above that are relevant in Tennessee.

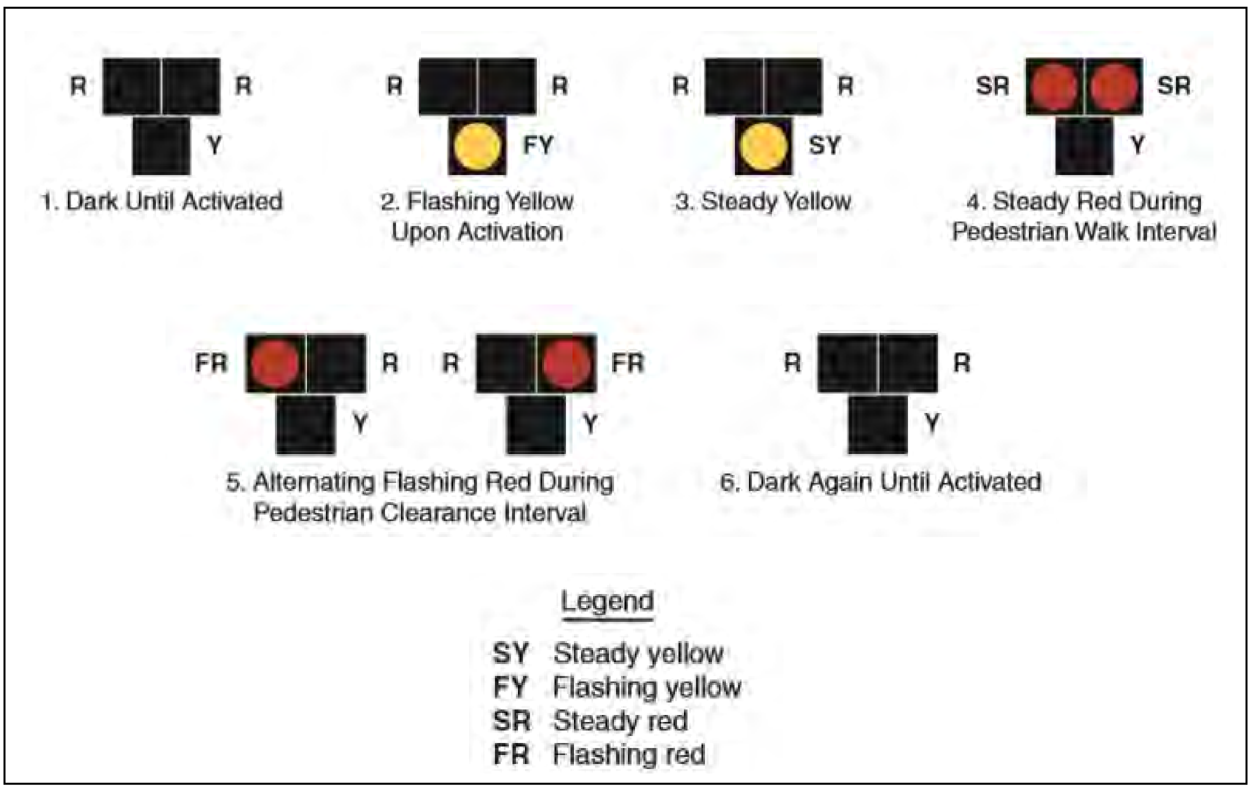
13.2 Pedestrian Hybrid Beacons

Generally, a pedestrian hybrid beacon is considered for installation to facilitate pedestrian crossings at a location that does not meet traffic signal warrants. When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then:

- At least two pedestrian hybrid beacon faces shall be installed for each approach of the major street;
- A stop line shall be installed for each approach to the crosswalk;
- A pedestrian signal head conforming to the provisions set forth in the *MUTCD Chapter 4E* shall be installed at each end of the marked crosswalk; and
- The pedestrian hybrid beacon shall be pedestrian actuated and shall conform to the provisions set forth in the *MUTCD Chapter 4F*.

Figure 13.1 presents a pedestrian hybrid beacon sequence display.

Figure 13.1 – Pedestrian Hybrid Beacon Sequence Display



13.3 Emergency Vehicle Traffic Control Signals

An emergency vehicle traffic control signal may be installed at a location that does not meet other traffic signal warrants, such as at an intersection or other location to permit direct access from a building housing the emergency vehicle (e.g. fire station).

13.3.1 Displays

The emergency signal shall display either steady green or flashing yellow to the public street approaches when not activated. If the flashing yellow signal indication is used instead of the steady green signal indication, it shall be displayed in the normal position of the steady green signal indication; while the red and steady yellow signal indications shall be displayed in their normal positions. When an emergency vehicle actuation occurs, a steady yellow change interval followed by a steady red interval shall be displayed to traffic on the public street. An emergency vehicle hybrid beacon may be installed instead of an emergency traffic control signal under specific conditions (*MUTCD Section 4G.04*). Figure 13.2 presents an emergency hybrid beacon sequence display.

13.3.2 Control

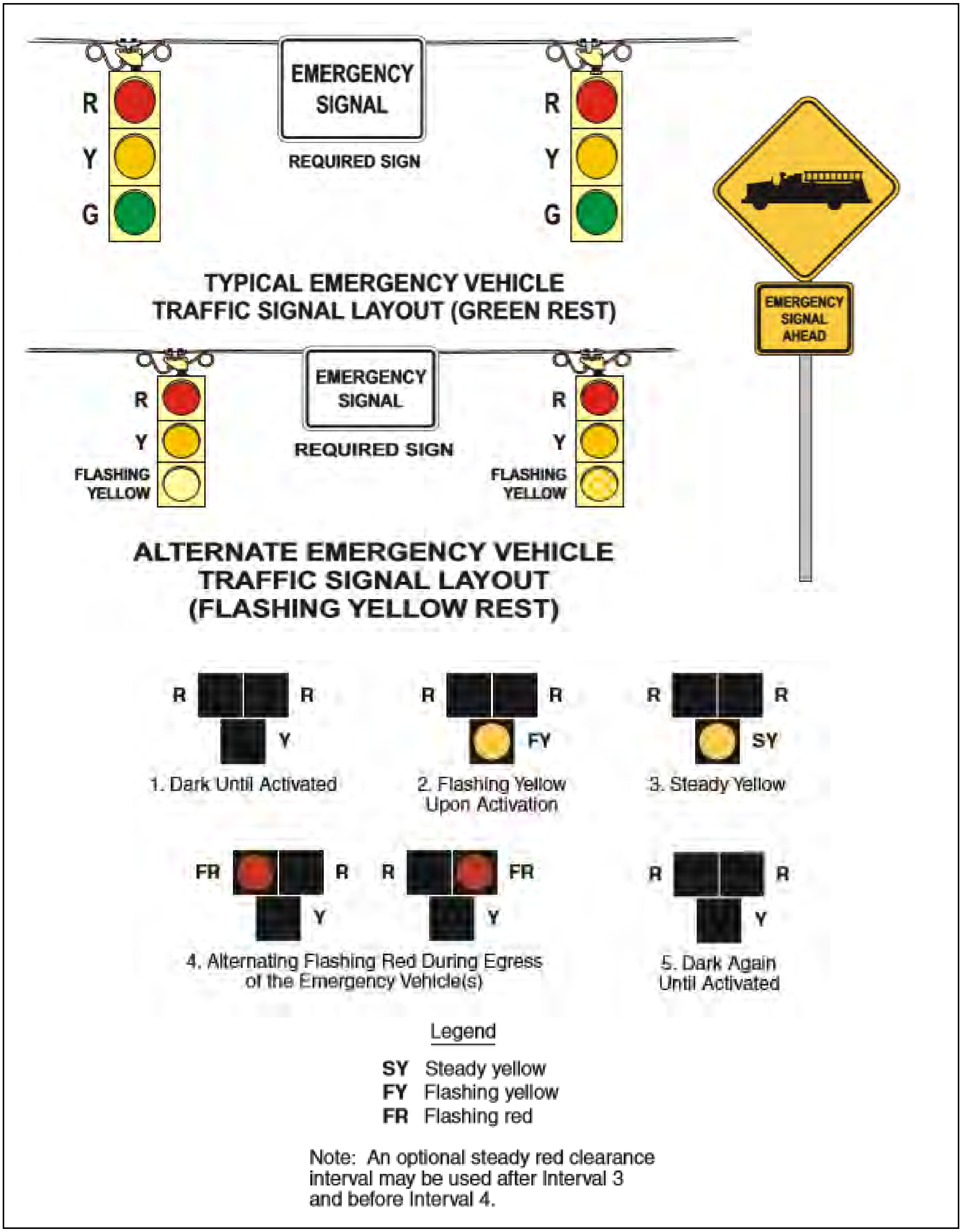
An emergency vehicle traffic control signal sequence may be initiated manually from a local control point, such as a fire station or police headquarters, or from an emergency vehicle equipped for remote operation of the signal.

13.3.3 Signing

If an emergency signal is used, the following signs shall be installed:

- An Emergency Vehicle (W11-8) sign with an Emergency Signal Ahead (W11-12P) supplemental plaque shall be placed in advance of an emergency vehicle signal. A warning beacon may be installed to supplement the Emergency Vehicle sign; and
- An Emergency Signal (R10-13) sign shall be mounted adjacent to a signal face on each street approach.

Figure 13.2 – Emergency Vehicle Traffic Signals



13.4 Flashing Beacons

A flashing beacon is composed of one or more traffic signal sections operating in a flashing mode. A flashing beacon can provide traffic control when used as an intersection control beacon, or it can provide warning, as described below. An automatic dimming feature may be used to reduce the nighttime brightness.

13.4.1 Intersection Control Beacons

Intersection control beacons consist of two signal faces per intersection approach, each with one signal section having a 12-inch lens (See Figure 13.3). Normally, flashing yellow signal indications will be displayed to the major street and flashing red signal indications to the minor street. At the intersection of two streets of equal importance, flashing red signal indications may be displayed to both streets. A Stop sign shall be used on approaches to which a flashing red signal indication on an intersection control beacon is shown. If two horizontally aligned red signal indications are used on an approach for an intersection control beacon, they shall be flashed simultaneously to avoid being confused with grade crossing flashing-light signals. If two vertically aligned red signal indications are used on an approach for an intersection control beacon, they shall be flashed alternately. Intersection control beacons are intended to be used as a supplement to and not a replacement for other traffic control devices at the intersection. An intersection beacon may be installed when conditions do not justify the installation of a conventional traffic signal, but crash rates indicate the possibility of a special need. The most common application for these beacons is at intersections with minor approach stop control, where some approaching vehicles on the controlled legs have failed to stop.

13.4.2 Stop Beacons (Red)

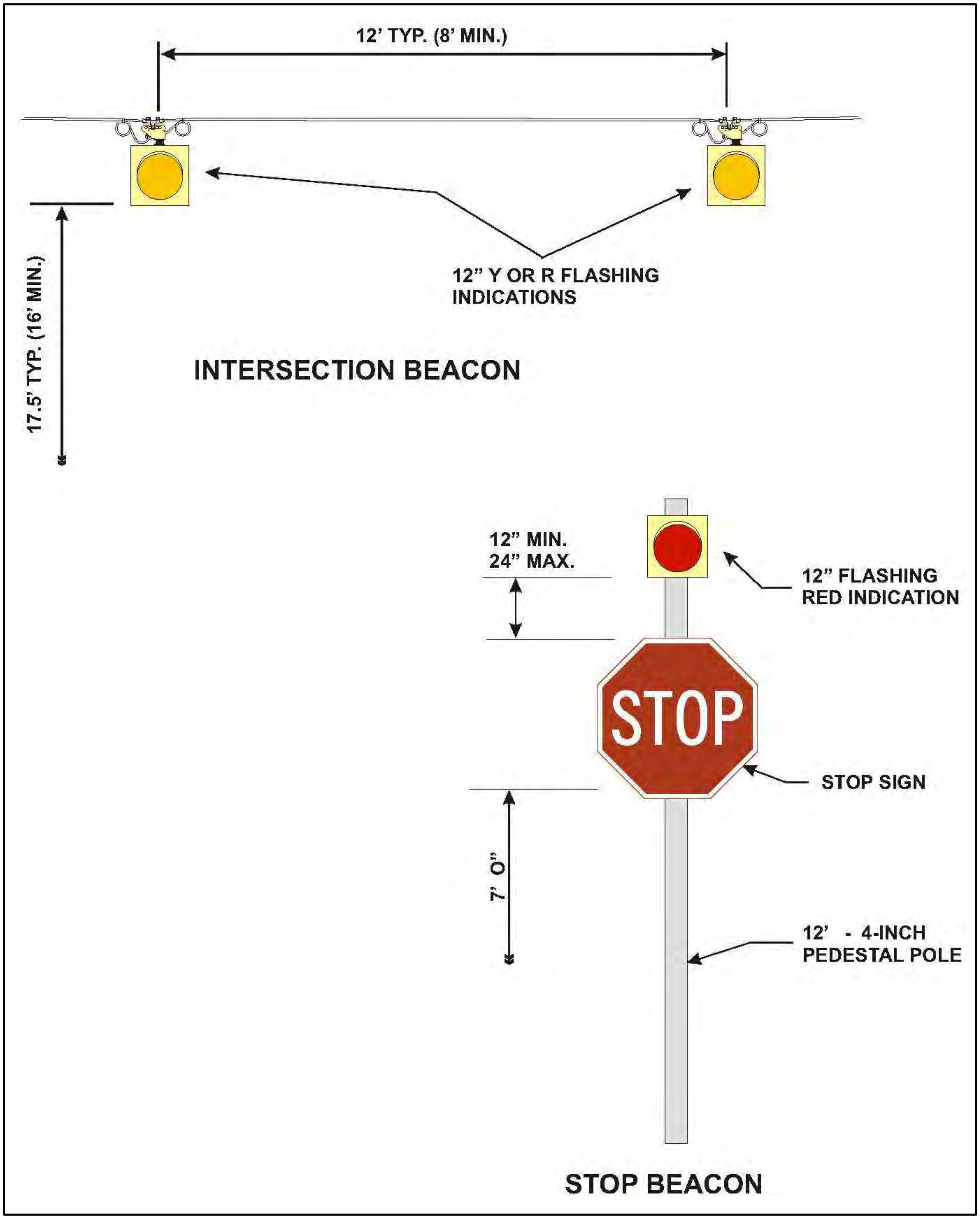
A stop beacon shall be used only to supplement a Stop sign, a Do Not Enter sign, or a Wrong Way sign. Stop sign beacons consist of one or more signal sections having flashing red 12-inch signal indications mounted on a Stop sign (See Figure 13.3). If two flashers are used on one sign, they shall flash simultaneously if mounted horizontally and alternately if mounted vertically. Stop beacons can be justified for Stop signs subject to the following considerations:

- **Violations:** A significant number of vehicles violate the stop condition.
- **Crashes:** A crash rate exists that indicates the presence of a special need.

13.4.3 Speed Limit Sign Beacons

A speed limit sign beacon consists of one or more signal sections with a flashing circular yellow signal indication in each section. It is used to supplement a Speed Limit sign. It may be installed with a fixed or variable Speed Limit sign (R2-1) where studies show a need to emphasize that a speed limit is in effect. Signal indications may be either 8-inch or 12-inch and they shall flash alternately.

Figure 13.3 – Intersection Control Beacons and Stop Beacons (Red)



13.4.4 School Zone Speed Limit Sign Beacons

A school zone flashing beacon consists of two signal sections with a flashing circular yellow signal indication in each section and is used in conjunction with the standard School Zone sign (S5-1) (See TDOT *Standard Drawing T-SG-13*). Figure 13.4 displays the typical layout. Eight-inch lenses may be used and installed within the borders of the sign. When 12-inch signal heads are used, they must be mounted on the outside of the sign. The two indications in a school zone speed limit beacon shall flash alternately. A school zone beacon may be installed and maintained by a school board or local government at an established school zone under a Traffic Control Device Permit. School zone beacons on State highways must be coordinated through the TDOT Regional Traffic Engineer.

13.4.5 Warning Beacons (Yellow)

Warning beacons are used only to supplement an appropriate warning or regulatory sign or marker (See Figure 13.5). Warning beacons consist of one or more signal sections, each having flashing yellow signal indications which flash alternately. Warning beacons may be justified by either of the following:

- **Obstruction Identification:** Warning beacons may be used to help identify obstructions in or immediately adjacent to the roadway where crash experience indicates that additional emphasis is needed to supplement existing signing and pavement markings. Such obstructions could include guardrail at T-intersections, bridge supports in or near the roadway, etc.
- **Supplement to Advance Warning Signs:** A flashing beacon may be used to supplement advance warning signs for a variety of conditions, where crash experience or field observation reveals that the warning signs alone are not effective. Such conditions could include sharp curves, obscured stop conditions, weather-related hazards such as fog and ice, obscured railroad crossings, truck crossings, plant entrances, etc. Warning beacons are also applicable to emphasize midblock crosswalks.

13.4.6 Traffic Signal Ahead Beacons

Traffic signal ahead beacons consist of one or more signal sections, each having alternately flashing yellow signal indications (See Figure 13.5). They are used in conjunction with the standard Signal Ahead warning sign (W3-3). Signal ahead beacons may be justified under either of the following conditions:

- **First Signal:** On highways with a posted speed limit 45 mph or greater that is approaching the first signalized intersection of a community or town, and the intersection experiences a crash rate that indicates the presence of a special need.
- **Sight Distance:** On highways with a posted speed limit 45 mph or greater that is approaching a traffic signal whose signal visibility is less than that called for in Table 9.2 (Minimum Sight Distance for Signal Visibility).

Figure 13.4 – School Zone Speed Limit Sign Beacons

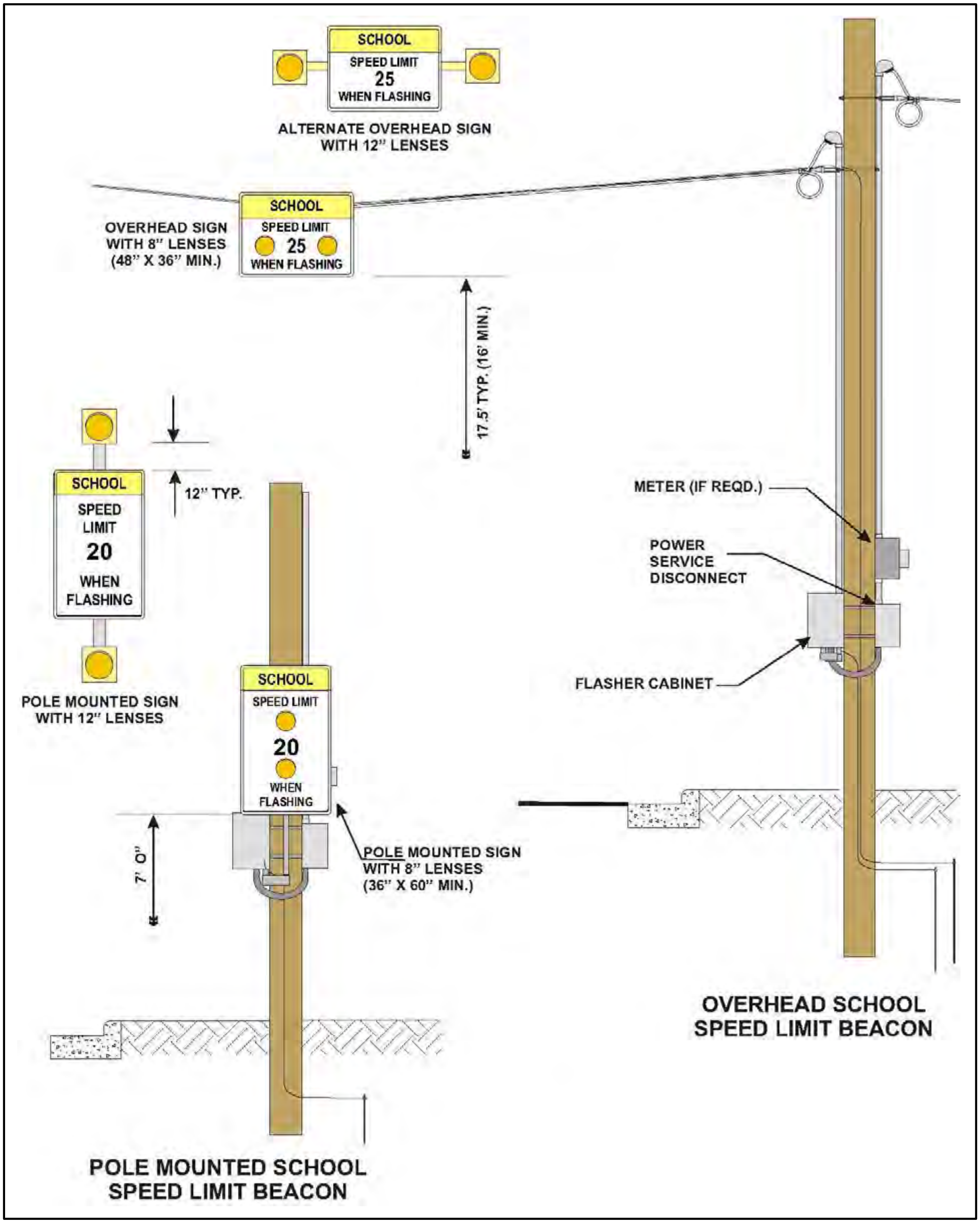
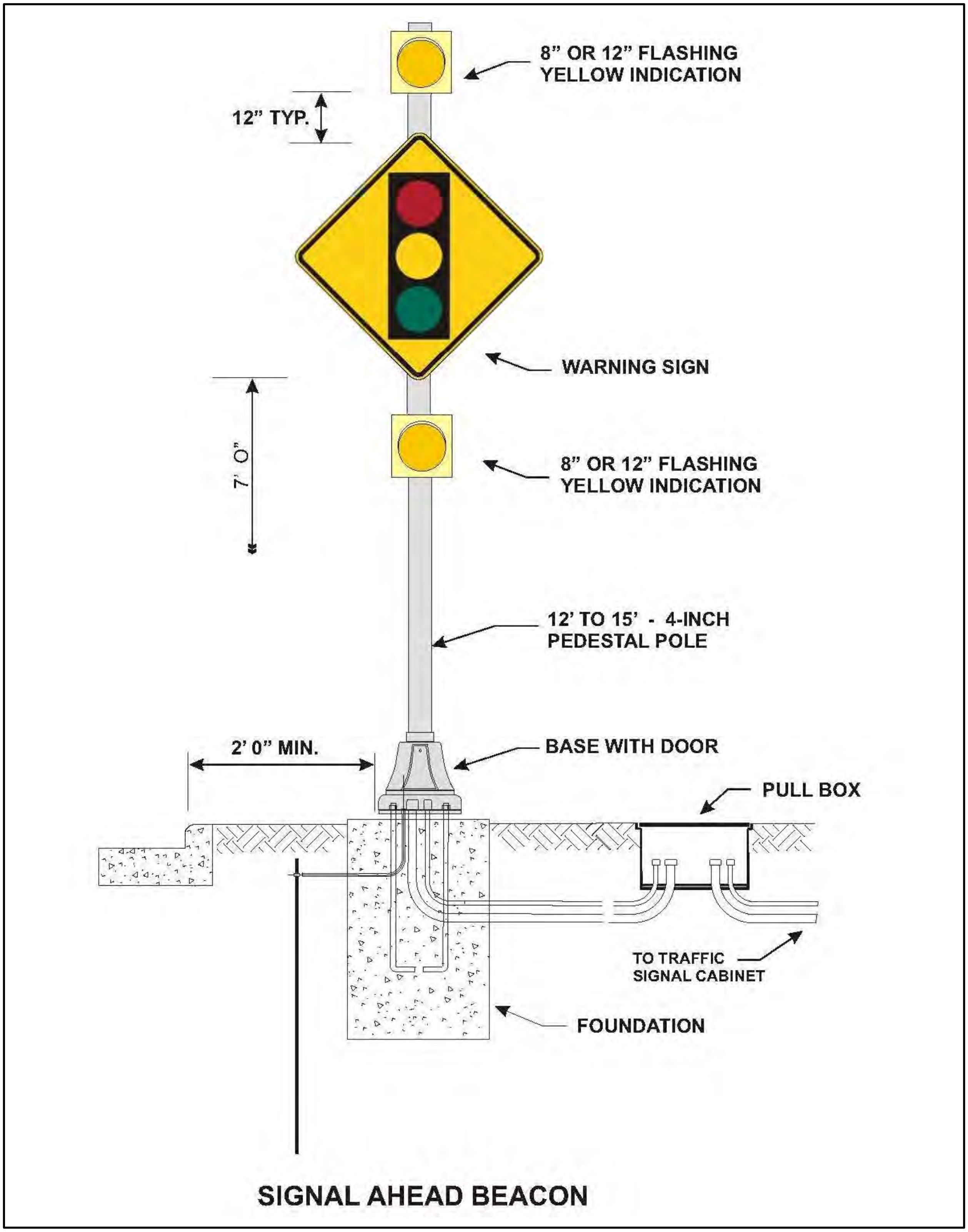


Figure 13.5 – Warning Beacons (Yellow) and Traffic Signal Ahead Beacons



[This page intentionally left blank.]

CHAPTER 14

SIGNING AND PAVEMENT MARKINGS

14.1 General Information

The designer is responsible for ensuring signing and/or pavement marking projects comply with the following documents:

- ***Manual on Uniform Traffic Control Devices (MUTCD), 2009 Edition:*** The *MUTCD* is the obligatory guide for signing and pavement marking and is published by FHWA in conjunction with the ITE, ATSSA, and AASHTO. The designer should review the FHWA *MUTCD* website for the latest edition of the *MUTCD* along with any interim updates and compliance dates.
- **Standard Highway Signs, FHWA:** This document contains detailed drawings of all standard highway signs in addition to standard alphabets, symbols, and arrows. Each sign is identified by a unique designation. Signs not included in the *Standard Highway Signs* or in the *TDOT Tennessee Supplement to Standard Highway Signs* must be detailed in the plans.
- **TDOT Supplement to Standard Highway Signs:** This document provides detailed drawings for signs and symbols that are applicable to Tennessee, but are not addressed in the *MUTCD*.
- **Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, AASHTO:** This document provides the design criteria for the structural design of highway sign supports, luminaires, and traffic signals.
- **Roadway and Traffic Operations Standard Drawings:** These standards are composed of a number of standard drawings or indexes that address specific situations that occur on a large majority of construction projects.
- **TDOT Standard Specifications for Road and Bridge Construction (Standard Specifications):** The standard specifications are the requirements adopted by TDOT for work methods, materials, and basis of payment used in construction. The standard specifications are intended for general and repetitive use. They provide TDOT criteria for the scope of work, control of work, control of materials, legal regulations and responsibilities to the public, contract prosecution and progress, and measurement and payment of contract items.
- **TDOT Roadway and Traffic Design Guidelines:** These guidelines establish uniform procedures for roadway and traffic design activities within TDOT and provide guidance in the preparation of construction plans and estimates.

14.2 Signing

All regulatory and warning signs shall meet the design and installation requirements of the *MUTCD*. Effective signing provides clear information and instruction to motor vehicle operators, pedestrians, and bicyclists. Properly installed signing facilitates legal, safe, and orderly progress on public roadways.

14.2.1 MUTCD

The guidance provided in the *MUTCD* is divided into four categories:

- Standard;
- Guidance;
- Option; and
- Support.

These categories are used to determine the appropriate application for the various traffic control devices. Where applicable, the designer is required to meet the criteria presented in the Standard category. Where applicable, the designer is recommended to meet the criteria presented in the Guidance category. If the designer decides to deviate from the guidance based on engineering judgment or engineering study, the designer should document why the guidance is not being followed. Where applicable, the designer is permitted to meet the criteria presented in the option category.

14.2.2 Application

Signs should be used only where required by the *MUTCD* and justified by engineering judgment or studies. Results from traffic engineering studies of physical and traffic factors should indicate the locations where signs are deemed necessary or desirable. Roadway geometric design and sign application should be coordinated so that signing can be effectively placed to give the road user any necessary regulatory, warning, guidance, and other information.

14.2.3 Sign Layouts

The *MUTCD*, TDOT *Supplement to Standard Highway Signs*, and TDOT *Roadway and Traffic Operations Standard Drawings* provide guidance on the placement of regulatory signs, warning signs, guide signs, information signs, service signs, and other signs used in Tennessee.

14.2.4 Conventional Highways (Non-Access Controlled) Signs

- **Directional and Route Signing at Intersections:** The following figures illustrate typical sign assemblies for directional assemblies and route signing at intersections:
  - Figure 14.1 – Intersection of Two Major Routes (4-Way Intersection)
  - Figure 14.2 – Intersection of Two Major Routes (3-Way Intersection)

  - Figure 14.3 – Intersection of Two Major Routes with Overlapping Route Numbers
  - Figure 14.4 – 4-Way Intersection Route Signing with Scenic (Bird) Route
  - Figure 14.5 – 3-Way Intersection Route Signing with Scenic (Bird) Route
  - Figure 14.6 – 3-Way Intersection Route Signing with Scenic (Bird) Route with Overlapping Route Numbers

- **One-Way and Wrong-Way Signing at Median Crossovers:** ONE-WAY signs shall be used to denote streets where only one direction of traffic is allowed. When installed, they should be placed on the near right and far left corners of the intersection. ONE-WAY signs are not required for divided streets with a median width of less than 30 feet. The following figures illustrate typical ONE-WAY and WRONG-WAY signing at median crossovers:

  - Figure 14.7 – Crossroad Signing, Medians less than 30 feet, One-Way and Wrong-Way Signing
  - Figure 14.8 – Signalized Intersection, Medians less than 30 feet, One-Way and Wrong-Way Signing
  - Figure 14.9 – “T” Intersection Right, Medians less than 30 feet, One-Way and Wrong-Way Signing
  - Figure 14.10 – “T” Intersection Left, Medians less than 30 feet, One-Way and Wrong-Way Signing
  - Figure 14.11 – Median Crossover, Medians less than 30 feet, One-Way and Wrong-Way Signing
  - Figure 14.12 – Crossroad Signing, Medians 30 feet or greater, One-Way and Wrong-Way Signing
  - Figure 14.13 – Signalized Intersection, Medians 30 feet or greater, One-Way and Wrong-Way Signing
  - Figure 14.14 – “T” Intersection Right, Medians 30 feet or greater, One-Way and Wrong-Way Signing
  - Figure 14.15 – “T” Intersection Left, Medians 30 feet or greater, One-Way and Wrong-Way Signing
  - Figure 14.16 – Median Crossover, Medians 30 feet or greater, One-Way and Wrong-Way Signing

Figure 14.1 – Intersection of Two Major Routes (4-Way Intersection)

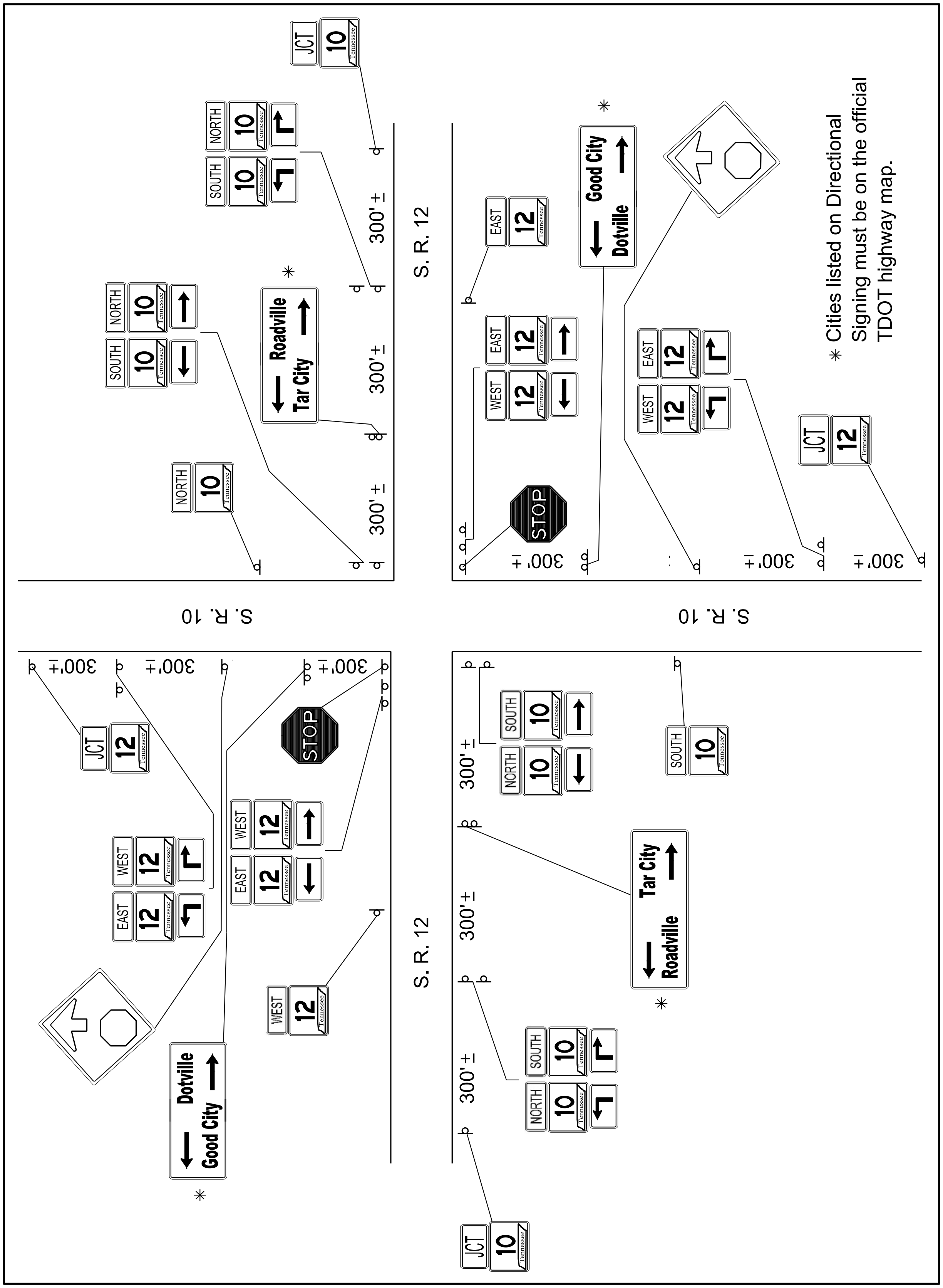


Figure 14.2 – Intersection of Two Major Routes (3-Way Intersection)

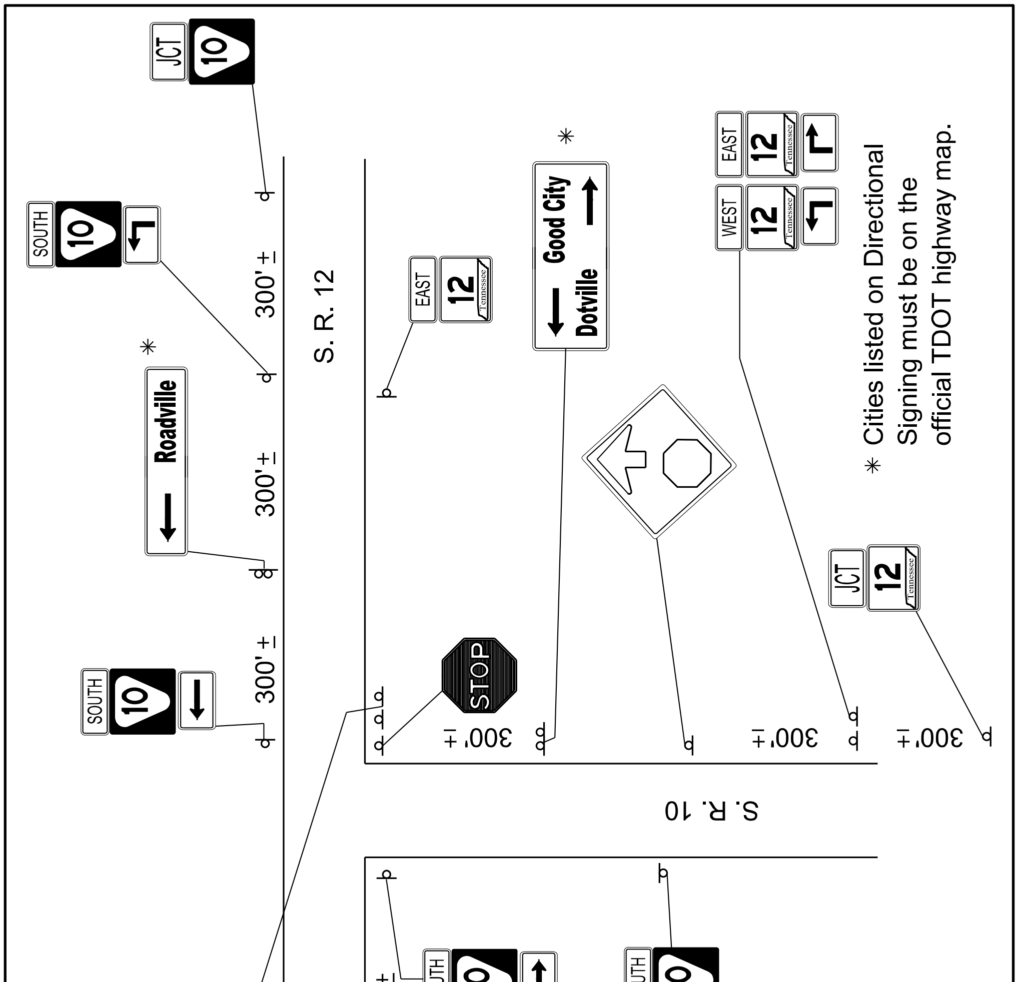


Figure 14.3 – Intersection of Two Major Routes with Overlapping Route Numbers

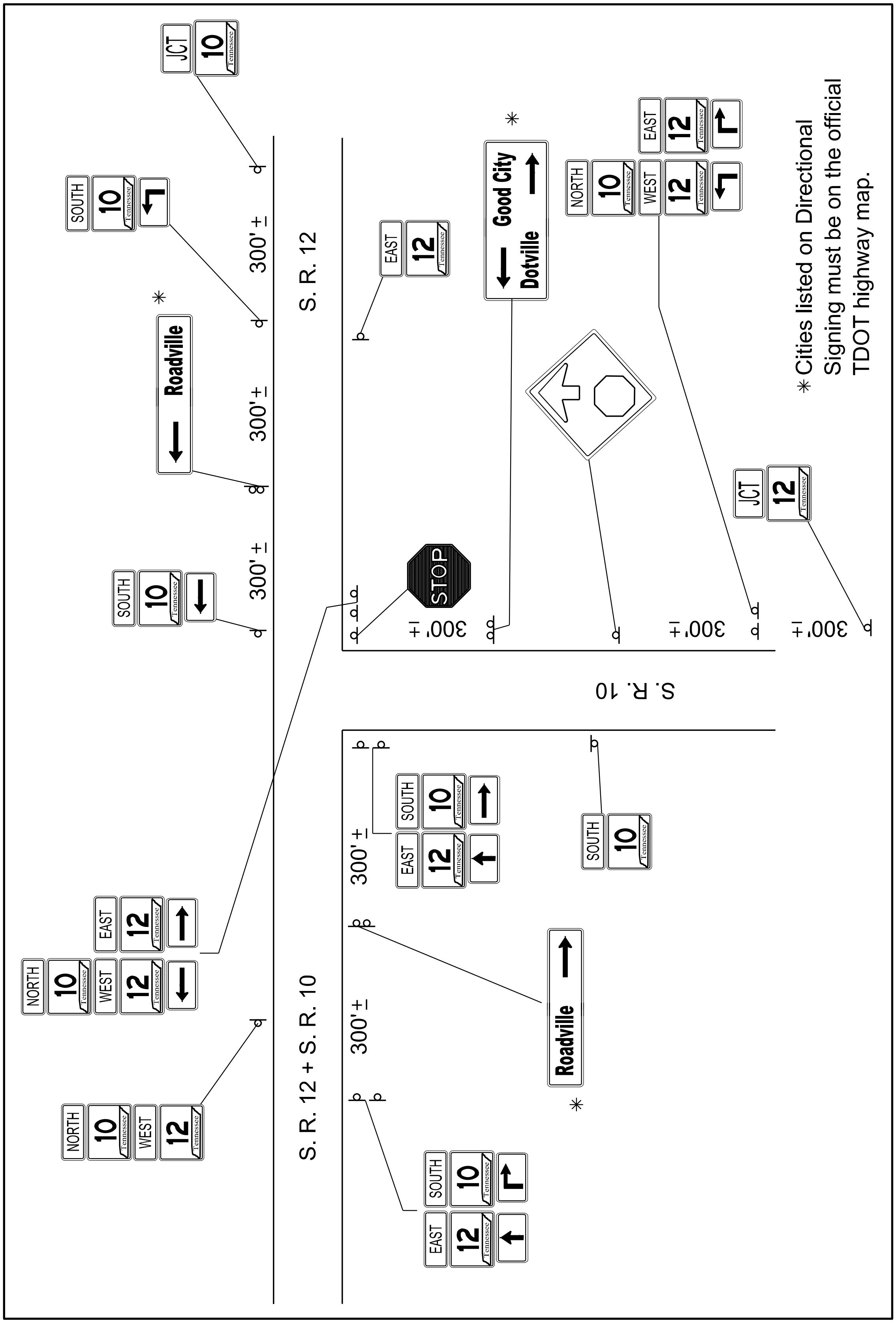


Figure 14.4 – 4-Way Intersection Route Signing with Scenic (Bird) Route

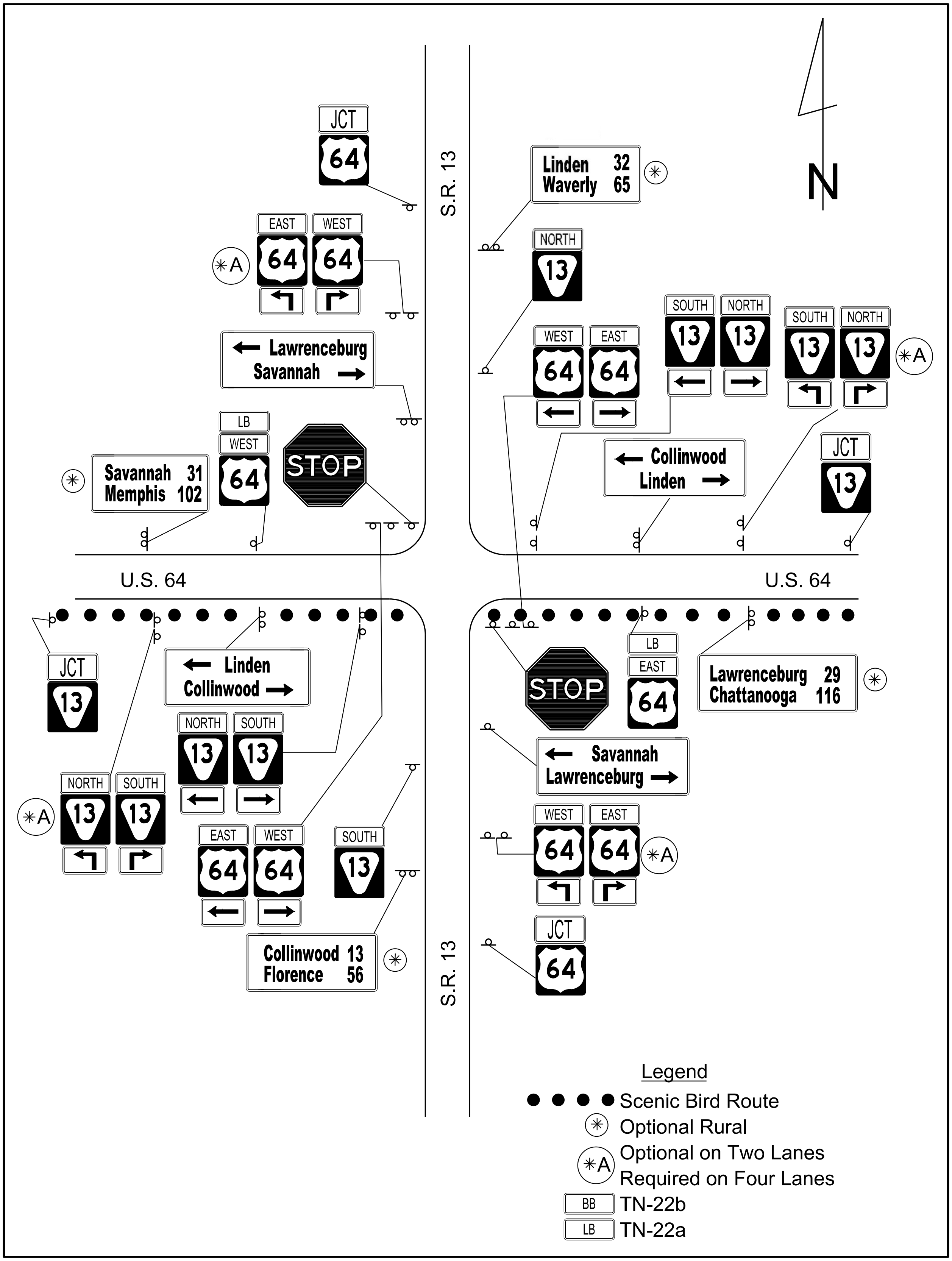


Figure 14.5 – 3-Way Intersection Route Signing with Scenic (Bird) Route

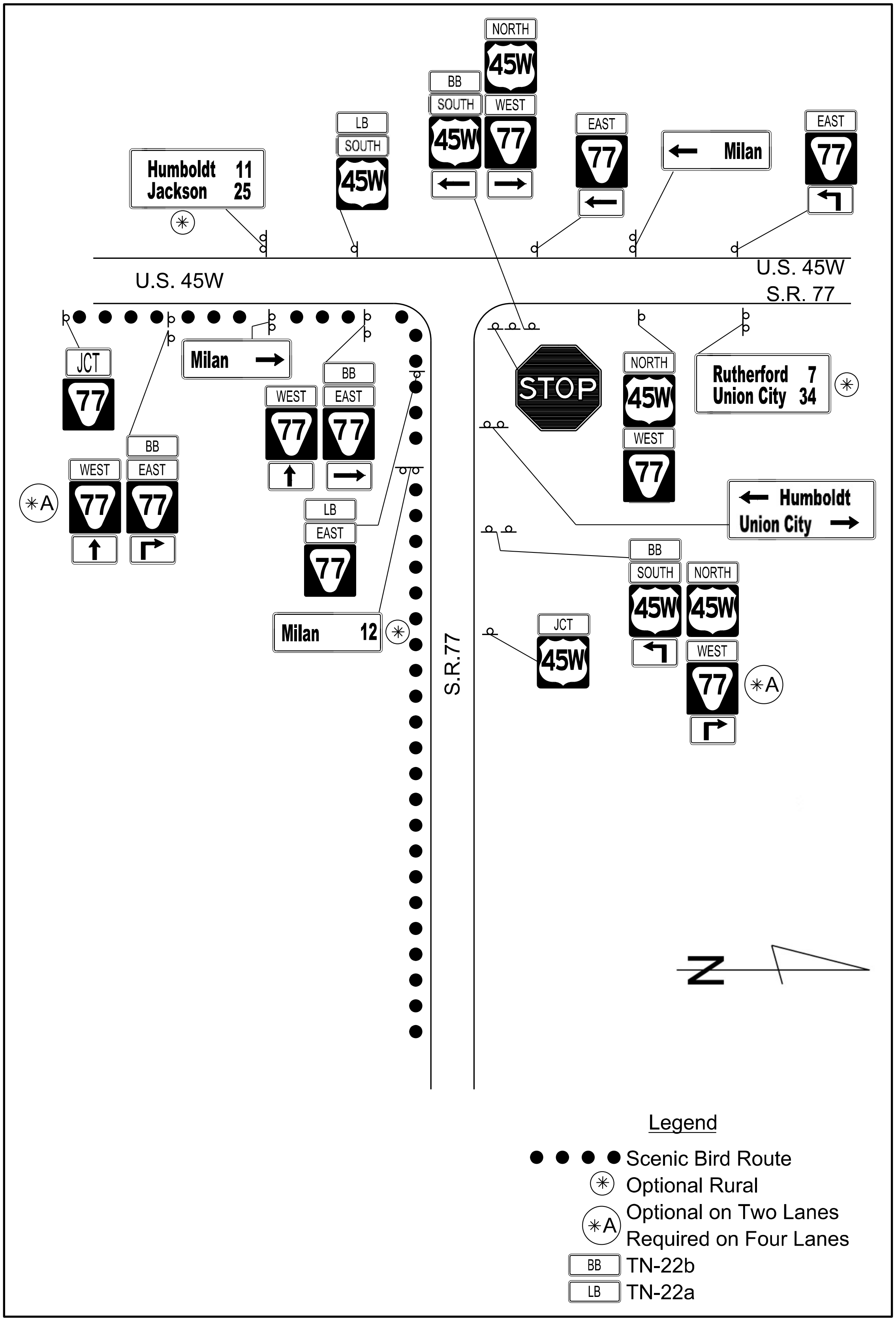


Figure 14.6 – 3-Way Intersection Route Signing with Scenic (Bird) Route with Overlapping Route Numbers

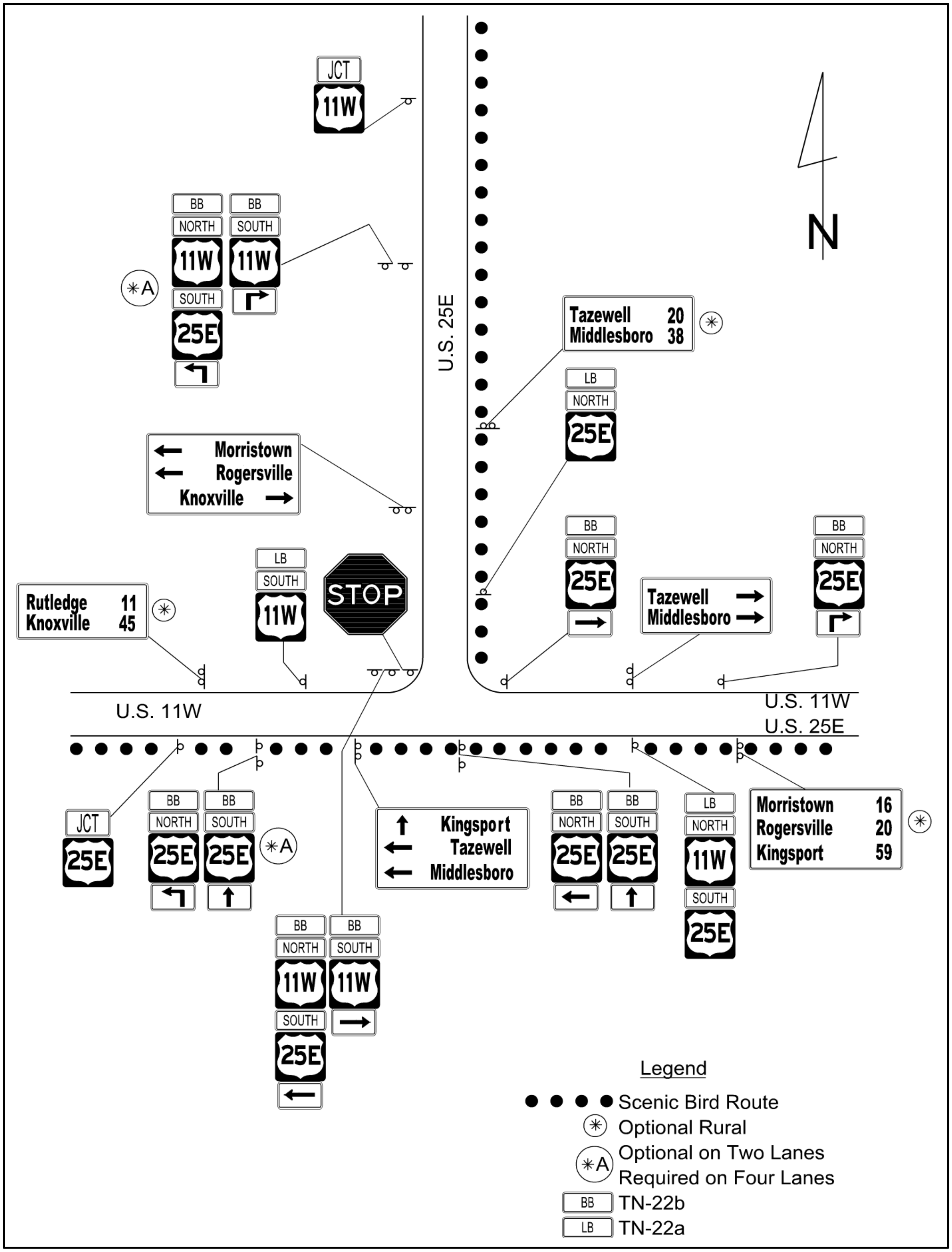


Figure 14.7 – Crossroad Signing, Medians less than 30 feet, One-Way and Wrong-Way Signing

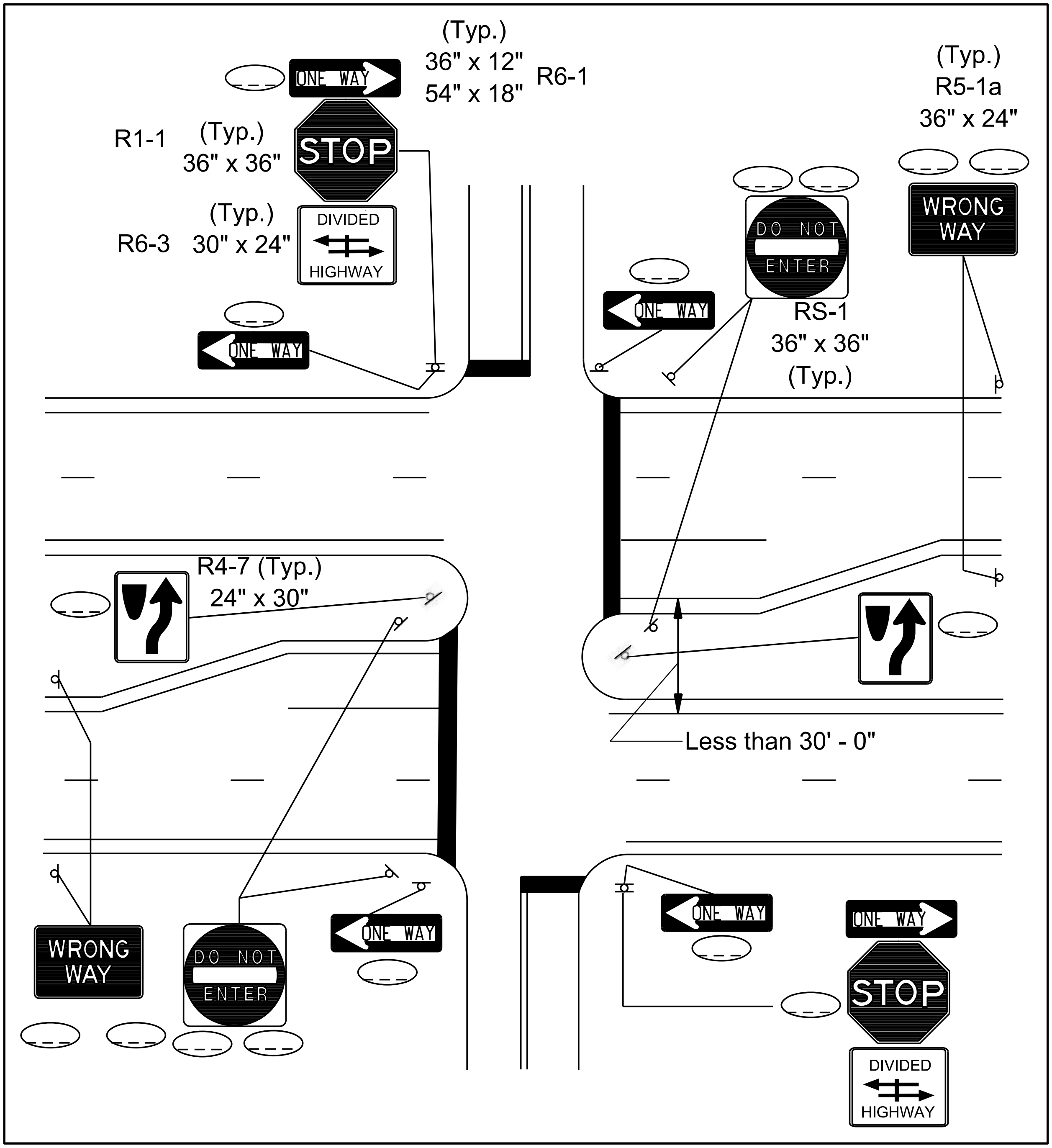


Figure 14.8 – Signalized Intersection, Medians less than 30 feet, One-Way and Wrong-Way Signing

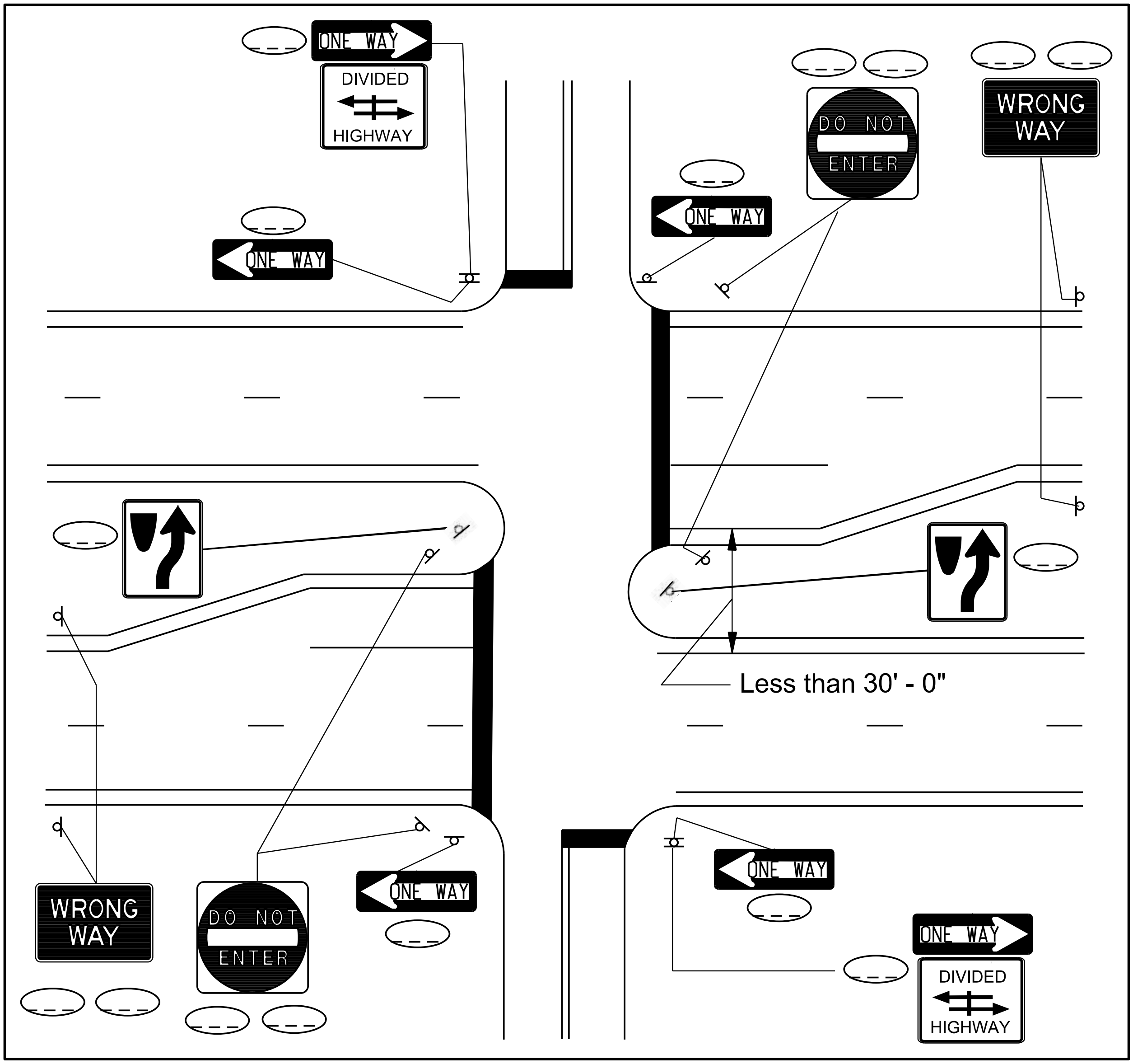


Figure 14.9 – "T" Intersection Right, Medians less than 30 feet, One-Way and Wrong-Way Signing

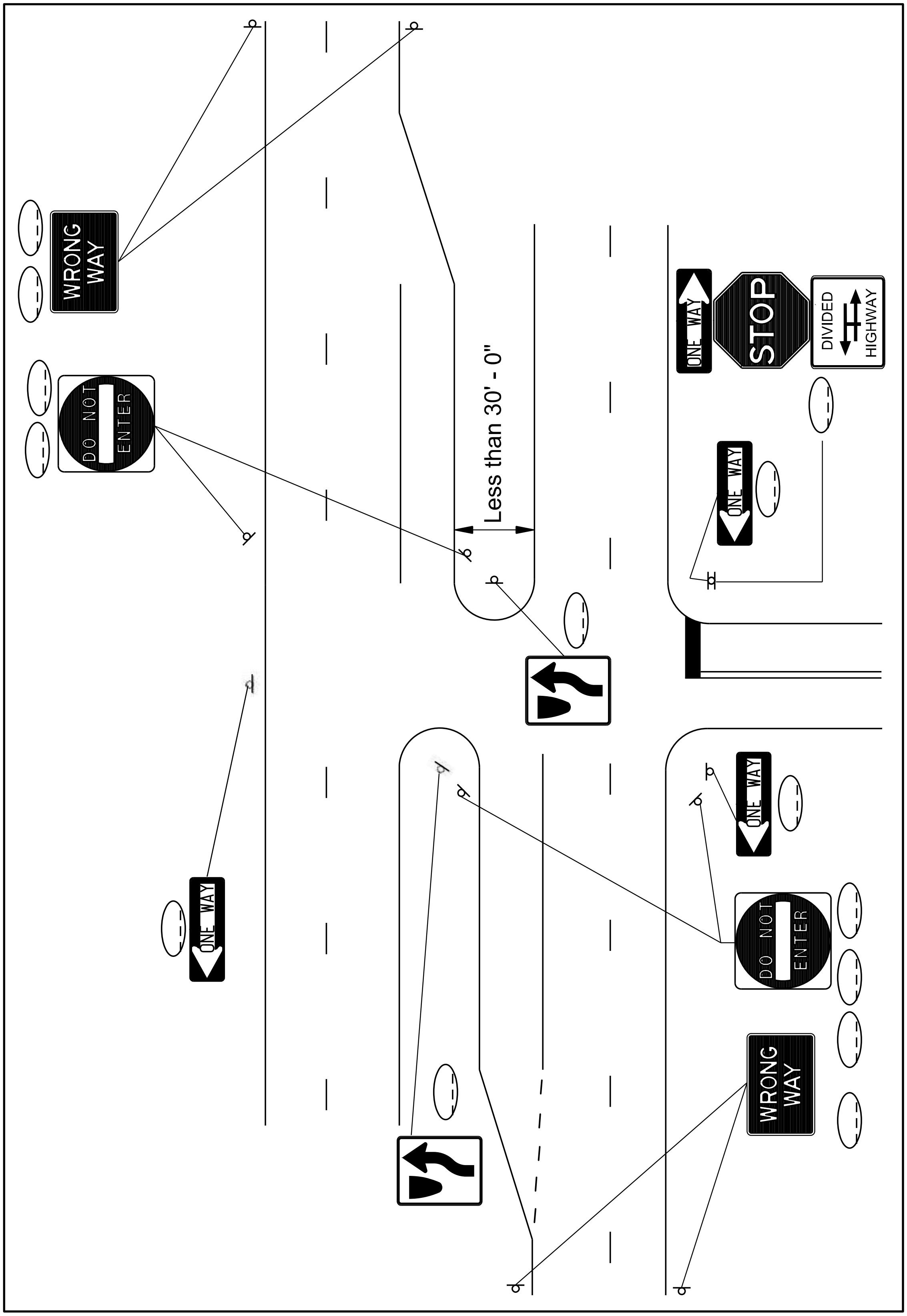


Figure 14.10 – "T" Intersection Left, Medians less than 30 feet, One-Way and Wrong-Way Signing

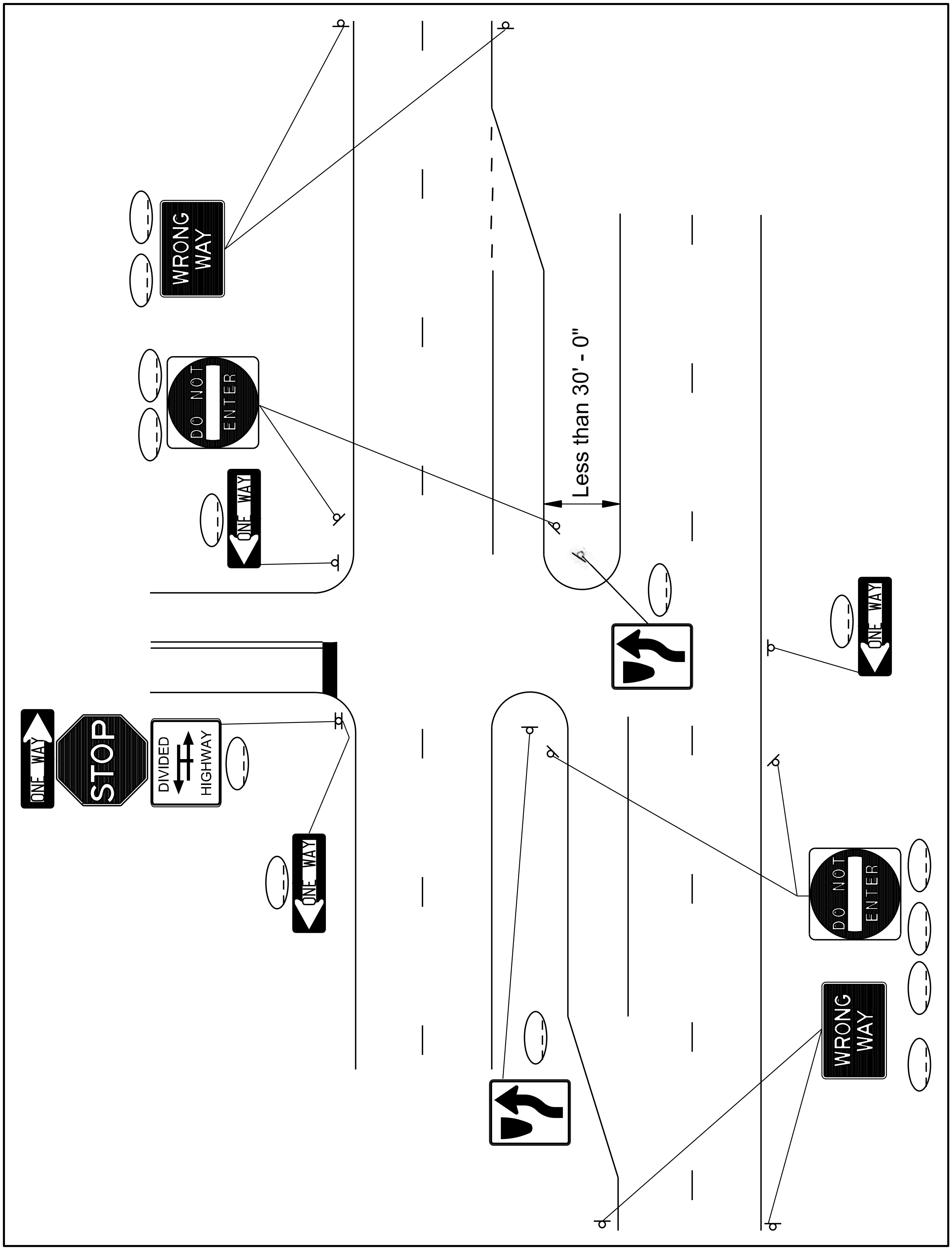


Figure 14.11 – Median Crossover, Medians less than 30 feet, One-Way and Wrong-Way Signing

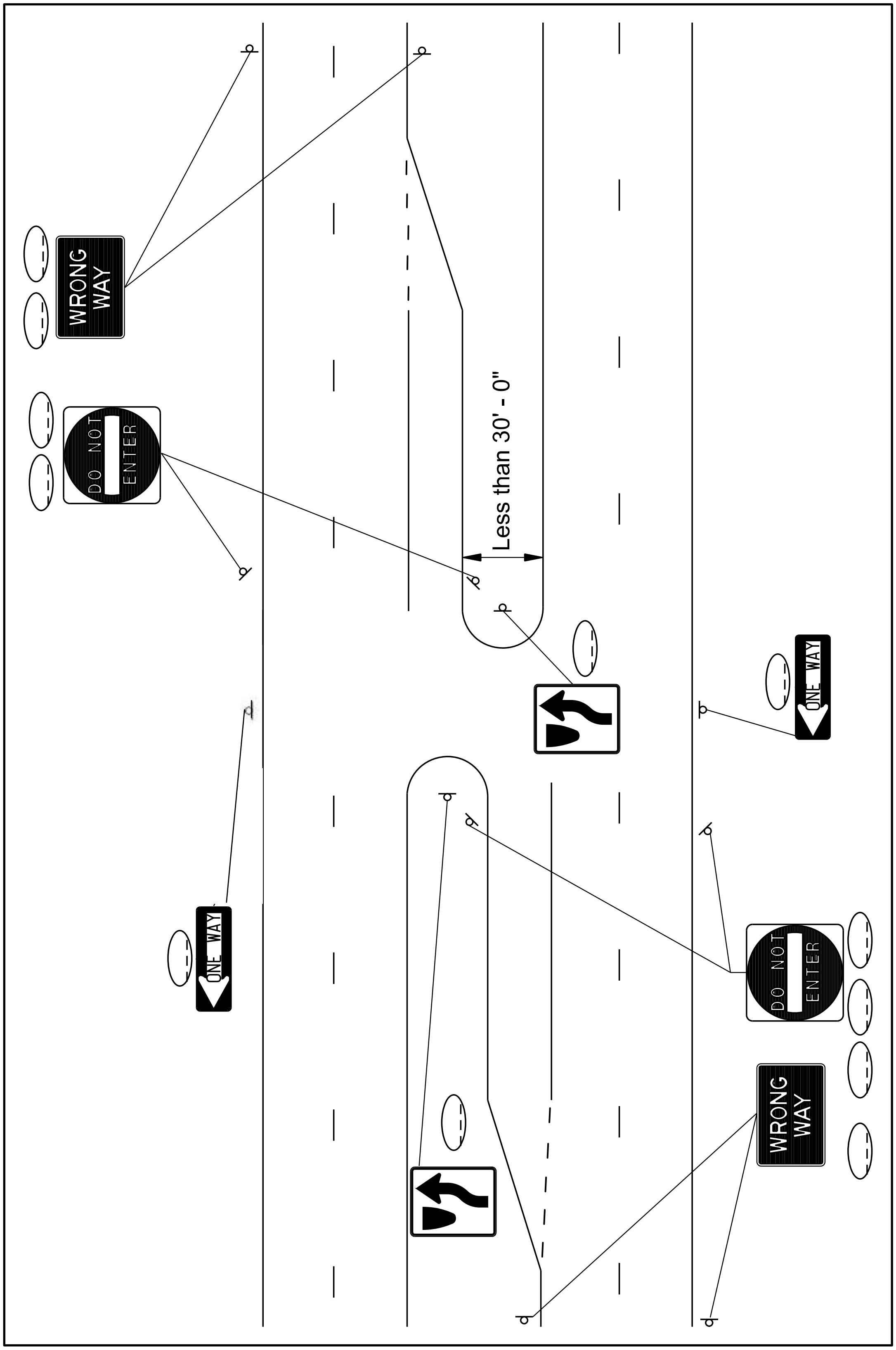


Figure 14.12 – Crossroad Signing, Medians 30 feet or greater, One-Way and Wrong-Way Signing

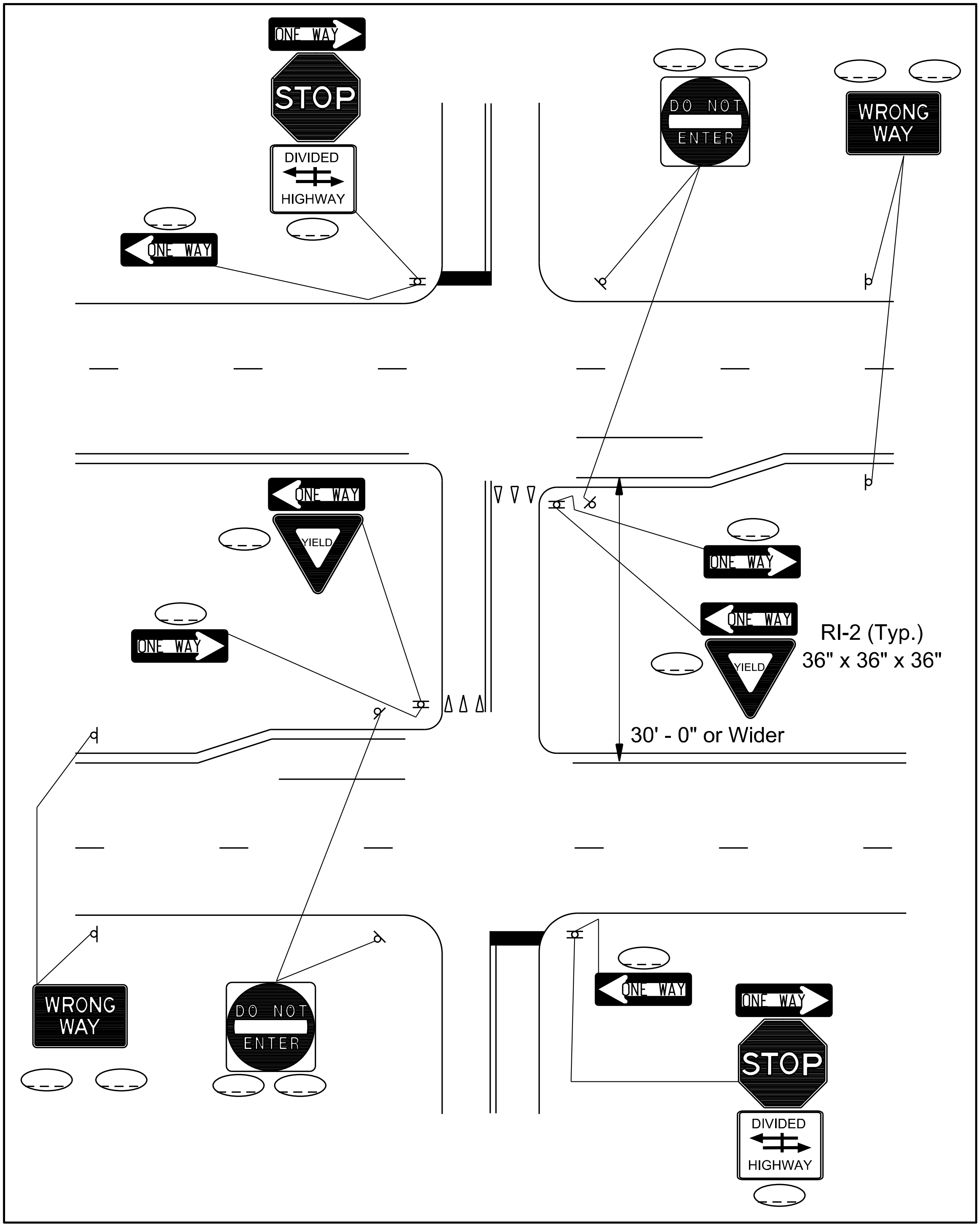


Figure 14.13 – Signalized Intersection, Medians 30 feet or greater, One-Way and Wrong-Way Signing

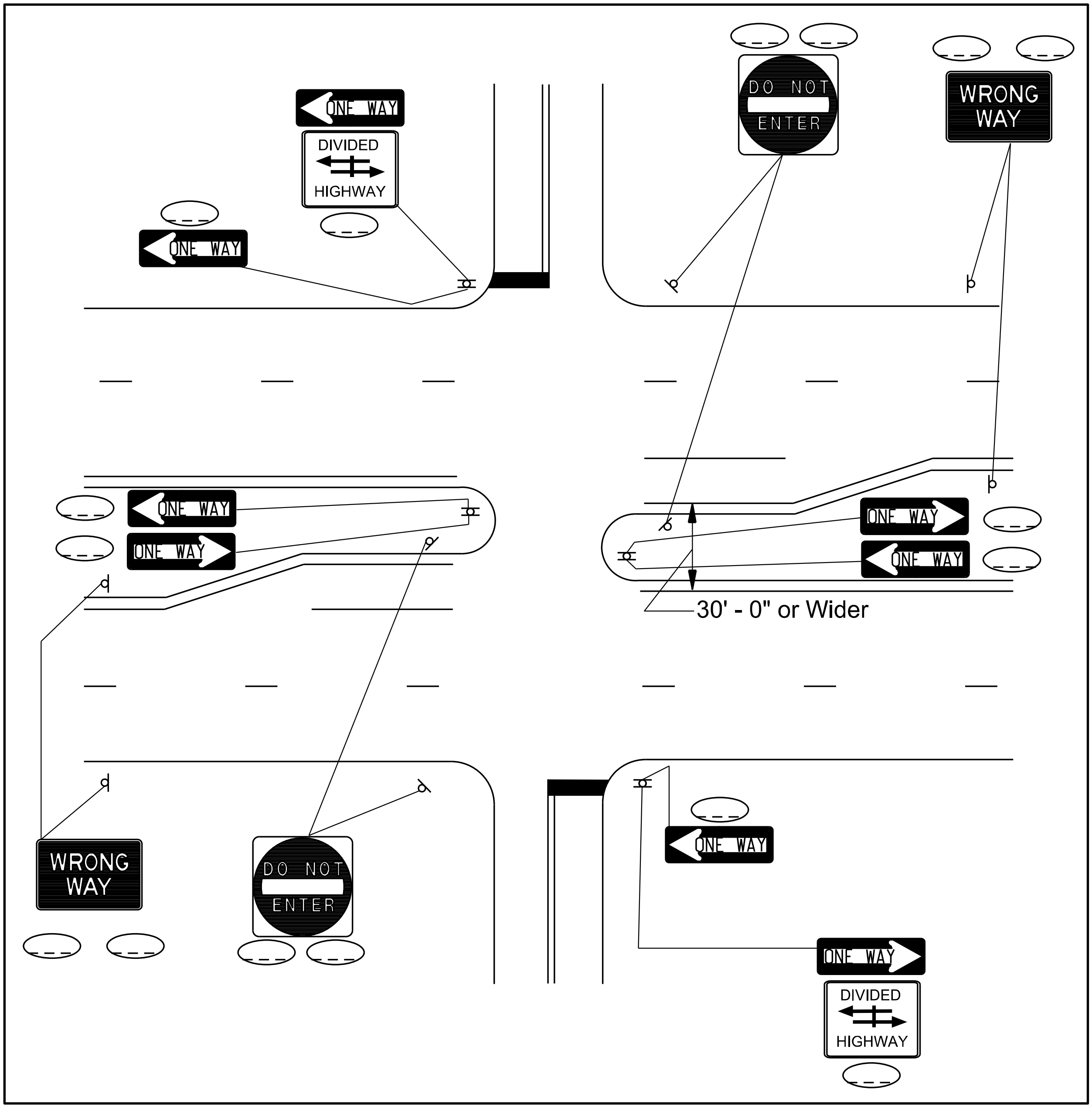


Figure 14.14 – "T" Intersection Right, Medians 30 feet or greater, One-Way and Wrong-Way Signing

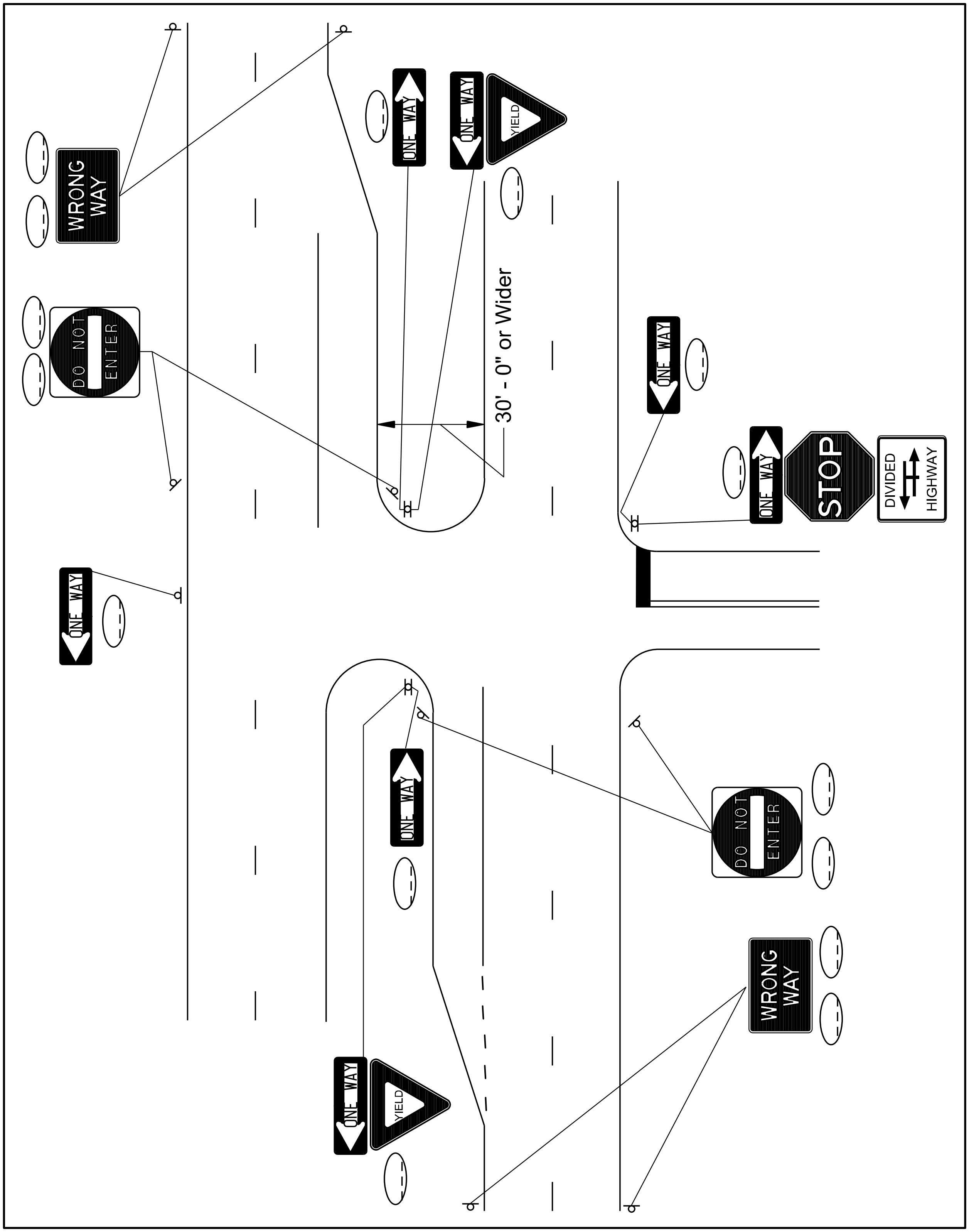


Figure 14.15 – "T" Intersection Left, Medians 30 feet or greater, One-Way and Wrong-Way Signing

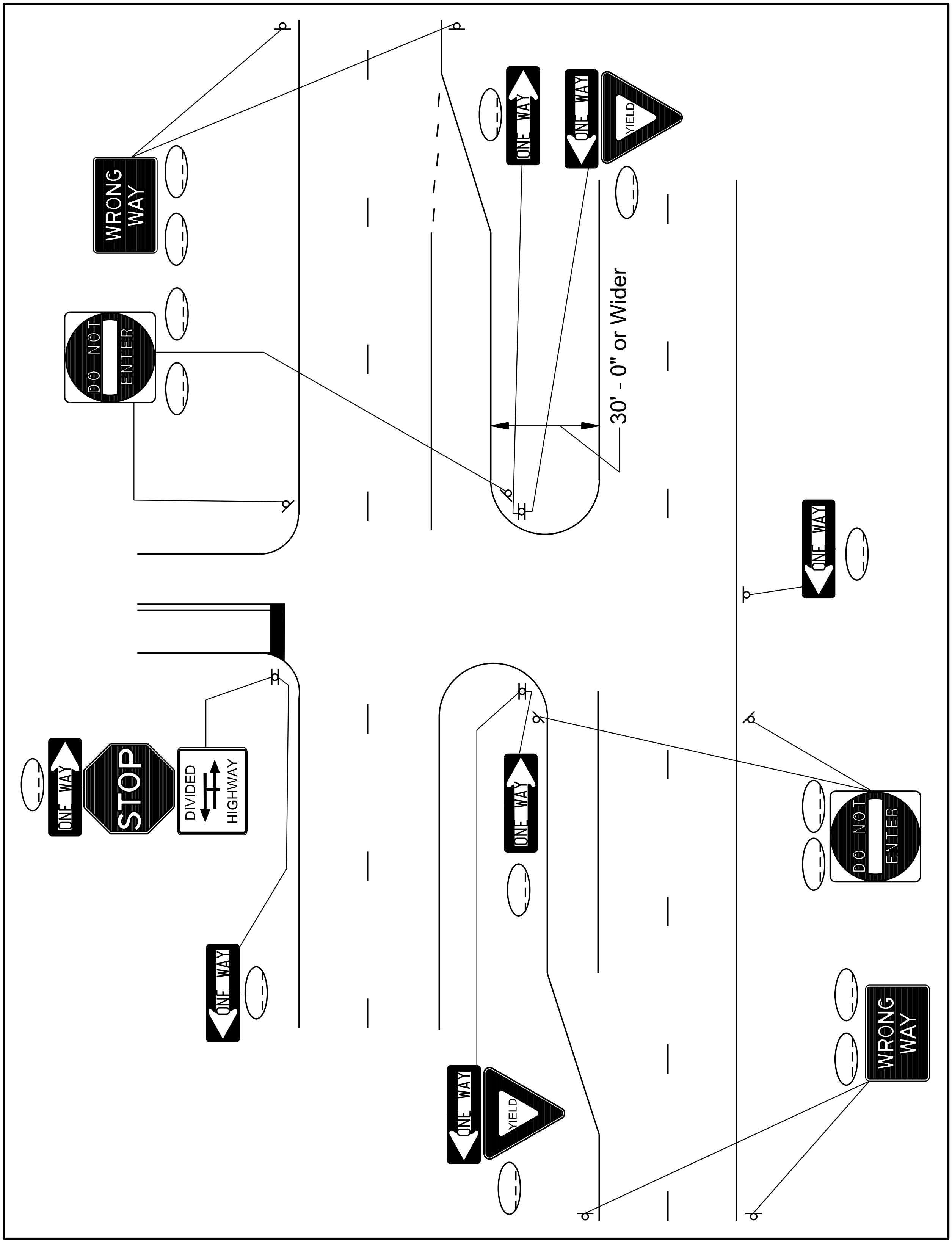
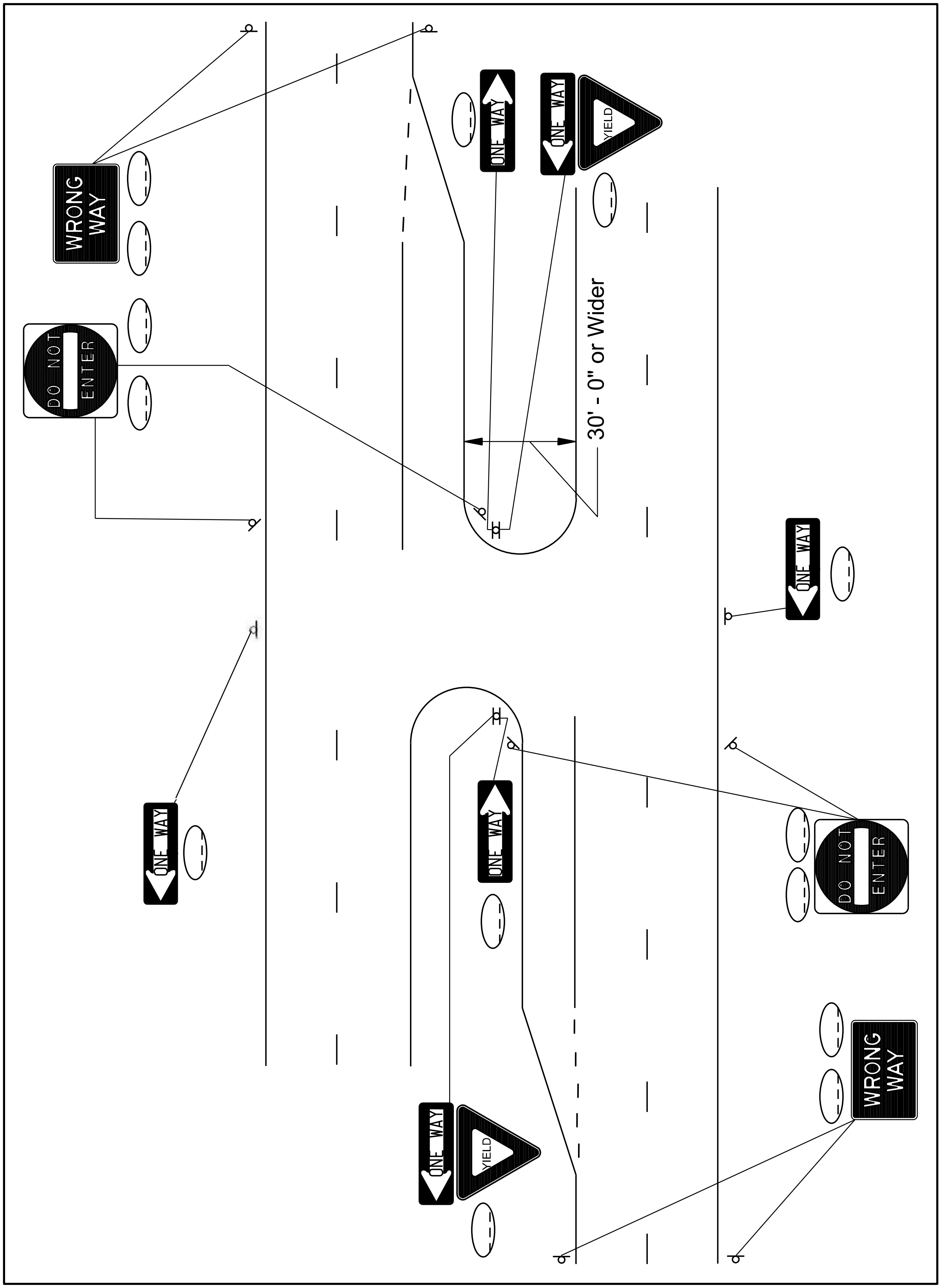


Figure 14.16 – Median Crossover, Medians 30 feet or greater, One-Way and Wrong-Way Signing



- **Roadside Sign Supports:** For roadside signs on two-lane, four-lane, and five-lane non-access controlled, conventional highways, U-post and P-post sign supports are most commonly used. Table 14.1 provides guidance on the selection of the appropriate post types based on the support length and sign assembly. For design purposes and quantity calculations, only use P-posts or U-posts, as applicable. When noted on the Sign Schedule Sheet, the Contractor may substitute the post type used in the design with an alternative post type (i.e., MU-post or R-posts). Figure 14.17 illustrates how to estimate the length of the sign supports for rural and urban roadside signs. Note the support lengths shown in Table 14.1 do not include the stub length in the ground. For P-posts, add three feet for the stub. For U-Posts, add 3.5 feet for the stub. For guidance on larger sign supports including breakaway supports, see Sections 14.2.5 and 14.2.6. Supply and installation of U-posts and P-posts are measured for payment by the pound. Compute the weight of U-posts using the weight per foot of the support multiplied by the combined length of the main post and stub post. Compute the weight of P-Posts using the weight per foot multiplied by the length of the support (excluding the stub) and then add the weight of the stub to the total. Table 14.2 provides the nominal weight per foot for the U-post and P-posts supports used by TDOT.
- **Strain Poles:** Certain overhead signs (e.g., street name signs, exclusive lane signs) are commonly attached to a cable wire over the roadway. The cable is then attached to a steel strain pole. Where steel strain poles are included in the design, the designer is responsible for including the strain pole foundation design in the Signing Detail Sheets. Figure 14.18 illustrates a typical foundation design and cable connection details for a strain pole. The strain pole itself is to be designed by the Contractor and is to meet the criteria in the latest version of the AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*.

Table 14.1 – Post Selection for Various Sign Assemblies (1 of 5)

Sign Face	Perforated Tube	U-Post (Franklin)
1 21"X15" 24"X24"	9'-11' P2 12'-13' P3/P8	9'-10' U3 11'-13' U6
2 21"X15" 30"X24"	9'-10' P2 11'-13' P3/P8	9'-12' U6 13' Not Applicable
3 21"X15" 24"X24" 24"X24"	11' P3/P8 12'-15' P5	Not Applicable
4 21"X15" 30"X24" 24"X24"	11' P3/P8 12'-15' P5	Not Applicable
5 21"X15" 30"X24" 30"X24"	11' P3/P8 12'-15' P5	Not Applicable
6 24"X12" 24"X24"	9'-11' P2 12'-13' P3/P8	9'-10' U3 11'-13' U6
7 24"X12" 30"X24"	9'-11' P2 12'-13' P3/P8	9'-12' U6 13' Not Applicable
8 24"X12" 24"X24" 24"X24"	11' P3/P8 12'-15' P5	Not Applicable
9 24"X12" 24"X24" 30"X24"	11'-15' P5	Not Applicable
10 24"X12" 30"X24" 30"X24"	11'-15' P5	Not Applicable
11 24"X12" 24"X24" 24"X12" 24"X24"	12'-15' P5 16' P6	Not Applicable

Table 14.1 – Post Selection for Various Sign Assemblies (2 of 5)

Sign Face	Perforated Tube	U-Post (Franklin)
12 24"X12" 24"X24" 24"X12" 30"X24"	12'-14' P5 15'-16' P6	Not Applicable
13 24"X12" 24"X24" 24"X12" 30"X24"	12'-14' P5 15'-16' P6	Not Applicable
14 24"X12" 24"X24" 21"X15"	10'-12' P3/P8 13'-14' P5	10'-11' U6 12' Not Applicable
15 24"X12" 30"X24" 21"X15"	10'-12' P3/P8 13'-14' P5	Not Applicable
16 24"X12" 24"X24" 24"X24" 21"X15"	12'-15' P5 16' P6	Not Applicable
17 24"X12" 24"X24" 30"X24" 21"X15"	12'-13' P5 14'-16' P6	Not Applicable
18 24"X12" 30"X24" 30"X24" 21"X15"	12'-13' P5 14'-16' P6	Not Applicable
19 24"X12" 24"X24" 24"X12" 24"X24" 21"X15"	13'-14' P5 15'-17' P6	Not Applicable

Table 14.1 – Post Selection for Various Sign Assemblies (3 of 5)

Sign Face	Perforated Tube	U-Post (Franklin)
20 24"X12" 24"X24" 24"X12" 30"X24" 21"X15"	13'-14' P5 15'-16' P6 17' Not Applicable	Not Applicable
21 24"X12" 30"X24" 24"X12" 30"X24" 21"X15"	13' P5 14'-16' P6 17' Not Applicable	Not Applicable
22 24"X12" 24"X24" 24"X24" 24"X12" 24"X24" 21"X15"	Not Applicable	Not Applicable
27 24"X12" 24"X12" 24"X24" 21"X15"	11' P3/P8 12'-15' P5	Not Applicable
28 24"X12" 24"X12" 30"X24" 21"X15"	11'-15' P5	Not Applicable
29 30"X30"	8' P1 9'-12' P2	8' U1 9'-11' U3 12' U6
30 36"X36"X36" 31.18"	8'-11' P1 12' P2	8'-9' U1 10'-12' U3
31 18"X18"	7'-11' P1	7'-11' U1
32 24"X24"	7'-10' P1 11' P2	7'-11' U1
33 24"X30"	8'-9' P1 10'-12' P2	8' U1 9'-12' U3

Table 14.1 – Post Selection for Various Sign Assemblies (4 of 5)

Sign Face	Perforated Tube	U-Post (Franklin)
34 24"X48"	9' P2 10'-12' P3/P8 13' P5	9'-11' U6 12' Not Applicable
35 30"X30"	8'-11' P2 12' P3/P8	8' U3 9'-12' U6
36 36"X12"	6'-10' P1	6'-10' U1
37 36"X24"	7' P1 8'-11' P2	7' U3 8'-11' U6
38 36"X48" 2-Post	9'-12' P2 13' P3/P8	9'-10' U1 11'-12' U3 13' U6
39 36"X72" 2-Post	11'-14' P3/P8 15' P5	11'-13' U6 14' Not Applicable
40 48"X24" 2-Post	7'-10' P1 11' P2	7'-11' U1
41 24"X24" 24"X18"	9'-10' P2 11'-13' P3/P8	9'-12' U6 13' Not Applicable
42 24"X24" 24"X6" 24"X6"	9'-11' P2 12'-13' P3/P8	9'-10' U3 11'-13' U6
43 24"X8" 24"X30" 24"X10"	10'-13' P3/P8 14' P5	10'-11' U6 12' Not Applicable
44 30"X30" 21.21"	9'-11' P2 12'-13' P3/P8	9'-11' U6 12' Not Applicable
45 30"X30" 24"X18"	11' P3/P8 12'-15' P5	Not Applicable
46 36"X36" 25.46"	10'-11' P3/P8 12'-14' P5	Not Applicable
47 36"X36" 24"X18"	10'-11' P3/P8 12'-14' P5	Not Applicable

Table 14.1 – Post Selection for Various Sign Assemblies (5 of 5)

Sign Face	Perforated Tube	U-Post (Franklin)
48 36"D	8'-10' P2 11'-12' P3/P8	8'-11' U6 12' Not Applicable
49 36"X12" 36"X36"	9' P8 10'-13' P5	Not Applicable
50 48"X18" 2-Post	7'-11' P1	7'-11' U1
51 60"X18" 2-Post	7'-10' P1 11' P2	7'-11' U1
52 72"X18" 2-Post	7'-9' P1 10'-11' P2	7'-11' U1
53 84"X18" 3-Post	7'-11' P1	7'-11' U1
54 96"X18" 3-Post	7'-10' P1 11' P2	7'-11' U1
55 48"X30" 2-Post	8'-9' P1 10'-12' P2	8'-11' U1 12' U3
56 60"X30" 2-Post	8'-10' P2 11'-12' P3/P8	8'-9' U1 10'-11' U3 12' U6
57 72"X30" 2-Post	8'-9' P2 10'-12' P3/P8	8' U1 9' U3 10'-12' U6
58 84"X30" 3-Post	8'-11' P2 12' P3/P8	8'-9' U1 10'-11' U3 12' U6
59 96"X30" 3-Post	8'-9' P2 10'-12' P3/P8	8' U1 9'-10' U3 11'-12' U6
60 36"X36"	10'-11' P3/P8 12'-14' P5	Not Applicable

Figure 14.17 – Estimating Length of Sign Support

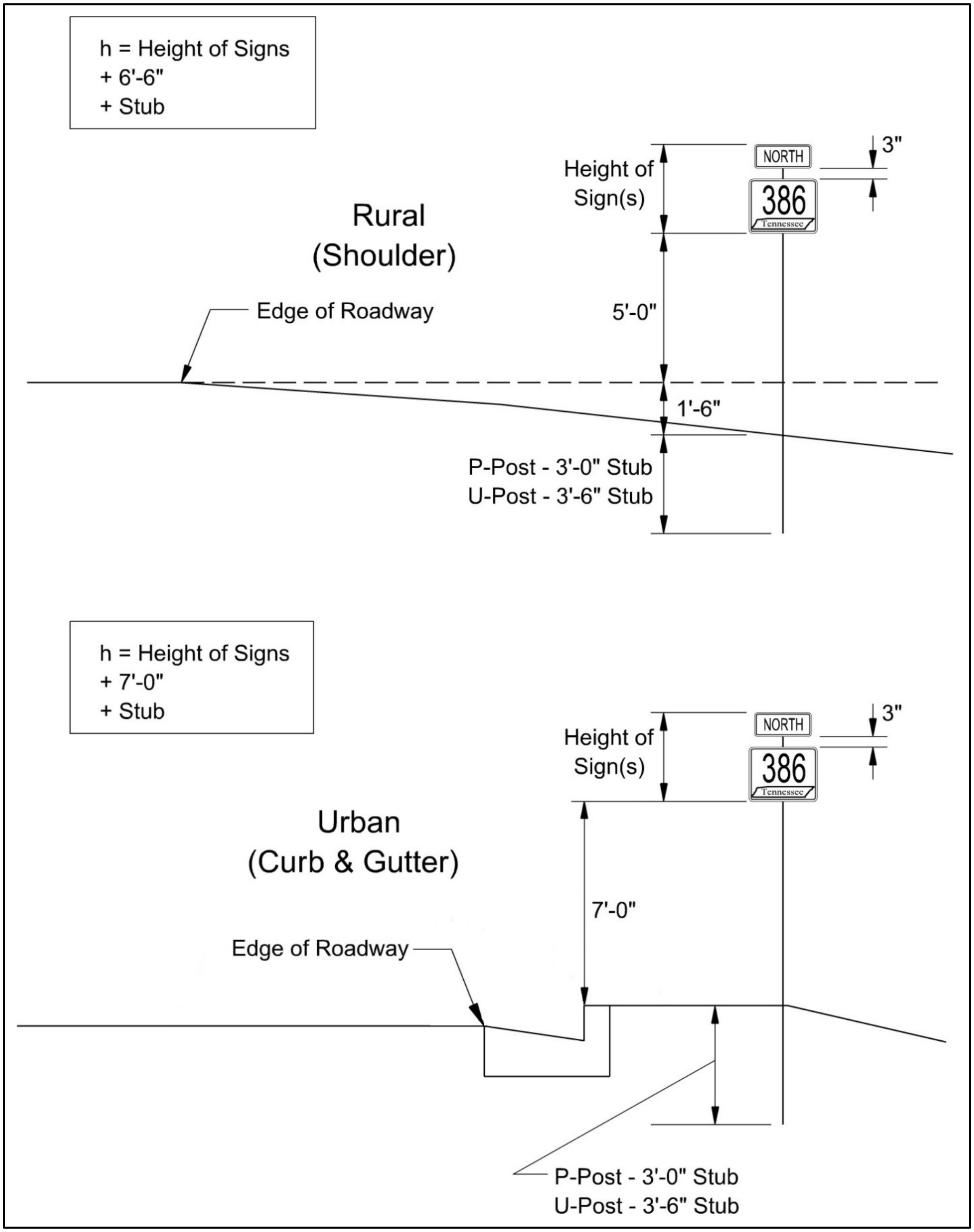
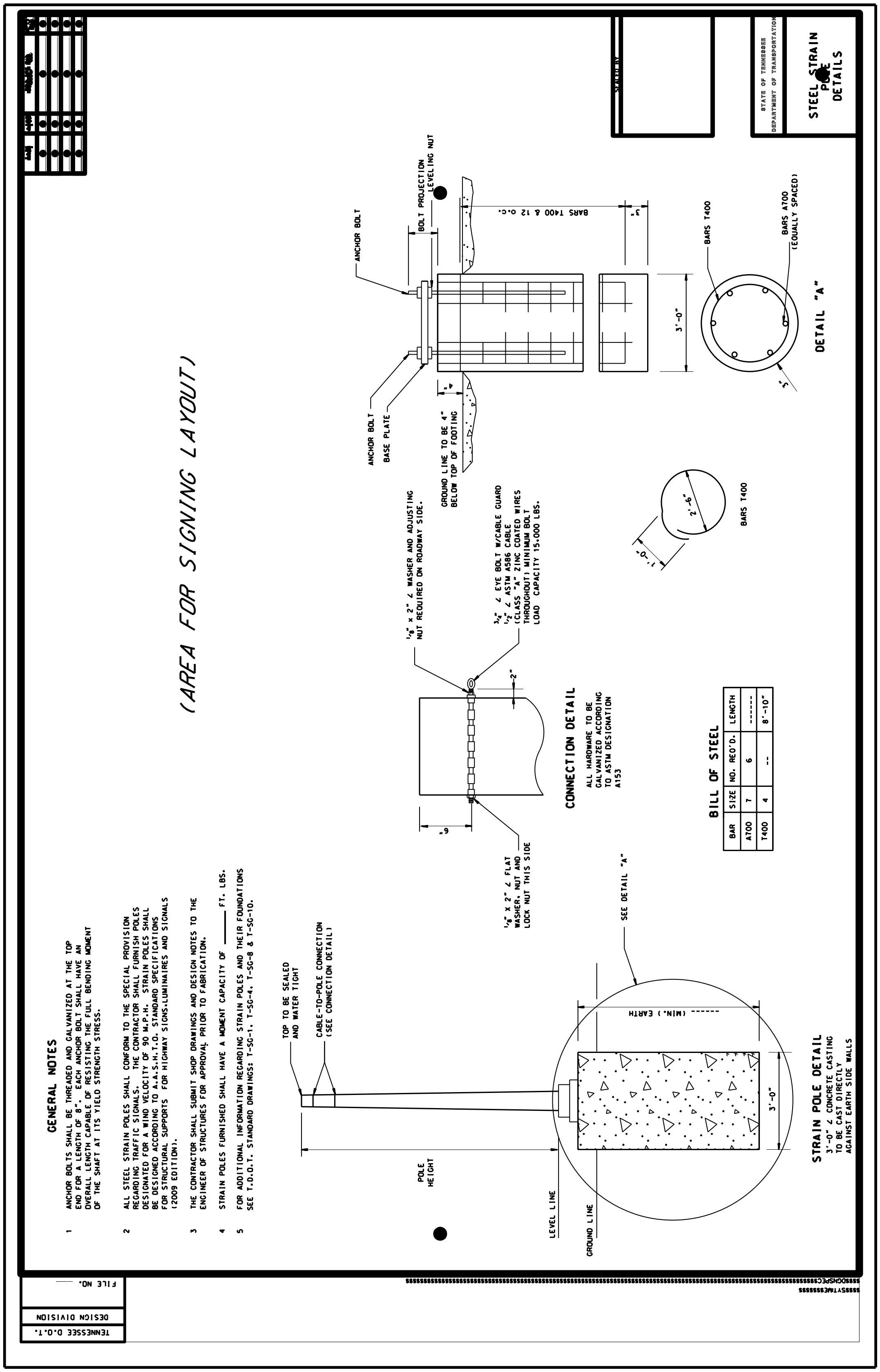


Table 14.2 – Determining Weight of Sign Supports

Perforated Tube (P-Post)			U-Post		
Member Designation	**Unit Post Weight (lbs/ft)**	**Stub Below Ground[(1)] (lbs)**	**Member Designation**	**Unit Post Weight (lbs/ft)**	**Stub Below Ground[(2)] (lbs)**
P1	1.702 1½″ ⊞	11.09	U1	2.00	2.00
P2	2.060 1¾″ ⊞	12.96	U2	2.25	2.25
P3	2.416 2″ ⊞	14.84	U3	2.50	2.50
P4	2.773 2¼″ ⊞	14.84	U4	2.75	2.75
P5	3.141 2½″ ⊞	23.72	U5	2.75	2.75
P6	4.006 2½″ ⊞	24.59	U6	3.00	3.00
P7	1.882 1¾″ ⊞	8.66	U7	4.00	4.00
P8	2.164 2″ ⊞	9.94			

- To determine the weight of the post, multiply the length of the support (above ground) by the unit weight in the table and then add the weight of the stub.
- Add the length of stub (3.5 feet) to the post length as determined from Figure 14.17 and multiply the total length by the unit weight shown in the table.

Figure 14.18 – Strain Pole Foundation and Cable Connection Details



14.2.5 Freeway and Expressway Signs (Access Controlled)

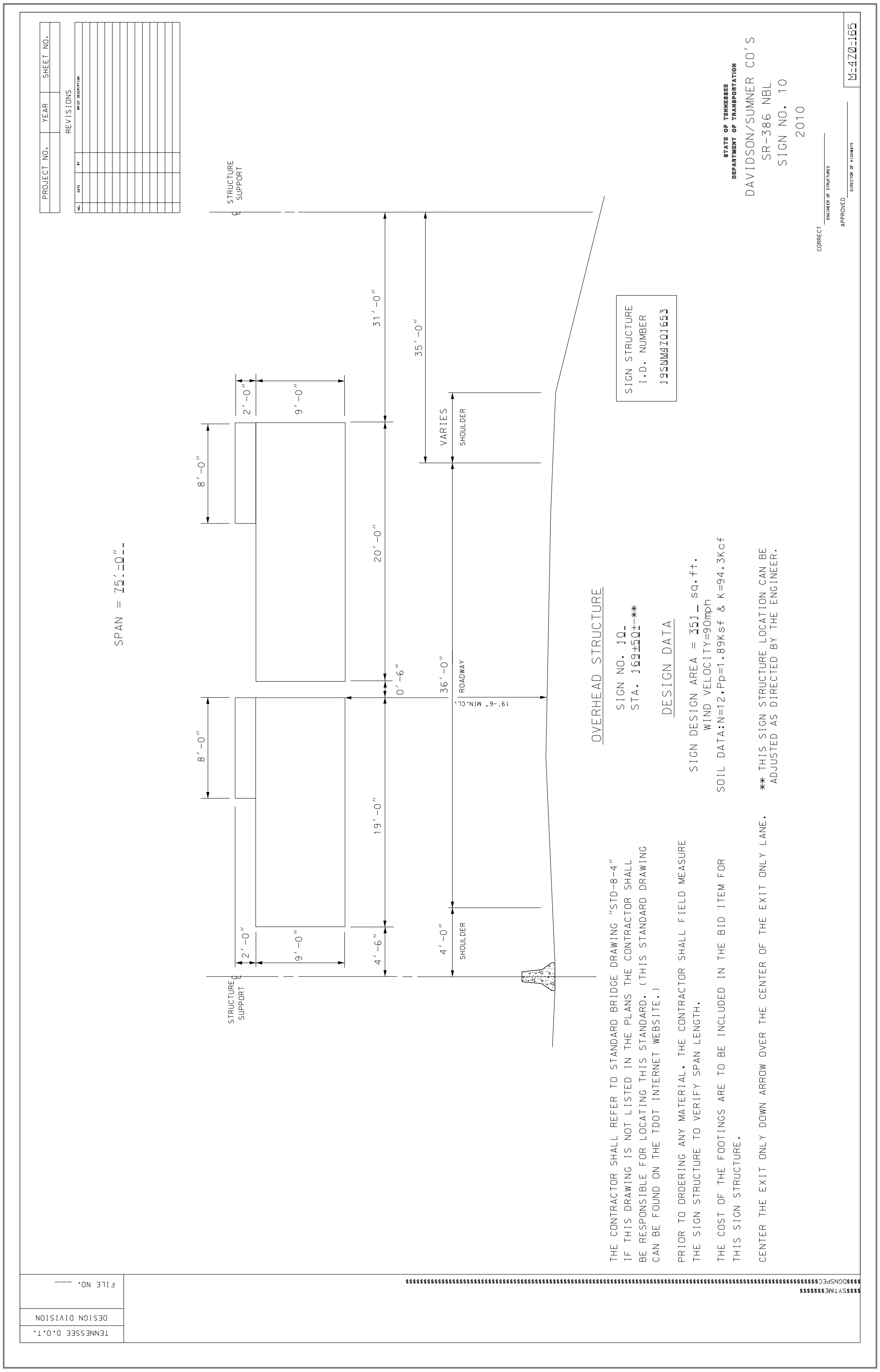
- **Overhead Signing:** For overhead signs on access-controlled facilities, the designer is responsible for including the necessary information on the Signing Detail Sheets to allow the Contractor to adequately design the overhead sign bridge or cantilever sign support. The cross-sectional view should include the following:

    - The overall span length of the overhead structure;
    - Width and height dimensions of the overhead sign, including the dimension for any auxiliary plaques;
    - Distance from each structural support to the overhead sign, width of the sign, and spacing between signs (if applicable);
    - The traveled way width and the distance from edge of the traveled way to each structural support;
    - Signs centered vertically on the truss and centered over the appropriate lane of traffic;
    - The location and distance of the minimum clearance between the roadway surface and the bottom of the tallest overhead sign;
    - The sign number and station of the sign;
    - The sign structure ID number *(Note: The designer must submit a print of the detail sheet to the TDOT Structures Division to obtain the ID number.)*;
    - Sign design data includes the design area of the sign, the minimum wind velocity, and applicable soil data parameters (See TDOT *Standard Drawing STD-8-4* for guidance); and
    - Other sign details and notes to the Contractor.

  Figure 14.19 illustrates an example of an Overhead Sign Detail Sheet. The design area of the sign is determined by multiplying the width of the traveled way, auxiliary lanes, and ramp width by the height of the tallest sign. Typically, the sign area for auxiliary plaques is not included in the overall design area of the sign. The minimum wind velocity for overhead signs is 90 mph. See the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* for guidance.

- **Structural Support Foundations:** If a sign is mounted on a CMB, the designer is responsible for ensuring the applicable standard drawings are noted in the contract plans.

Figure 14.19 – Example of Overhead Sign Detail Sheet



- **Roadside Supports:** The following supports are commonly used for roadside signs on four-lane, six-lane and eight-lane access-controlled freeways and expressways:
  - 2, 2½, and 3-inch square posts (TDOT *Standard Drawing T-S-12*);
  - S3x5.7 to S7x15.3 steel posts (TDOT *Standard Drawing* *T-S-13*);
  - W6x15 to W10x30 I-beam steel posts (TDOT *Standard Drawing T-S-14*).

14.2.6 Sign Vertical Clearances

Sign vertical clearances are as follows:

- **Rural:** The minimum height of signs installed at the side of the road in rural areas shall be five feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement (See Figure 14.20). The height to the bottom of a secondary sign mounted below another sign may be one foot less.
- **Urban:** The minimum height of signs installed at the side of the road in business, commercial, or residential areas where parking or pedestrian movements are likely to occur, or where the view of the sign might be obstructed, shall be seven feet, measured vertically from the bottom of the sign to the top of the curb (See Figure 14.20). In the absence of curb, the minimum height is measured vertically from the bottom of the sign to the elevation of the near edge of the traveled way. The height to the bottom of a secondary sign mounted below another sign may be one foot less than the height specified above. The minimum height of signs installed above sidewalks shall be seven feet, measured vertically from the bottom of the sign to the sidewalk. If the bottom of a secondary sign that is mounted below another sign is mounted lower than seven feet above a pedestrian sidewalk or pathway, the secondary sign shall not project more than four inches into the pedestrian facility. Signs that are placed 30 feet or more from the edge of the traveled way may be installed with a minimum height of five feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement.
- **Freeways and Expressways:** Directional signs on freeways and expressways shall be installed with a minimum height of seven feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement. All route signs, warning signs, and regulatory signs on freeways and expressways shall be installed with a minimum height of seven feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement. If a secondary sign is mounted below another sign on a freeway or expressway, the major sign shall be installed with a minimum height of eight feet and the secondary sign shall be installed with a minimum height of five feet, measured vertically from the bottom of the sign to the elevation of the near edge of

the pavement. Where large signs having an area exceeding 50 square feet are installed on multiple breakaway posts, the clearance from the ground to the bottom of the sign shall be at least seven feet.

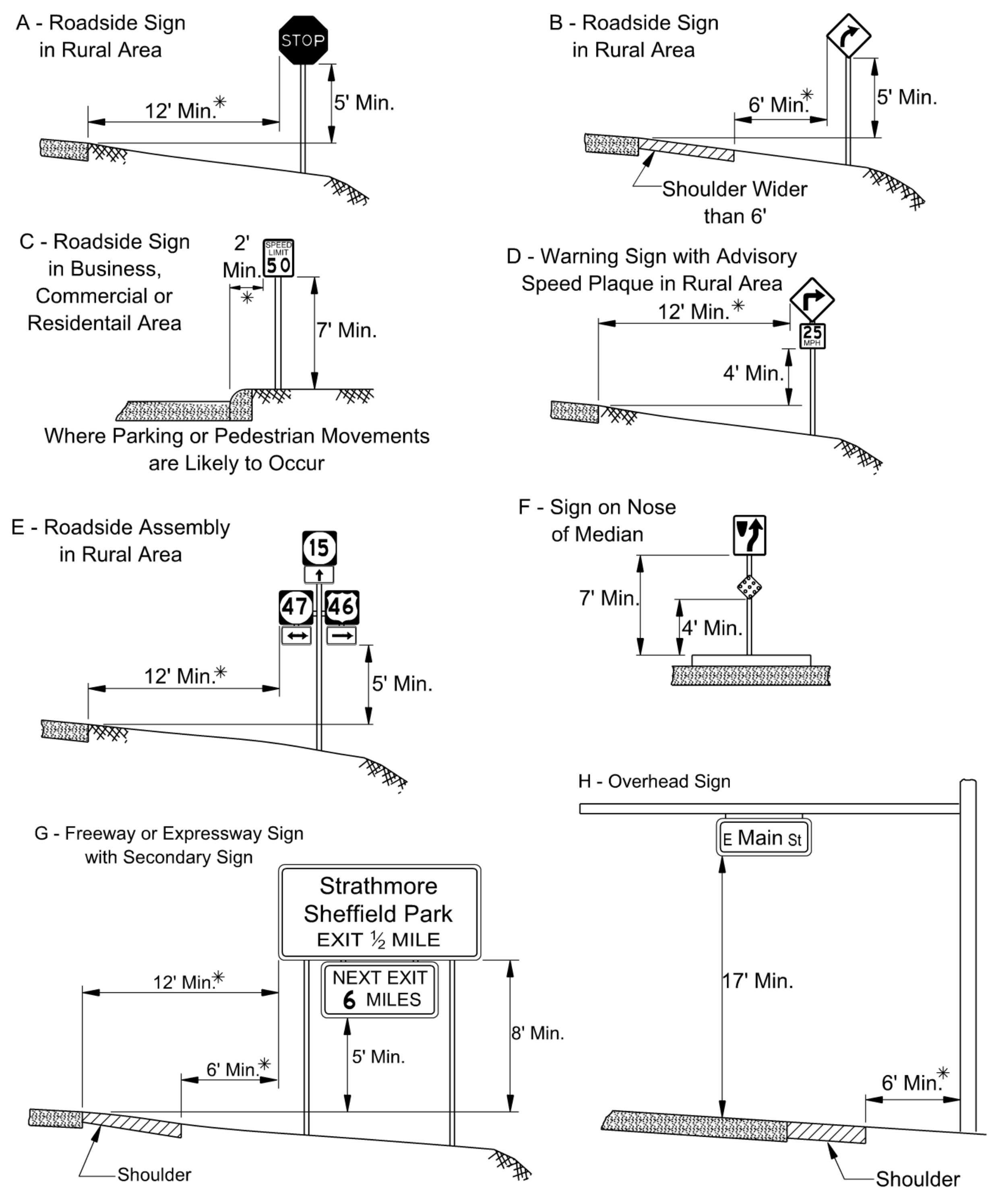
- **Route Signs:** A route sign assembly consisting of a route sign and auxiliary signs may be treated as a single sign for the purposes of this Section.
- **Steep Backslopes:** The mounting height may be adjusted when supports are located near the edge of the right-of-way on a steep backslope in order to avoid the sometimes less desirable alternative of placing the sign closer to the roadway.
- **Overhead Signs/Structures:** Overhead signs shall provide a minimum vertical clearance of not less than 17 feet to the sign, light fixture, sign bridge, or walkway over the entire width of the pavement and shoulders, except where the structure on which the overhead signs are to be mounted or other structures along the roadway near the sign structure have a lesser vertical clearance. If the vertical clearance of other structures along the roadway near the sign structure is less than 16 feet, the vertical clearance to an overhead sign structure or support may be as low as 1-foot higher than the vertical clearance of the other structures in order to improve the visibility of the overhead signs.

14.2.7 Traffic Signal Signs

The following guidance is provided for traffic control signs at or in advance of signalized intersections. Figure 14.21 illustrates some of the traffic signs associated with traffic signals.

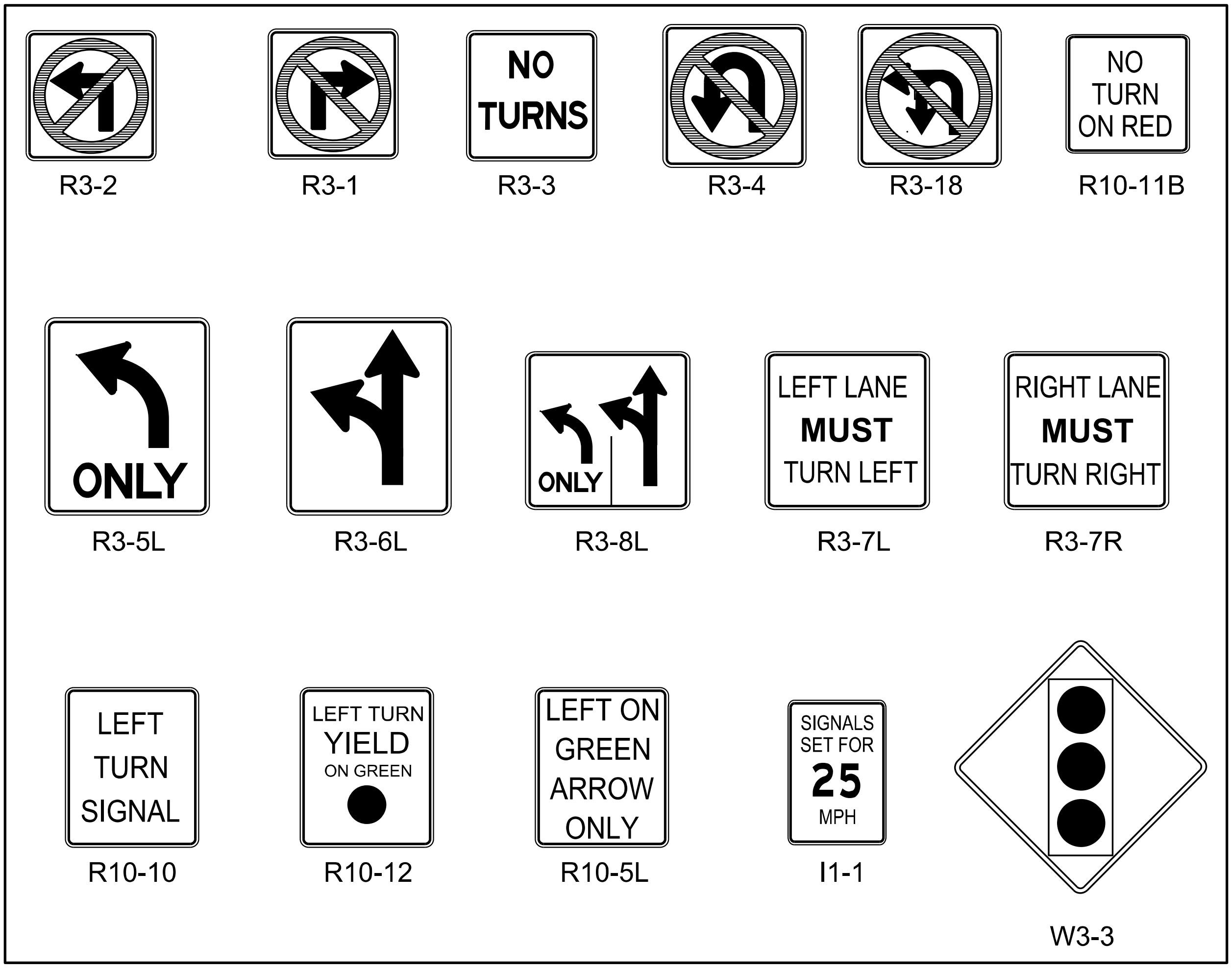
- **Span Wire/Mast Arm Mounted:** Where overhead signs are provided, the minimum vertical clearance over the entire roadway is 19.5 feet.
  - **LEFT TURN SIGNAL Signs (R10-10, R10-12)**
    - **LEFT TURN SIGNAL Sign (R10-10):** This sign is normally installed for a protected only left turn phase. The R10-10 sign is required when a Red Ball indication is used (R, ←Y, ←G). Install the sign directly adjacent to and left of the signal head. Additionally, install this sign to the left of each left turn signal (R, ←Y, ←G) in a dual left turn situation.
    - **LEFT TURN YIELD ON GREEN BALL Signs (R10-12):** This optional sign may be installed with a protected–permissive left turn phase adjacent to and to the left of the five-section left turn signal head (R, Y, G, ←Y, ←G).

Figure 14.20 – Sign Vertical Clearances



* See 2009 MUTCD Section 2A.19 "Lateral Offset" and Section 2A.18 "Mounting Height."

Figure 14.21 – Typical Signal Related Signs



- **Shared Lanes:** Where there are two or more movements from a specific lane and one of those movements is not normally expected, install an Optional Movement Lane Control Sign (R3-6).
    - **Lane Control Signs (R3-5 and R3-8):** Lane use control signs should be used to alert drivers of unexpected or unusual turn requirements for a lane. Where needed, mount these signs overhead in the center of the lane to which they apply. The use of an overhead sign for one lane does not require the installation of signs for the other lanes. The R3-5 and R3-8 series signs are intended for overhead use. Install these signs directly over a lane for which they apply in order to convey the proper message to a driver. They should not be used for side of road installations. See the *MUTCD* for guidance on post mounted lane use control signs.
    - **Turn Prohibition Signs (Signs R3-1, R3-2, R3-3, R3-4):** In general, where turns are prohibited, install the appropriate turn prohibition signs (R3-1 through R3-4), unless one-way signs are used.
        - The NO RIGHT TURN sign (R3-1) may be installed adjacent to the signal face for the right lane;
        - The NO LEFT TURN (R3-2) or NO U-TURN (R3-4) signs may be installed adjacent to a signal face viewed by road users in the left lane;
        - A NO TURNS (R3-3) sign may be placed adjacent to a signal face for all lanes on that approach or two signs should be used;
        - Where ONE-WAY signs are used, turn prohibition signs may be omitted.
    - **LEFT or RIGHT ON GREEN ARROW ONLY Sign (R10-5):** Where needed, install the R10-5 sign adjacent to the applicable turn signal head. The R10-5 sign is used where it is unsafe to turn left or right except when protected by the green arrow display. The R10-5 sign or a modified R-10-11a sign shall be used if an all-arrow turn signal (Type 130A3) is installed (See TDOT *Standard Drawing T-SG-7*).
    - **NO TURN ON RED Sign (R10-11a):** Where needed, install the R10-11a sign near the appropriate signal head. A No Turn on Red sign should be considered when an engineering study finds that one or more of the following conditions exists:
        - Where there is inadequate sight distance to vehicles approaching from the left (or right, if applicable);
        - Where there are geometrics or operational characteristics of the intersection that might result in unexpected conflicts;

- Where there is an exclusive pedestrian phase;
- Where there are an unacceptable number of pedestrian conflicts with RTOR maneuvers, especially involving children, older pedestrians, or persons with disabilities;
- Where there are more than three RTOR crashes reported in a 12-month period for the particular approach;
- Where the skew angle of the intersecting roadways creates difficulty for drivers to see traffic approaching from their left;
- At railroad crossings where the design vehicle cannot be safely stored in the clear storage distance between the railroad crossing and the adjacent traffic signal (i.e., to prevent trapping a vehicle) (See Section 7.10.2 for further guidance);
- For multi-lane applications, the use of R10-11c or R10-11d may be used to restrict the RTOR from a specific lane.

- **Blank Out Signs:** Blank Out Signs are internally illuminated signs that are blanked out (show no message) when not illuminated. They are often used when a turn prohibition is in effect only at certain times of the day or during one or more portion(s) of a particular cycle of the traffic signal. Another application of blank out signs is where a traffic signal has a railroad preemption sequence and the left-turns and right-turns towards the tracks are prohibited once an approaching train is detected. In this turn prohibition application, the blank sign would be located to the right of the right-most signal if the right-turn is prohibited, and to the left of the left-most signal if the left-turn is prohibited.
- **Street Name Sign (D3-1):** For overhead mounted street name signs, ensure the support poles are designed to accommodate loadings for street name signs if they will be installed during or after the project. For proposed overhead street name sign layouts, see Section 14.2.9.

➢ **Ground Mounted Signs:** The following discusses ground-mounted signs to be used at or in advance of signalized intersections.

- **Turn Lane Supplemental Signs (R3-7):** Ground mounted mandatory lane control signs should be used to alert drivers of unexpected or unusual turn requirements for a lane or if turning movement traffic frequently fills the turn lane to capacity. The R3-7 signs, LEFT (RIGHT) LANE MUST TURN LEFT (RIGHT) can be installed to alert the driver, but is not required for all turn lanes. Simply having a dedicated right turn lane does not automatically require the installation of RIGHT LANE MUST TURN RIGHT signs. However, if a through lane ends as a right turn only lane, then install the appropriate R3-5 overhead sign and/or R3-7 ground mounted sign.

- **SIGNAL AHEAD Sign (W3-3):** The installation of this sign is appropriate under the following conditions:
  - **Signal Visibility:** Where visibility of the traffic signal heads on any approach is less than the distances shown in *MUTCD Table 4D-2*, install an advance Signal Ahead sign (W3-3) to warn approaching traffic of the signal.
  - **Speed:** On high-speed rural approaches, approaching the first signal in an urbanized area, the W3-3 sign may be justified.
  - **Engineering Judgment:** In other situations where engineering judgment reveals the need for and the location of the W3-3 sign (e.g. for additional emphasis even where the visibility distance to the device is sufficient).

  A warning beacon may be used to provide additional emphasis to a Signal Ahead sign (see Section 13.4.6).

- **Street Name Signs (D3-1):** Ground mounted street name signs are typically installed by the local jurisdiction. The minimum lettering heights are six inches for initial upper-case letters and 4.5 inches for lower-case letters. For multi-lane facilities where the speed limit is greater than 40 mph, the minimum lettering heights are eight inches for initial upper-case letters and six inches for lower-case letters.

14.2.8 Other Traffic Control Signs:

The following discusses other traffic control signs to be used at or in advance of signalized intersections.

- **SPEED LIMIT Signs (R-2 series):** SPEED LIMIT signs shall be posted at the points where the speed limit changes. Ensure that both directions are consistent. Additional signs should be installed beyond major intersections to inform traffic of the posted speed limit.
- **Two-Way Left-Turn Lane Signs (R3-9 series):** Two-Way Left-Turn Lane signs are installed to inform drivers of the required use of a center turn lane. They are installed as a supplement to the standard pavement markings and should be located as often as the speed limit signs.
- **School Signs (S Series):** School signs shall have a fluorescent yellow-green background with a black legend and border.

14.2.9 Proposed Overhead Street Name Sign Layouts

For traffic signal design projects, the size of the proposed overhead street name sign should be as follows:

- **Height:** 24 inches.
- **Width:** Varies depending on the legend required (6-foot minimum, 8-foot maximum except as noted below).

To determine the width of the proposed overhead street name sign, the recommended procedure to follow is:

1. Using Series "D" lettering style (12-inch upper-case, 9-inch lower-case), calculate the length of the legend required and include the design criteria listed in the following section to determine the overall sign width. Round up to the nearest six inch increment (e.g. 7-foot, 6-inch). Supplementary lettering to indicate the type of street (i.e. Street, Avenue, or Road, etc.) or the section of the city (i.e. NE, NW, SE, SW, etc.) can be downsized to 8-inch upper-case, 6-inch lower-case.
2. If the Series "D" calculated sign width distance exceeds eight feet, then use Series "C" lettering style (12-inch upper-case, 9-inch lower-case). Supplementary lettering downsizing as described previously is still applicable.
3. If the Series "C" calculated sign width distance exceeds eight feet, then use Series "B" lettering style (12-inch upper-case, 9-inch lower-case). Supplementary lettering downsizing as described previously is still applicable.
4. If the Series "B" calculated sign width distance exceeds eight feet, then the maximum sign width can be increased up to ten feet. Supplementary lettering downsizing as described previously is still applicable.
5. If the Series "B" calculated sign width distance still exceeds ten feet, then contact the Traffic Operations Division for further guidance.

Other proposed overhead street name sign design criteria includes:

- **Color:** White on green background.
- **Sheeting:** Retro-reflective.
- **Corner Radii:** 2.25 inches.
- **Border Color:** White.
- **Border Width:** One inch.
- **Minimum distance between the Sign Border and the Legend:** Six inches.

14.3 Pavement Markings

All pavement markings shall meet the design and installation requirements of the *MUTCD*. Pavement markings are constantly degrading and must be replaced at regular intervals to be effective.

14.3.1 Stop Lines

- **Guidance:** Stop lines should be used to indicate the point behind which vehicles are required to stop to be in compliance with a stop sign, traffic signal, or other traffic control devices. Stop lines have the following characteristics:
  - **Line Type:** Solid.
  - **Line Width:** 24 Inches.
  - **Color:** White.
  - **Orientation:** Generally parallel to cross street curb line (See Figures 14.22 and 14.23).
- **Placement:** When determining the placement of the stop line, consider the following:
  - **Sight Distance:** Position the stop line to allow the motorist adequate sight distance of the cross street traffic.
  - **Staggered:** Stop lines may be staggered longitudinally on a lane-by-lane basis (See Figure 14.22). Check turning paths of the design vehicles from the cross street to ensure there are no conflicts. For most intersections, use the turning path of a single-unit (SU) design vehicle to determine the location of the stop line.
  - **Crosswalks:** Where crosswalks are used, place the stop line a minimum of four feet in advance of the nearest crosswalk line at controlled intersections, except at midblock crosswalks (See Figure 14.23).
  - **No Crosswalk:** In the absence of a marked crosswalk, place the stop line at the desired stopping point, but not more than 30 feet or less than four feet from the nearest edge of the intersecting traveled way (See Figure 14.23).
  - **Mid-block Crossings:** Stop lines at midblock signalized locations should be placed at least 40 feet in advance of the nearest signal indication.
  - **Uncontrolled Multi-lane Approaches:** If stop lines are used at a crosswalk that crosses an uncontrolled multi-lane approach, the stop lines should be placed 20 feet to 50 feet in advance of the nearest crosswalk line, and parking should be prohibited in the area between the stop line and the crosswalk.

Figure 14.22 – Stop Line Placement

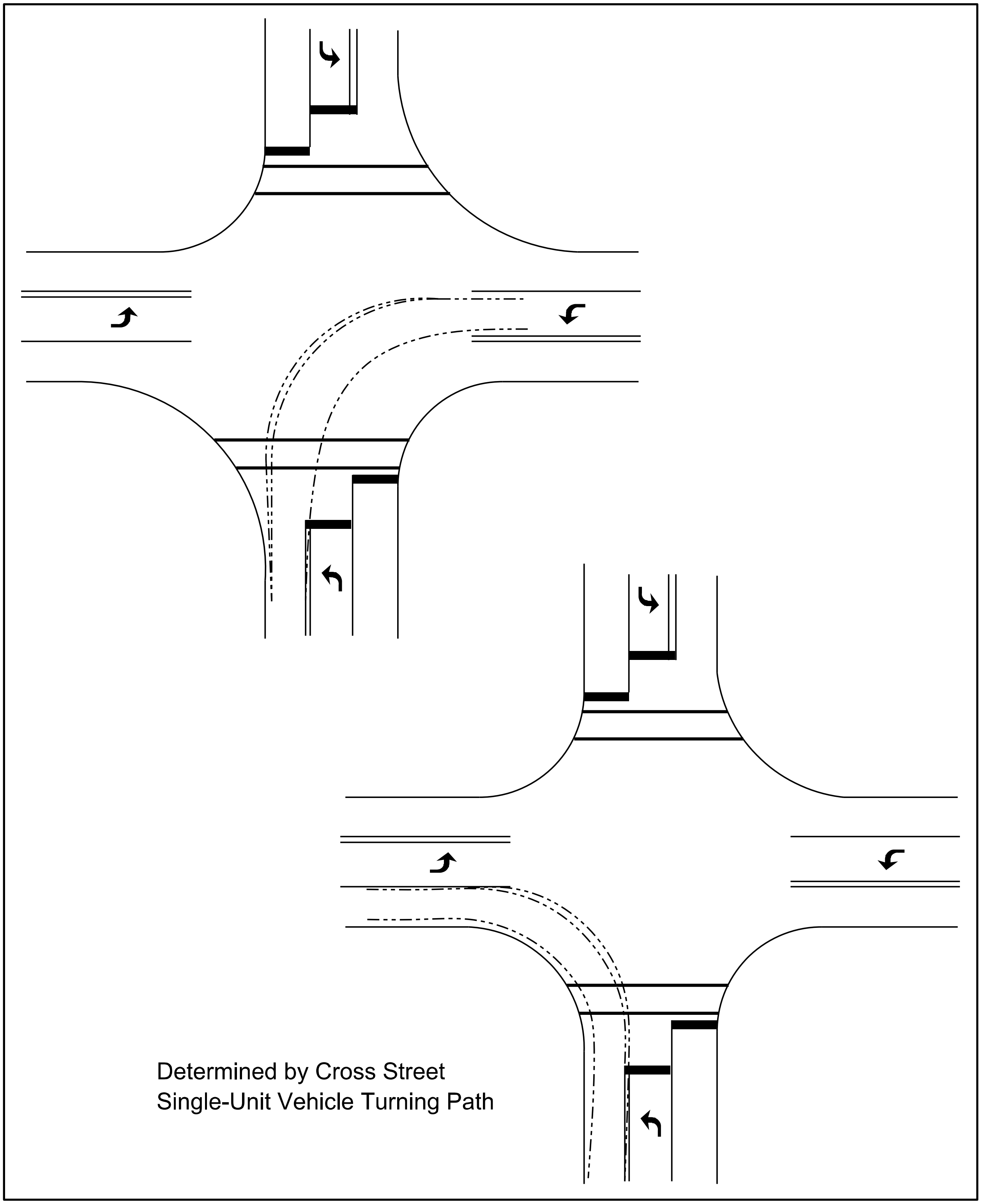
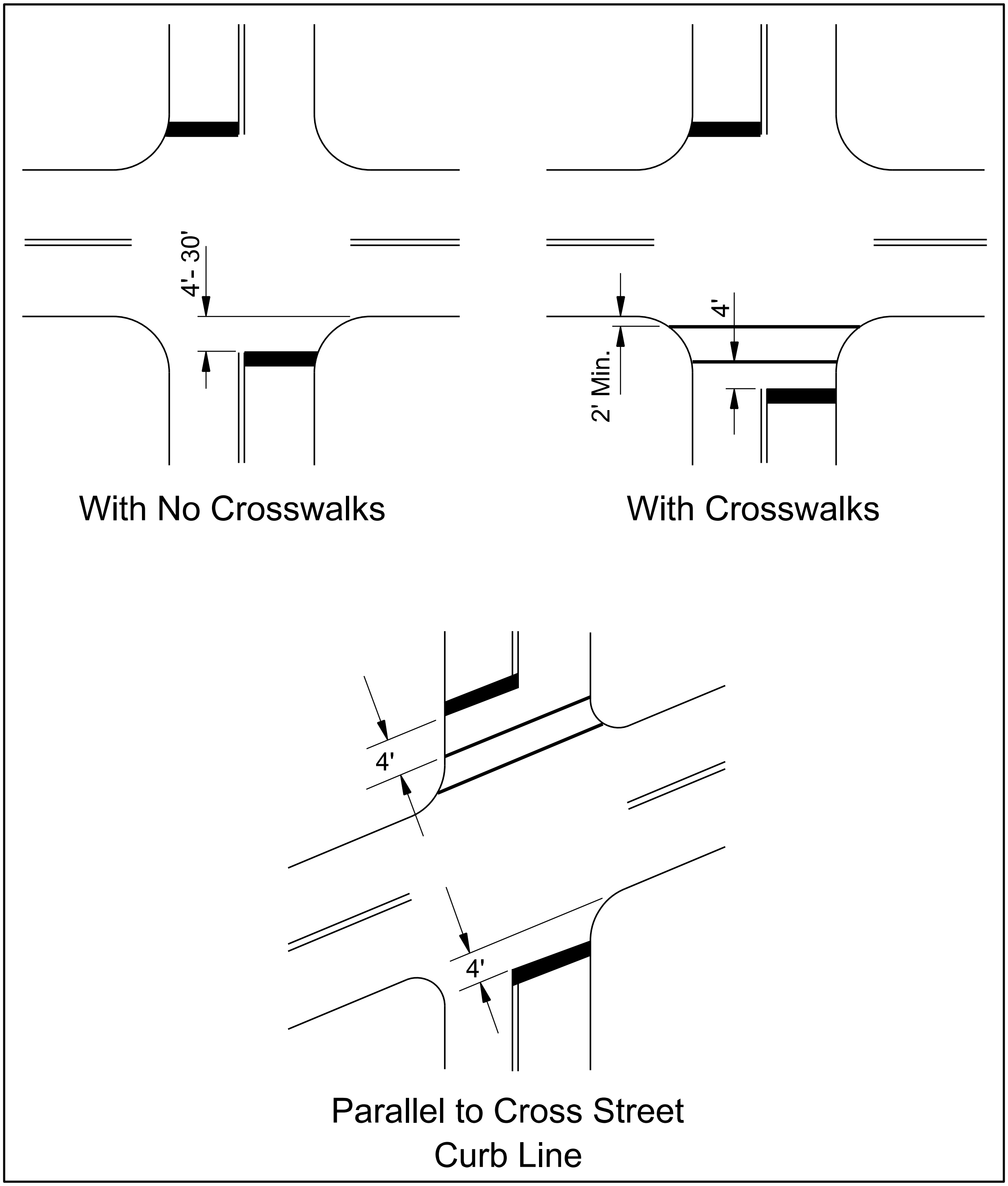


Figure 14.23 – Stop Line Locations



14.3.2 Yield Lines

- **Guidance:** Yield lines may be used to indicate the point behind which vehicles are required to yield in compliance with a YIELD (R1-2) sign or a Yield Here To Pedestrians (R1-5 or R1-5a) sign. Yield lines have the following characteristics:
  - **Symbol:** Solid triangle.
  - **Base Width:** Twelve inches to 24 inches.
  - **Height:** 1.5 times the base width.
  - **Color:** White.
  - **Orientation:** Generally parallel to cross street curb line.
  - **Spacing between Triangles:** Three inches to twelve inches.
- **Placement:** When determining the placement of the yield line, consider the following:
  - **Sight Distance:** Position the yield line to allow the motorist adequate sight distance of the cross street traffic.
  - **Staggered:** Yield lines may be staggered longitudinally on a lane-by-lane basis. Check turning paths of the design vehicles from the cross street to ensure there are no conflicts. For most intersections, use the turning path of a single-unit (SU) design vehicle to determine the location of the yield line.
  - **Crosswalks:** Where crosswalks are used, place the yield line a minimum of four feet in advance of the nearest crosswalk line at controlled intersections or roundabouts, except at midblock crosswalks.
  - **No Crosswalk:** In the absence of a marked crosswalk, place the yield line at the desired yield point, but not more than 30 feet or less than four feet from the nearest edge of the intersecting traveled way.
  - **Uncontrolled Multi-lane Approaches:** If yield lines are used at a crosswalk that crosses an uncontrolled multi-lane approach, the yield line should be placed 20 feet to 50 feet in advance of the nearest crosswalk line, and parking should be prohibited in the area between the yield line and the crosswalk. If yield lines are used at a crosswalk that crosses an uncontrolled multi-lane approach, Pedestrians (R1-5 series) signs shall be used.
  - **Roundabouts:** A yield line may be used to indicate the point behind which vehicles are required to yield at the entrance to a roundabout.

14.3.3 Crosswalks

- **Guidance:** Crosswalks are used to define a location where pedestrians are to cross a roadway and to alert motorists as to the crossing location. Crosswalks should be installed at locations controlled by traffic control signals or on approaches controlled by STOP or YIELD signs, or where engineering judgment indicates they are needed to direct pedestrians to the proper crossing path(s). Crosswalks have the following characteristics:
  - **Type lines:** Solid.
  - **Line width:** Eight inches or twelve inches.
  - **Color:** White.
  - **Crosswalk Width:** Six feet minimum.
- **Engineering Study:** Crosswalk lines should not be used indiscriminately. An engineering study should be performed before a marked crosswalk is installed at a location away from a traffic control signal or an approach controlled by a STOP or YIELD sign. The engineering study should consider:
  - Number of lanes;
  - Presence of a median;
  - Distance from adjacent signalized intersections;
  - Pedestrian volumes and delays;
  - Average Daily Traffic (ADT);
  - Posted or statutory speed limit (i.e. 85th-percentile speed);
  - Geometry of the location;
  - Possible consolidation of multiple crossing points;
  - Availability of street lighting; and
  - Other appropriate factors.
- **Placement:** When determining the placement of crosswalks, consider the following:
  - **Location:** Crosswalks should be in line with the sidewalk approaches. Crosswalk lines should extend across the full width of pavement or to the edge of the intersecting crosswalk to discourage diagonal walking between crosswalks.
  - **Type:** Normally, transverse lines are used. Where additional crosswalk visibility is required, diagonal or longitudinal lines should be used.
  - **Orientation:** The crosswalk should be oriented parallel to the cross street.

- **Accessibility:** A pedestrian access route shall be provided within pedestrian street crossings, including medians and pedestrian refuge islands, and pedestrian at-grade rail crossings. The pedestrian access route shall connect departure and arrival sidewalks. All pedestrian street crossings must be accessible to pedestrians with disabilities. If pedestrian crossing is prohibited at certain locations, No Pedestrian Crossing signs (R9-3) should be provided, along with detectable features (e.g. grass strips, landscaping, planters, chains, fencing, and railings).
- **Curb Ramps:** The curb ramp, excluding any flared sides, or blended transition shall be contained wholly within the width of the pedestrian street crossing served.
- **Roundabouts:** Pedestrian crosswalks shall not be marked to or from the central island of roundabouts. If pedestrian facilities are provided, crosswalks should be marked across roundabout entrances and exits to indicate where pedestrians are intended to cross. Crosswalks should be a minimum of 20 feet from the edge of the circulatory roadway.

14.3.4 Turn Arrows

Pavement marking arrows should be used for specific turn lanes. The turn arrow marking will suffice and the word ONLY is optional. Where a through lane approaching an intersection becomes a mandatory turn lane, the word ONLY used with the turn arrow is required (See TDOT *Standard Drawing T-M-4* for guidance).

14.3.5 Materials

All stop lines, crosswalks, and arrows shall be constructed of reflectorized thermoplastic or pre-formed plastic pavement marking material. The material used shall be in accordance with the *TDOT Standard Specifications*.

CHAPTER 15

ROADWAY AND INTERSECTION LIGHTING

15.1 General Information

The primary objective of roadway lighting is to enhance roadway safety. Properly designed roadway lighting should provide a level of visibility that enables the motorist and pedestrian to quickly discern significant details of the roadway. Those details include the roadway alignment, the surrounding environment, obstacles on or near the roadway, and vehicles, people or animals that are about to enter the roadway. In summary, lighting:

- Enables the driver to determine the geometry and condition of the roadway at extended distances;
- Promotes safety at night by enhancing visibility so that drivers and pedestrians can comfortably make decisions;
- Delineates the roadway and its surroundings and alerts motorists to potential obstructions and other hazards;
- Assists the motorists in orienting themselves to the roadway's geometry;
- Illuminates long underpasses and tunnels during the day to permit adequate visibility while entering, traveling through, and exiting such corridors;
- Discourages street crime at night or in other dark situations;
- Enhances commercial and other activity zones to attract users.

The criteria found in this standard when used in conjunction with *TDOT Standard Specifications for Road and Bridge Construction* and the *TDOT Standard Drawings* provides the engineer with minimum requirements for roadway lighting in the state of Tennessee.

15.1.1 Need for Engineering Expertise

Most states require that final design documents be signed and sealed by a registered professional engineer. The registrant is normally required to only sign and seal documents that the registrant prepared or documents where the registrant was responsible for the direction and control of the work. Lighting designs, as described in this guide, meet the criteria for the requirements of an engineering seal. The required expertise is in the area of roadway lighting and associated electrical systems. The expertise required for TDOT lighting designs includes:

- Lamp types and characteristics, including depreciation factors;
- Ballast types and characteristics;
- Fixture mechanical characteristics;
- Lens types;

- Photometric performance of luminaires and factors impacting such performance;
- Fixture mounting types;
- Pole mechanical and electrical characteristics;
- Breakaway device options and when appropriate to use;
- Clear zone criteria;
- Pole types, mounting options, and loading considerations;
- Foundation and support details;
- Pavement reflection factors;
- Mounting height and spacing options;
- Light trespass and sky glow (Light Pollution) issues including laws and ordinances;
- Lighting quality requirements, such as illuminance, luminance, veiling luminance, and visibility;
- Electrical system requirements such as circuitry, voltage drop, and equipment sizing;
- Maintenance considerations for individual components and the lighting system as a whole;
- Energy and life-cycle costs;
- Coordination with master lighting plans.

Designers for the lighting system should exercise engineering judgment when balancing all of the above.

15.1.2 Priorities and Funding Guidelines

TDOT recognizes that under certain conditions, the installation of roadway lighting can improve the safety of a road or intersection. Consequently, TDOT includes roadway lighting in State highway projects when certain conditions are met.

- **Interstate Highway System:** TDOT will typically prepare plans and assume all costs for installation of new roadway lighting as part of the related Interstate highway construction project when:
  - Freeway lighting is determined to be warranted by the Traffic Engineering Office and as prescribed by IES, the *AASHTO Roadway Lighting Design Guide, and the FHWA Lighting Handbook*;
  - Roadway construction requires the replacement or relocation of the existing lighting, and the local governing agency agrees to maintain the installation.

- **Interstate Interchange Lighting:** Interchanges not under construction or not eligible for other funding may be approved and lighting installed provided the local governing agency submits a request for the interchange lighting to the TDOT Commissioner in writing. The local governing agency must also submit funding to cover 50% of the costs for interchange lighting to TDOT when the project is programmed.
- **Non-Interstate Highways:** TDOT generally does not replace or install new lighting on non-Interstate system highways. Installation or relocation of lighting on non-Interstate system highways or related projects occurs only under the following specific circumstances:
    - Replacement of existing lighting impacted by construction on a State roadway project shall first be considered a utility relocation issue. The local agency shall prepare relocation plans and submit through TDOT Utilities Office. The TDOT Utilities Office will determine reimbursement eligibility. Relocation shall be accomplished by the local agency upon additional review and approval of plans by the Traffic Operations Division;
    - Installation or relocation of roadway lighting in a State project occurs only at the local agency's request. The Design Division Director shall approve the installation or relocation of roadway lighting projects. The project must be constructed under specific funding allowing such usage;
    - The local governing agency may request relocation be installed under the State project as a non-participating item when, the local agency working through the TDOT Utilities Office prepares relocation plans and submits funds to cover relocation costs prior to letting;
    - All requests for roadway lighting installations on non-interstate highways will be reviewed and approved by the TDOT Traffic Engineering Office.
- **Bridges:** On new or widened bridges in urbanized areas, TDOT will provide conduit, pull boxes and foundations in the parapet wall for the future installation of lighting. Where there is existing lighting on a bridge project, TDOT will replace the lighting.

15.2 Analyzing Roadway Lighting Needs

Driver visibility should be considered when analyzing roadway lighting needs. Principal considerations for the lighting needs analysis are:

- Vehicular traffic volume;
- Interchange spacing;
- Relative frequency of vehicular traffic maneuvers;
- Land development;
- Artificial lighting conditions of the surrounding area;
- Night-to-day crash ratio.

15.2.1 Freeways

Use the criteria presented in the following sections when analyzing the lighting needs for freeway facilities.

- **Continuous Freeway Lighting:** CFL should be considered under the following conditions:
  - **Freeway Volume:** On those freeway sections in and near cities where the current ADT is 30,000 or more, CFL should be considered.
  - **Interchange Spacing:** CFL should be considered where three or more successive interchanges are located with an average spacing of 1.5 miles or less, and adjacent areas outside the right-of-way are substantially urban in character.
  - **Land Development/Lighting Conditions:** Consider providing CFL where, for a length of two miles or more, the freeway passes through a substantially developed suburban or urban area in which one or more of the following conditions exist:
    - Local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway;
    - The freeway passes through a series of residential, commercial or industrial areas which include roads, parking areas or yards that are lighted;
    - Separate cross streets, both with and without connecting ramps, occur with an average spacing of 0.5 miles or less, some of which are lighted as part of the local street system; or
    - Freeway cross-section elements (e.g. median, shoulders), are substantially reduced in width below desirable criteria in relatively open country.

- **Night-To-Day Crash Ratio:** CFL should be considered where the night-to-day ratio of crash rates is at least 2.0 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. The number of nighttime crashes also should be evaluated.

- **Local Agency Needs:** CFL should be provided where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to pay an appreciable percentage of, or wholly finance, the installation, maintenance and operation of the lighting facilities.

➢ **Complete Interchange Lighting:** CIL is defined as a lighting system that provides relative uniform lighting within the limits of the interchange, including:

  - Main lanes;
  - Direct connections;
  - Ramp terminals;
  - Frontage road or crossroad intersections.

  CIL should be considered under the following conditions:

  - **Ramp Volume:** CIL should be considered where the total current ADT ramp traffic entering and exiting the freeway within the interchange area exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

  - **Crossroad Volume:** CIL should be considered where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

  - **Land Development/Lighting Conditions:** CIL should be considered at locations where there is substantial commercial or industrial development which is lighted during hours of darkness, and is located in the vicinity of the interchange; or where the crossroad approach legs are lighted for 0.5 miles or more on each side of the interchange.

  - **Night-To-Day Crash Ratio:** CIL should be considered where the night-to-day ratio of crash rates within the interchange area is at least 1.5 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. The number of nighttime crashes also should be evaluated.

  - **Local Agency Needs:** CIL should be considered where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to pay an appreciable percentage of, or wholly finance, the installation, maintenance and operation of the lighting facilities.

- **Continuous Freeway Lighting:** CIL should be considered at interchanges where continuous freeway lighting is provided.

➢ **Partial Interchange Lighting:** PIL is defined as a lighting system that provides illumination only of decision making areas of roadways including:

- Acceleration and deceleration lanes;
- Ramp terminals;
- Crossroads at frontage road or ramp intersections;
- Other areas of nighttime hazard.

Where partial interchange lighting is provided, luminaires should be located to best light the through lanes and speed change lanes at diverging and merging locations (decision-making areas). Figure 15.1 shows examples of partial interchange lighting with separate illustrations for different ramp conditions for crossing types A and B. The lighting engineer should display sound engineering judgment in determining whether the number of fixtures shown is sufficient. Recommendations provided shall consider light level uniformity to whatever extent is possible keeping in mind that the primary concern is safety. In conjunction with lighting the gore/nose areas at the interchange, PIL should also include lighting at complex ramp terminals and simple ramp terminals as shown below. For crossing types C and D, the engineer shall provide roadway illumination consistent with design criteria as shown in Figure 15.2. In an effort to provide affordable solutions to the local agencies growing desire to provide lighting in more locations and under more affordable conditions, PIL may be considered at interchanges under the following conditions:

- **Ramp Volume:** PIL should be considered where the total current ADT ramp traffic entering and exiting the freeway within the interchange area exceeds 5,000 for urban conditions, 3,000 for suburban conditions, or 1,000 for rural conditions.
- **Freeway Volume:** PIL should be considered where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban condition, 20,000 for suburban conditions, or 10,000 for rural conditions.

Figure 15.1 – Partial Interchange Lighting (Crossing Types A and B)

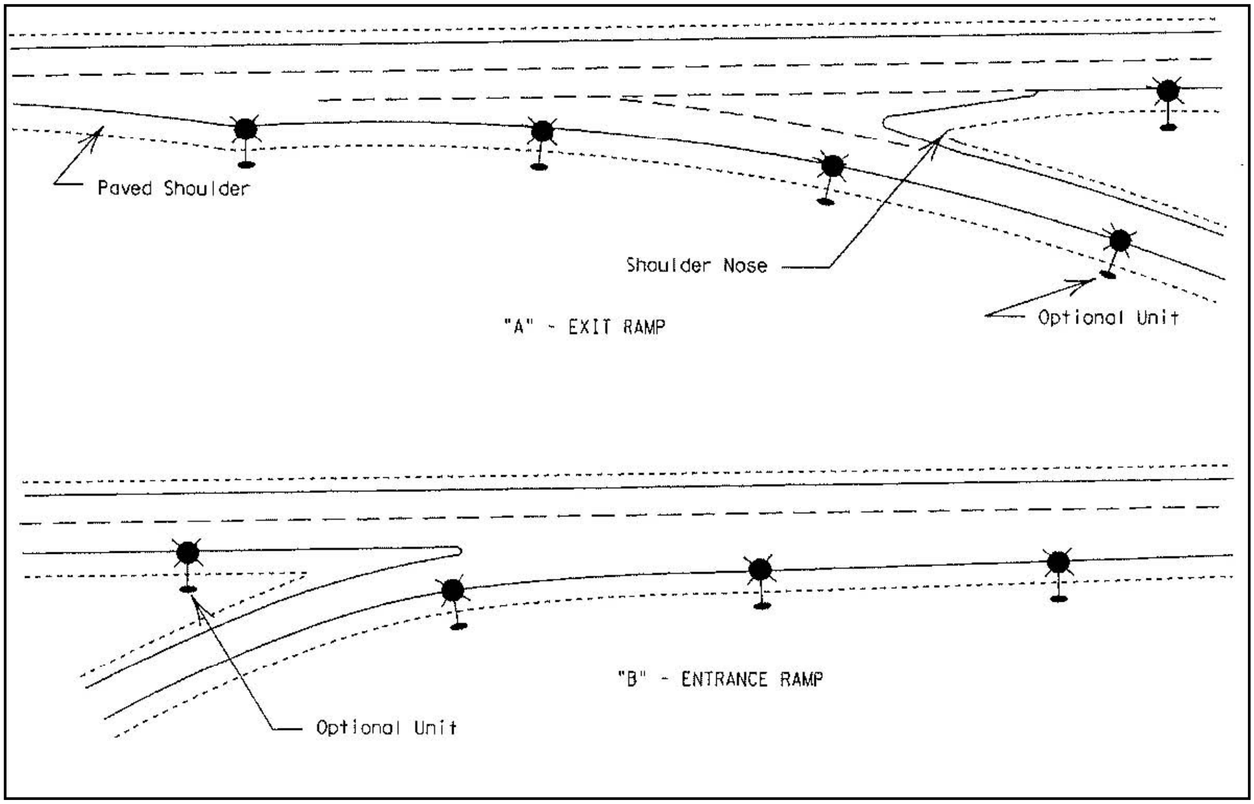
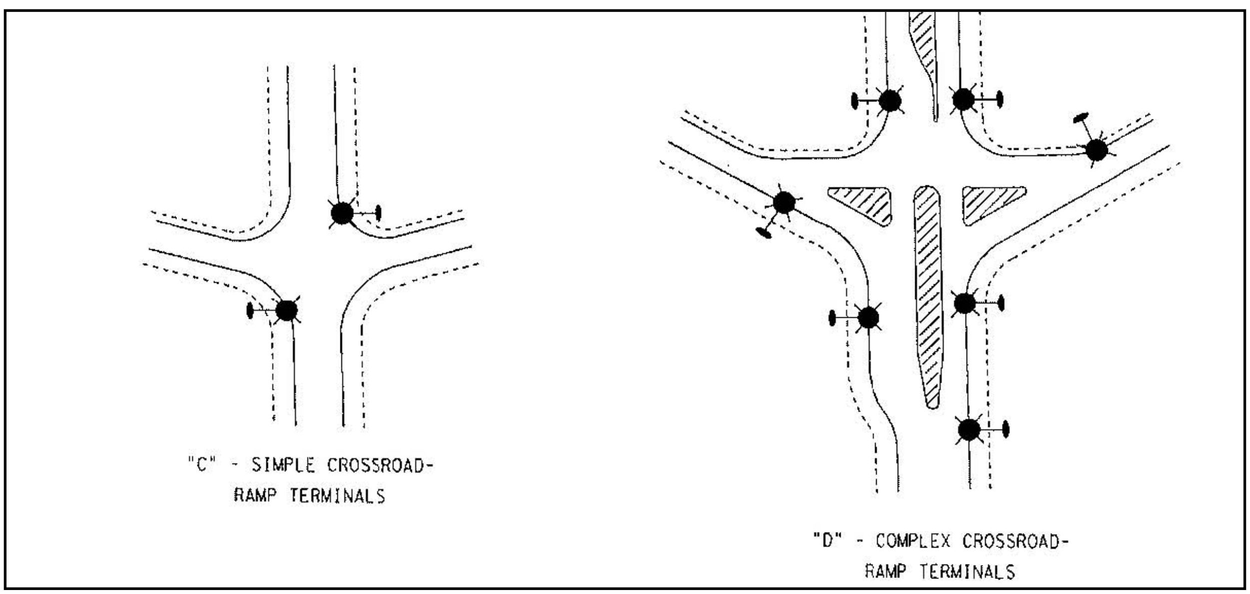


Figure 15.2 – Partial Interchange Lighting (Crossing Types C and D)



- **Night-To-Day Crash Ratio:** PIL should be considered where the night-to-day ratio of crash rates within the interchange area is at least 1.25 or higher than statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in significant reduction in the night crash rate. The number of nighttime crashes also should be evaluated.
- **Local Agency Needs:** PIL should be considered where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to pay an appreciable percentage of, or wholly finance, the installation, maintenance and operation of the lighting facilities.
- **Continuous Freeway Lighting:** PIL should be considered where continuous freeway lighting is justified, but not initially installed. The freeway section should be in or near a city where the current ADT is 30,000 or more, or the interchange should be among three or more successive interchanges located with an average spacing of 1.5 miles or less with adjacent areas outside of right-of-way being substantially urban in character.
- **Complete Interchange Lighting:** PIL should be considered where complete interchange lighting is justified, but not initially fully installed, a partial lighting system which exceeds the normal partial installation in number of lighting units is considered to be justified.

➢ **Crossroad Ramp Terminal Lighting:** Crossroad ramp terminal lighting should be considered, regardless of traffic volumes, where the crossroad ramp terminal of freeway interchanges incorporates raised channelizing or divisional islands or where there is poor sight distance.

15.2.2 Streets and Highways Other Than Freeways

Use the criteria presented in the following sections when analyzing the lighting needs for Streets and Highways Other Than Freeways.

➢ **General Considerations:** Urban and rural conditions, traffic volumes (both vehicular and pedestrian), intersections, turning movements, signalization, channelization, and varying geometrics are factors that should be considered when determining the lighting needs of streets and highways other than freeways. Generally, the following are considered when assessing the lighting needs of such facilities (e.g. streets):

- **Facilities with Raised Medians:** Consider highway lighting along facilities that have raised medians.
- **Major Urban Arterials:** Consider highway lighting along major arterials that are located in urban areas.

- **Intersections:** Consider intersection lighting at rural intersections that meet any one of the following conditions:
  - There are 2.4 or more crashes per million vehicles in each of three consecutive years;
  - There are 2.0 or more crashes per million vehicles per year and 4.0 or more crashes per year in each of three consecutive years;
  - There are 3.0 or more crashes per million vehicles per year and 7.0 or more crashes per year in each of two consecutive years;
  - The intersection is signalized and there have been, in the past year, 5.0 or more reported nighttime crashes and a day-to-night crash ratio of less than 2.0;
  - Substantial nighttime pedestrian volume exists;
  - Less than desirable alignment exists on any of the intersection approaches;
  - The intersection is an unusual type requiring complex turning maneuvers;
  - Commercial development exists in the vicinity which causes high nighttime traffic peaks;
  - Distracting illumination exists from adjacent land development; and/or
  - There exists recurrent fog or industrial smog in the area.
  - For roundabouts, see *IES Design Guide for Roundabout Lighting. Publication DG-19-08* for guidance.
- **Isolated Intersections:** Consider providing lighting along isolated intersections located within the fringe of corporate limits which are suburban or rural in character provided they meet the above criteria and the Local Agency assumes all ownership responsibility, installation, operational and maintenance costs.
- **High Conflict Locations:** Consider providing lighting along roadway sections with high vehicle-to-vehicle interactions (e.g., sections with numerous driveways, significant commercial or residential development, high percentage of trucks). Lighting generally improves traffic safety and efficiency at such locations.
- **Complex Roadway Geometry:** Consider providing lighting at spot locations in rural areas where the driver is required to pass through a roadway section with complex geometry.

- **Night-to-Day Crash Ratio:** Lighting should be considered at locations or sections of streets and highways where the night-to-day ratio of crash rates is higher than the statewide average for similar locations, and a study indicates that lighting may be expected to significantly reduce the night crash rate. The number of nighttime crashes also should be evaluated.
- **Local Agency Needs:** Lighting should be considered where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to wholly finance, the installation, maintenance and operation of the lighting facilities.

➢ **TDOT Requirements:**

- **Lighting on Streets and Highways Other Than Interstates:** TDOT provides lighting for interstate highways and bridges. New lighting installations on the State highway system will be reviewed by TDOT using breakaway, non-breakaway and utility distribution poles (joint usage). The following are prime considerations when installing lighting on state highways:
    - Providing adequate levels of illumination;
    - Minimizing the amount of glare;
    - Reducing the number of poles required.
- **Submittal of Street Lighting Designs:** Street lighting plans submitted to the TDOT Traffic Engineering Office for approval must provide photometric calculations and the type of lighting equipment to be installed. Poles that will be used for street lights must be shown on the lighting design. In order to reduce the time involved to review and approve lighting designs, the agency or their designee should contact TDOT to discuss and resolve problems or concerns prior to the lighting plans submittal. If questions arise in the interpretations of the rules and regulations regarding roadway lighting, the TDOT Traffic Operations Division Director will make the final administrative and engineering determinations.

➢ **Other Design Considerations:**

- The recommended mounting height is 45 feet. In the relocation of utility poles on State highway Right-of-Way, every effort shall be taken to relocate these poles to provide for their use for roadway lighting. This will provide an economical system, allowing utility poles to be used for street lighting as well as electrical distribution. It will also reduce the number of the fixed objects most frequently involved in motor vehicle accidents. Where electrical distribution or communication lines are in existence, mounting heights less than 45 feet may be approved in order to utilize existing poles to the full extent; however, the effectiveness of a satisfactory lighting job should not be jeopardized just to use existing poles. All installation must meet the minimum requirements set by the Illuminating Engineering Society (RP-8-14 & other related Publications);

- Pole setback from the edge of the pavement shall be 20 feet minimum, or at the right-or-way line if located less than 20 feet from the edge of pavement. In urban areas, poles shall be located as near to the right-of-way line as possible, but in no case shall they be less than two feet from the face of the curb;
- Where a utility strip or grass plot is located between the face of curb and the sidewalk, poles may be allowed in this area if they can be set at least two feet from the face of the curb;
- Poles shall not be set in the median of the roadway, except where a 20 foot minimum setback can be obtained, or where protected by guardrail already existing for other safety considerations;
- Mast arm length shall be no greater than six feet, except as approved for the lighting design;
- Foot-candle levels shall be used as recommended in Tables 15.3 and 15.4;
- Concrete pole bases should be flush but shall not extend over four inches above ground level;
- Lighting standard mountings shall be of an approved AASHTO breakaway type. Consider non-breakaway mountings in highly developed areas with high pedestrian activity, where there is eminent danger of an impacted support striking a pedestrian, private property or other traffic. Where sidewalk and curb and gutter are present, non-breakaway poles shall be used in the installation. All poles must be installed a minimum of four feet behind the face of the guardrail. Poles to be located behind existing guardrail, rock bluffs, embankments or ditches are not required to be the breakaway type. The breakaway poles that are used for street lighting installation must meet AASHTO's breakaway requirements. Non-breakaway poles recommended specifically for street lighting installations must be located outside of the clear zone. If the right-of-way is limited and sidewalk, curb and gutter are not provided along highways, then poles equipped with AASHTO approved breakaway bases must be installed;
- Non-breakaway poles may be used where joint use of utility poles for roadway lighting and electrical distribution is practical, and the effectiveness of a satisfactory lighting job would not be jeopardized. Joint use of utility poles is an economical system, which reduces the number of fixed objects along the roadway. The luminaire

mounting height for joint usage installations may be approved for less than 45 feet but should not be less than 25 feet;

- Offset lighting may be used in a lighting system required to be located 20 feet or greater from the edge of the highway. Offset lighting may be considered if the design parameters cannot be met due to geometric constraints;
- Rapid changes in levels of illumination may be compensated by using transition lighting or Adaptation Lighting. When transition lighting (See Page 15.21) is provided the roadway sector requiring transition lighting should be illuminated so as to allow the motorist's eyes to adjust to a different level of illumination. Equation 15.1 is a practical formula for calculating the required roadway length for transition lighting.

$$L = S \times C \times T$$

Equation 15.1 – Roadway Length for Transition Lighting

Where,

L = Length of Transition Lighting

S = Speed Along Roadway Section in MPH (design speed)

C = 1.47 (Converts MPH to feet per Second)

T = 15 Seconds (Recommended exposure time to allow motorist's eyes to adjust to different level of illumination).

- **Ornamental Lighting:** There is a growing desire for Ornamental and Pedestrian scaled lighting on state roadways and bridges. Decorative street lighting that replaces an existing conventional street lighting installation must provide uniform illumination along the State's highways. Since the use of higher wattage luminaires on shorter poles and shorter spacing could contribute to disability glare, special attention should be paid when using higher wattage luminaires, shorter spacing or shorter poles. However, the use of shorter poles in roadway lighting does not inherently produce glare. There are some ornamental luminaires with distribution patterns that will control the light and meet *ANSI/IES RP-8-14* and AASHTO requirements. At the request of a Local Agency, ornamental lighting may be permitted by TDOT on a State facility if TDOT's minimum requirements are met and the Local Agency is responsible for construction, funding, ownership, and maintenance of such lighting both during and after construction. All requests for special or ornamental lighting shall be reviewed and approved by the TDOT manager before design begins.
- **Lighting on Bridges:** All street lighting designs submitted for luminaires to be mounted on bridges must be approved by the TDOT Structures Division. This portion of the lighting plan layout must show how the conduit is to be routed on the structure of the bridges. When the TDOT's bridge projects are in the early phase of development, the local agencies should

contact TDOT Structures Division so that proposed changes needed to support future lighting can be incorporated into the designs for new bridges. TDOT may provide the conduit for the future street lighting during the construction of the bridges.

- **Median Street Lighting:** Street lighting installed in depressed medians may be considered on a case by case basis, because this type of installation is a variance to TDOT's street lighting policies. Light standards may be installed in depressed medians that have a minimum width of 48 feet provided minimum clear zone requirements are met. The light standards are to be located four feet on either side of the drainage ditch. Light standards may be installed in depressed medians behind existing or proposed guardrail or barriers.
- **Lighting at Isolated Intersections:** Where an isolated intersection requires lighting, consideration should be given to providing additional lighting before and beyond the intersection. AASHTO guidelines refer to a light barrier created when glare from an isolated light source causes visibility to be restricted to the beginning of the light bubble. To extend visibility into the bubble; additional fixtures may be required for at least the required stopping sight distance. The engineer should use his or her judgment and experience to determine if such measures are needed.
- **Roadway Lighting Plans Exceptions:** If questions arise in the interpretations of the rules and regulations regarding roadway lighting, the TDOT Traffic Operations Division Director will make the final administrative and engineering determinations. Requests for street lighting that is to be installed with TDOT Local Programs Office funding should be submitted to the TDOT Commissioner's Office.

15.2.3 Other Locations

The following categories are areas where TDOT may install lighting on a limited and case-by-case basis.

- **Highway Sign Illumination:** TDOT does not generally light highway signs.
- **Rest areas:** For lighting at rest areas, there is typically no involvement by TDOT in the design, installation or maintenance. The following general guidelines are noted:
  - Lighting is typically provided at rest areas that offer complete rest facilities (e.g. comfort station, information kiosk, picnic areas);
  - Illuminate all areas within the facility that have pedestrian activities (e.g. parking areas, immediate area of building);
  - Provide lighting at rest area ramps, gore areas, and other decision points.

- **Weigh stations:** For lighting at weigh stations, there is typically no involvement by TDOT in the design, installation or maintenance. Lighting is typically provided at all permanent truck weigh stations where weighing occurs after daylight hours. Illuminate the weighing area, parking area, speed change lanes, ramps, and gore areas.

- **Tunnels:** A tunnel is defined as a structure over a roadway, which restricts the normal daytime illumination of a roadway section such that the driver's visibility is substantially diminished. Daytime tunnel lighting is justified when driver visibility requirements are not satisfied without the use of a lighting system to supplement natural sunlight. Visibility requirements vary considerably with such items as:

  - Portal to portal tunnel length (i.e., short or long);
  - Tunnel portal design;
  - Geometry of tunnel and its approaches;
  - Vehicular and pedestrian traffic characteristics;
  - Treatment of pavement, portal, interior, and environmental reflective surfaces;
  - Climate and orientation of tunnel; and
  - Visibility objectives to provide for safe and efficient tunnel operation.

  For tunnel lighting use the requirements in the ANSI/IESNA PR-22-05 publication IESNA Recommended Practice for Tunnel Lighting.

- **Navigation and Obstruction Lighting:** Highway structures over navigable waterways require waterway obstruction warning luminaires in accordance with U.S. Coast Guard requirements. The TDOT Structures Office will coordinate with the Coast Guard. Any need for aviation obstruction warning luminaires on highway structures will be coordinated with the Federal Aviation Administration by the Traffic Design Office. For information on navigable airspace obstructions, consult the *FAA Advisory Circular AC 70/7460-2J Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace*.

- **Temporary and Replacement Lighting:** The need to provide temporary highway lighting will be considered on a case-by-case basis. For example, construction zones requiring complex traffic maneuvers (e.g. crossovers) may justify the provision of temporary lighting. In addition, if existing lighting is affected or relocated during construction, temporary replacement lighting should be provided in like kind and quality during the construction phase.

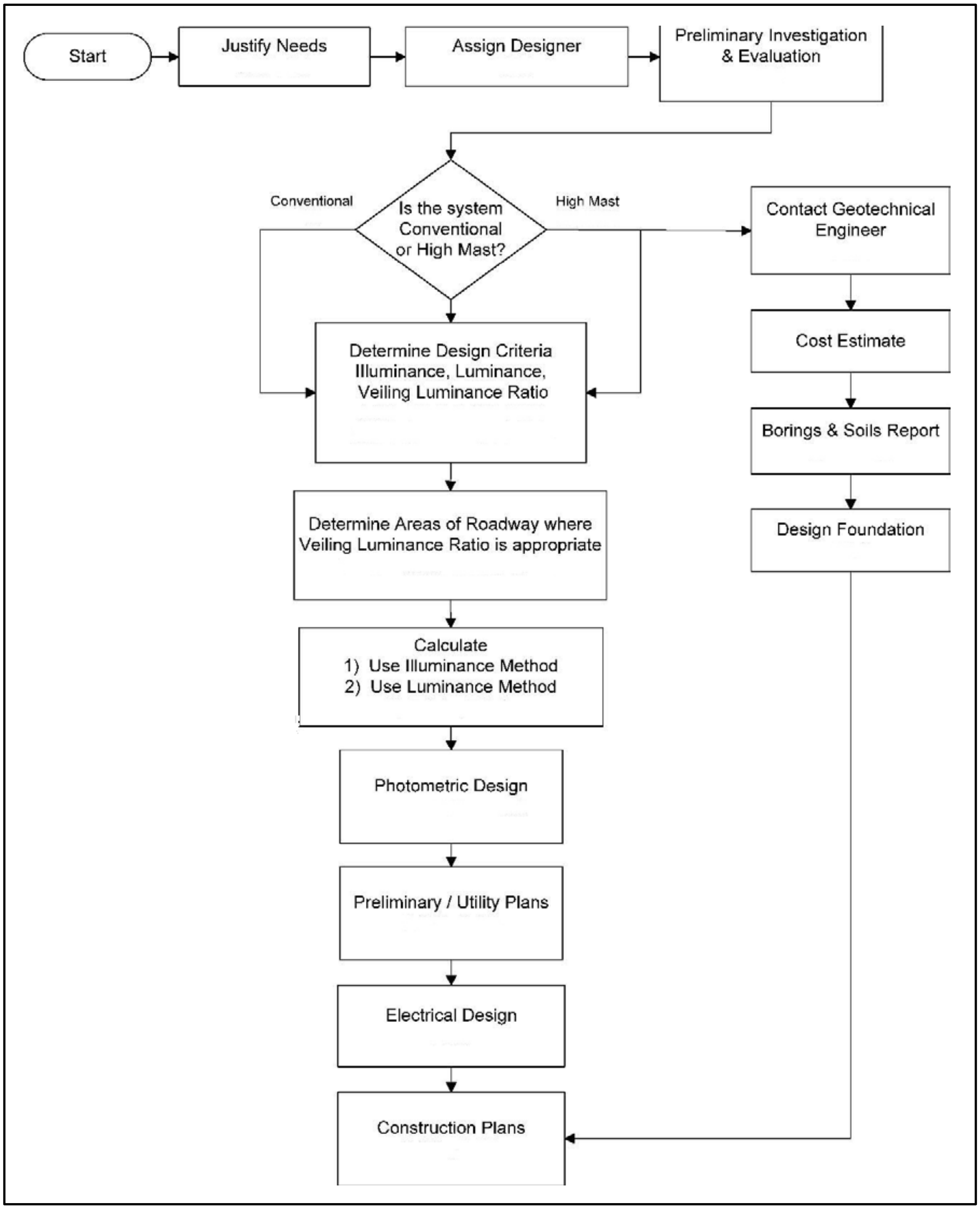
15.3 New Lighting Projects

The information in this section pertains to new lighting projects.

15.3.1 Lighting Design Process Flow Chart

A lighting design process flow chart is provided in Figure 15.3.

Figure 15.3 – Lighting Design Process Flow Chart



15.3.2 Design Process

- **Establish Contact with Utility Owner/Maintaining Agency:** Typically, the maintaining agency for a lighting system is the local government. The local government often contracts the local power company for maintenance operations. First contact should be with the governmental agency through involvement of the TDOT Traffic Operations Design Manager, to determine proper protocol for contact with the local power company. This will enable the lighting designer to prepare a lighting design that will satisfy both the TDOT Traffic Engineering Office's lighting design criteria and the Utility Owner/Maintaining Agency's specifications. The lighting designer should obtain the following information from the Utility Owner/Maintaining Agency:
  - Determine the specific light fixtures recommended for use;
  - Determine the service voltage available;
  - Determine the local specifications for wire size used;
  - Determine the maximum allowable circuit breaker size;
  - Determine acceptable locations for proposed control centers and service points;
  - Determine any special mounting height requirements.
- **Conventional Photometric Design Overview:** The following briefly describes the steps used in any conventional highway lighting photometric design:
  1. **Select Lighting Equipment:** Select the lighting equipment and associated design parameters that will be used for the project. This will include items such as luminaire mounting height, pole setback, light source, lamp wattage, etc. It will be necessary to make some initial assumptions during preliminary design. Design parameters then may be iteratively changed to meet the highway lighting criteria. It will be necessary to contact the municipality slated to take possessions of the lighting system. It may also be necessary to coordinate design efforts with that municipality's agent hired to perform maintenance operations for the system.
  2. **Select Luminaire Arrangement:** Select an appropriate luminaire arrangement for the project. This will depend on local site conditions and engineering judgment. Alternative arrangements may need to be considered.
  3. **Luminaire Spacing:** Typically, luminaire spacing will be determined by computer software. The Department recommends that the designer use AGI32 computer software for lighting design layouts. Foot-candle (fc) is a unit of illuminance expressed in lumens per square foot (lm/ft^2). Therefore, the average horizontal

foot-candle on a highway is equal to the total lumens cast on the highway by a single unit divided by the spacing between units times the width of the roadway. Total lumens that a luminaire will cast on the roadway equals lamp lumens at replacement time times the coefficient of utilization times the luminaire maintenance factor. This relationship can be rearranged to solve for luminaire spacing as shown in Equation 15.2.

$$S = \frac{LL \bullet CU \bullet MF}{E_h \bullet W}$$

Equation 15.2 – Luminaire Spacing

Where:

S = Luminaire Spacing (feet)

LL = Initial Lamp Lumens (lm)

CU = Coefficient of Utilization

MF = Maintenance Factor (i.e., LLD • LDD)

E_h = Average Maintained Horizontal Illumination (foot-candle)

W = Width of Lighted Roadway (feet)

4. **Check Uniformity:** Once luminaire spacing has been determined, check the uniformity of light distribution and compare this value to the lighting criteria selected in Step 1. Adjust design parameters and recalculate as necessary to meet criteria. Use Equation 15.3 to determine the uniformity ratio.

$$UR = \frac{E_h}{E_{\min}}$$

Equation 15.3 – Uniformity Ratio

Where:

UR = Uniformity Ratio

E_h = Average Maintained Horizontal Illuminance

E_{min} = Maintained Horizontal Illuminance at the Point of Minimum Illumination on the Pavement

5. **Select Optimum Design:** Because computerized design is relatively quick and easy, consider developing and testing several alternative designs. It generally is not good engineering practice to consider only one design, even if found to satisfy the lighting criteria. There often are several alternatives that will work. Optimize and select the most cost-effective and maintenance-free design.

Notes: A uniform spacing may not always be possible to maintain because of variation in roadway widths and alignment. Formulas shown above were extracted from *ANSI/IES RP-8-14*.

15.3.3 Design Considerations

When selecting design criteria for a lighting project, it is necessary to determine classifications for the roadway facility, the area the roadway traverses, and the pavement type. The following sections discuss these classifications for the purpose of highway lighting design only.

15.3.4 Determine Classifications

Determine the roadway classification, area classification, pavement classification, and environmental conditions. Verify with the TDOT Traffic Engineering Office the classification of any interchange or freeways as urban, suburban, or rural.

- **Roadway Classification:** Use the following definitions to classify roadway facilities for TDOT highway lighting projects:
  - **Freeway:** A divided major highway with full control of access and with no crossings at grade.
    - **Freeway Class A:** Roadways with greater visual complexity and highway traffic volumes. Usually this type of freeway will be found in major metropolitan areas in or near the central core, and will operate through some of the early evening hours of darkness at or near design capacity;
    - **Freeway Class B:** All other divided roadways with full control of access
  - **Expressway:** A divided major arterial highway for through traffic with full or partial control of access and generally with interchanges at major crossroads. Expressways for non-commercial traffic within parks and park-like areas generally are known as parkways.
  - **Major:** The part of the roadway system that serves as the principle network for through traffic flow. The routes connect areas of principle traffic generation and important rural highways entering the city.
  - **Collector:** The distributor and collector roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial, and industrial areas.
  - **Local:** Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways generally will be divided into short sections by the collector roadway system.
  - **Isolated interchange:** A grade-separated roadway crossing, which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

- **Isolated Intersection:** The general area where two or more non-continuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. A special type is the channelized intersection, in which traffic is directed into definite paths by islands with raised curbing.
- **Isolated Traffic Conflict Area:** A traffic conflict area is an area on a road system where an increased potential exists for collisions between vehicles, vehicles and pedestrians, or vehicles and fixed objects. Examples include intersections, crosswalks and merge areas. When this area occurs on a roadway without a fixed lighting system (or separated from one by 20 seconds or more of driving time), it is considered an isolated traffic conflict area.

➢ **Ancillary Classifications:**

- **Alley:** A narrow public way within a block, generally used for vehicular access to the rear of abutting properties.
- **Sidewalk:** Paved or otherwise improved areas for pedestrian use, located within public street right-of-way which also contains roadways for vehicular traffic.
- **Pedestrian Way:** Public sidewalks for pedestrian traffic generally not within right-of-way for vehicular traffic. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to park or block interiors, and crossings near centers of long blocks.
- **Bikeway:** Any road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or are to be shared with other transportation modes. Five basic types of facilities are used to accommodate bicyclists:
    - **Shared Lane:** Shared motor vehicle/bicycle use of a standard width travel lane.
    - **Wide Outside Lane:** An outside travel lane with a width of at least 13.8 feet.
    - **Bike Lane:** A portion of the roadway designated by striping, signing, and/or pavement markings for preferential or exclusive use of bicycles.
    - **Shoulder:** A paved portion of the roadway to the right of the edge stripe designed to serve bicyclists.

   - **Separate Bike Path:** A facility physically separated from the roadway and intended for bicycle use (See *IESNA DG-5-94, Lighting for Walkways and Class 1 Bikeways* for requirements in these areas).

- **Median:** The portion of a divided roadway physically separating the traveled ways for traffic in opposite directions. TDOT discourages lighting poles mounted in the median or on median barrier walls.

➢ **Area Classification:** For TDOT lighting projects, use the following definitions to classify the area in which the roadway traverses:

- **Commercial:** That portion of a municipality in a business development where ordinarily there are large numbers of pedestrians and a heavy demand for parking space during periods of peak traffic or a sustained high pedestrian volume and a continuously heavy demand for off-street parking space during business hours. This definition applies to densely developed business areas outside of, as well as those that are within, the central part of a municipality.

- **Intermediate:** That portion of a municipality which is outside of a downtown area but generally within the zone of influence of a business or industrial development, often characterized by a moderately heavy nighttime pedestrian volume and a somewhat lower parking turnover than is found in a commercial area. This definition includes densely developed apartment areas, hospitals, public libraries, and neighborhood recreational centers.

- **Residential:** A residential development, or mixture of residential and commercial establishments, characterized by few pedestrians and a low parking demand or turnover at night. This definition includes areas with single family homes, townhouses, and/or small apartments. Regional parks, cemeteries, and vacant lands also are included.

➢ **Pavement Classification:** Table 15.1 shows pavement type classifications of the roadway facility:

Table 15.1 – Pavement Classification

Class	Q_o*	Description	Mode of Reflectance
R1	0.10	Portland cement concrete road surface. Asphalt road surface with a minimum of 12 percent of the aggregates composed of artificial brightener (e.g., Synopal) aggregates (e.g., labradorite, quartzite).	Mostly diffuse
R2	0.07	Asphalt road surface with an aggregate composed of minimum 60 percent gravel [size greater than 0.4 inches] Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix. (Not normally used in North America).	Mixed (diffuse and specular)
R3	0.07	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	0.08	Asphalt road surface with very smooth texture.	Mostly specular

*Q_o = Representative mean luminance coefficient. Because the R tables also provides considerations for the pavement's reflectance, it is recommended not to make any adjustments to the Qo values given for computer design calculations.

➢ **Lighting Design Levels**

- **Crossroads at Interchanges:** Lighting levels on crossroad approaches should not be reduced through an interchange area. If existing crossroad lighting currently is deemed inadequate, it should be considered for upgrading to ensure safe and efficient traffic operation.
- **Partial Interchange Lighting:** Where partial interchange lighting is provided, luminaires should be located to best light the speed change lanes at diverging and merging locations. The design controls of basic levels of lighting and uniformity should be subordinate to overall lighting of the roadway area at these locations. The designer should use engineering judgment when considering the light levels on the through lanes.
- **Bridge Structures and Underpasses:** Where justified, underpass lighting level and uniformity ratios should duplicate, to the extent practical, the lighting levels on the adjacent facility. On continuously lighted freeways and lighted interchanges, the lighting of bridges and overpasses should be at the same level and uniformity as the roadway.
- **Transition Lighting:** Transition lighting is a technique intended to provide the driver with a gradual reduction in lighting levels and glare when leaving an illuminated area. Several implementation

methods exist. The designer also may consider extending delineation 1000 feet beyond the last luminaire for traffic lanes emerging from a lighted area (e.g. ambient light). This will provide an additional measure of effectiveness. Vision adjustment when approaching a lighted area is not impacted greatly and therefore requires no special consideration. For more information on transition lighting, refer to Section 15.2.2.

- **Navigation and Obstruction Lighting:** The lumen output for waterway and aviation obstruction luminaires will be based on the requirements of the U.S. Coast Guard and the Federal Aviation Administration, respectively.
- **Other Locations:** Where lighting is justified for tunnels, overhead signing, and other facilities not covered under this section, contact the Traffic Design Office for further information.

➢ **Luminaire Considerations:** Design issues related to luminaires are discussed as follows:

- **Light Distribution:** Light distribution is a major factor in highway lighting design. It affects the selection of luminaire mounting height, placement, and arrangement. Specific photometric data and light distribution sheets are available from each luminaire manufacturer. Manufacturers typically classify their luminaire products based on the IES luminaire classification system. The following briefly describes the IES classification system:
  - **Vertical Light Distribution:** There are three IES classifications of vertical light distribution – short, medium, and long. The selection of a particular vertical light distribution is dependent upon the luminaire mounting height and application. The following defines each type:
    - **Short Distribution:** The maximum candlepower strikes the roadway surface between one and 2.25 mounting heights from the luminaire. The theoretical maximum luminaire spacing, using the short distribution, is 4.5 mounting heights.
    - **Medium Distribution:** The maximum candlepower is between 2.25 and 3.75 mounting heights from the luminaire. The theoretical maximum luminaire spacing is 7.5 mounting heights. Medium distribution is commonly used in highway applications.
    - **Long Distribution:** The maximum candlepower is between 3.75 and 6.0 mounting heights from the luminaire. The theoretical maximum luminaire spacing is 12 mounting heights. From a practical standpoint, the medium distribution is predominantly used in

highway practice, and the spacing of luminaires normally does not exceed five to six mounting heights. Short distributions are not used extensively for reasons of economy, because extremely short spacing is required. At the other extreme, the long distribution is not used to any great extent because the high beam angle of maximum candlepower often produces excessive glare.

- **Lateral Light Distribution:** IES has developed seven classifications for lateral light distribution. The following provides application guidelines for each luminaire type:
  - **Type I:** The Type I luminaire is placed in the center of the roadway or area where lighting is required. It produces a long, narrow, oval-shaped lighted area. Some types of high-mast lighting are considered a modified form of Type I.
  - **Type I – 4-Way:** This luminaire type is located over the center of the intersection and distributes the lighting along the four legs of the intersection.
  - **Type II:** The Type II luminaire is placed on the side of the roadway or edge of the area to be lighted. It produces a long, narrow, oval-shaped lighted area which is usually applicable to narrower roadways.
  - **Type II – 4-Way:** This luminaire type is placed at one corner of the intersection and distributes the light along the four legs of the intersection.
  - **Type III:** The Type III luminaire is placed on the side of the roadway or edge of the area to be lighted. It produces an oval-shaped lighted area and is usually applicable to medium width roadways.
  - **Type IV:** The Type IV luminaire is placed on the side of the roadway or the edge of area to be lighted. It produces a wider, oval-shaped lighted area and is usually applicable to wide roadways.
  - **Type V:** The Type V luminaire is located over the center of the roadway, intersection, or area to be lighted. It produces a circular, lighted area. Type V often is used in high-mast lighting applications.
- **Control of Distribution:** As the vertical light angle increases, disability and discomfort glare also increase. To distinguish the glare effects on the driver created by the light source, IES has defined the vertical control of light distribution as follows:

- **Cutoff (C):** A luminaire light distribution is designated as C when the candlepower per 1000 lamp lumens does not numerically exceed 25 (2.5%) at an angle of 90° above nadir (i.e., horizontally), and 100 (10%) at a vertical angle 80° above nadir. This applies to any lateral angle around the luminaire.
- **Semi-Cutoff (SC):** A luminaire light distribution is designated as SC when the candlepower per 1000 lamp lumens does not numerically exceed 50 (5%) at an angle of 90° above nadir (i.e., horizontally), and 200 (20%) at a vertical angle of 80° above nadir. This applies to any lateral angle around the luminaire.
- **Non-Cutoff (NC):** A luminaire light distribution is designated as NC where there is no limitation on the zone above the maximum candlepower.

A plan view of the theoretical light distribution (i.e., roadway coverage) and schematics of the intended application of each type of IES luminaire are illustrated in Figure 15.4.

- **Mounting Heights:** Higher mounting heights used in conjunction with higher wattage luminaires enhances lighting uniformity and typically reduces the number of light poles needed to produce the same illumination level. In general, higher mounting heights tend to produce a more cost-effective design. For practical and aesthetic reasons, the mounting height should remain constant throughout the system. The manufacturer's photometric data is required to determine an appropriate mounting height. Typical mounting heights used by TDOT for conventional highway lighting purposes range from 35 feet to 55 feet. Mounting heights for light towers typically are greater than 80 feet.
- **Coefficient of Utilization:** A utilization curve is used to obtain a luminaire's CU. Manufacturers typically provide utilization curves and Isolux diagrams with each of their respective luminaire products. Figure 15.5 illustrates a sample utilization curve. The utilization curve relates to the luminaire rather than to the light source. It provides the percentage of bare lamp lumens which are utilized to light the pavement surface. If the luminaire is placed over the traveled way (i.e. out from the curb or edge of pavement), the total lumen utilization is determined by adding the street-side and curb-side (i.e. house-side) light. In essence, the utilization curve defines how much of the total lumen output reaches the area being lighted.

Figure 15.4 – Plan View of Roadway Coverage from IES Luminaires

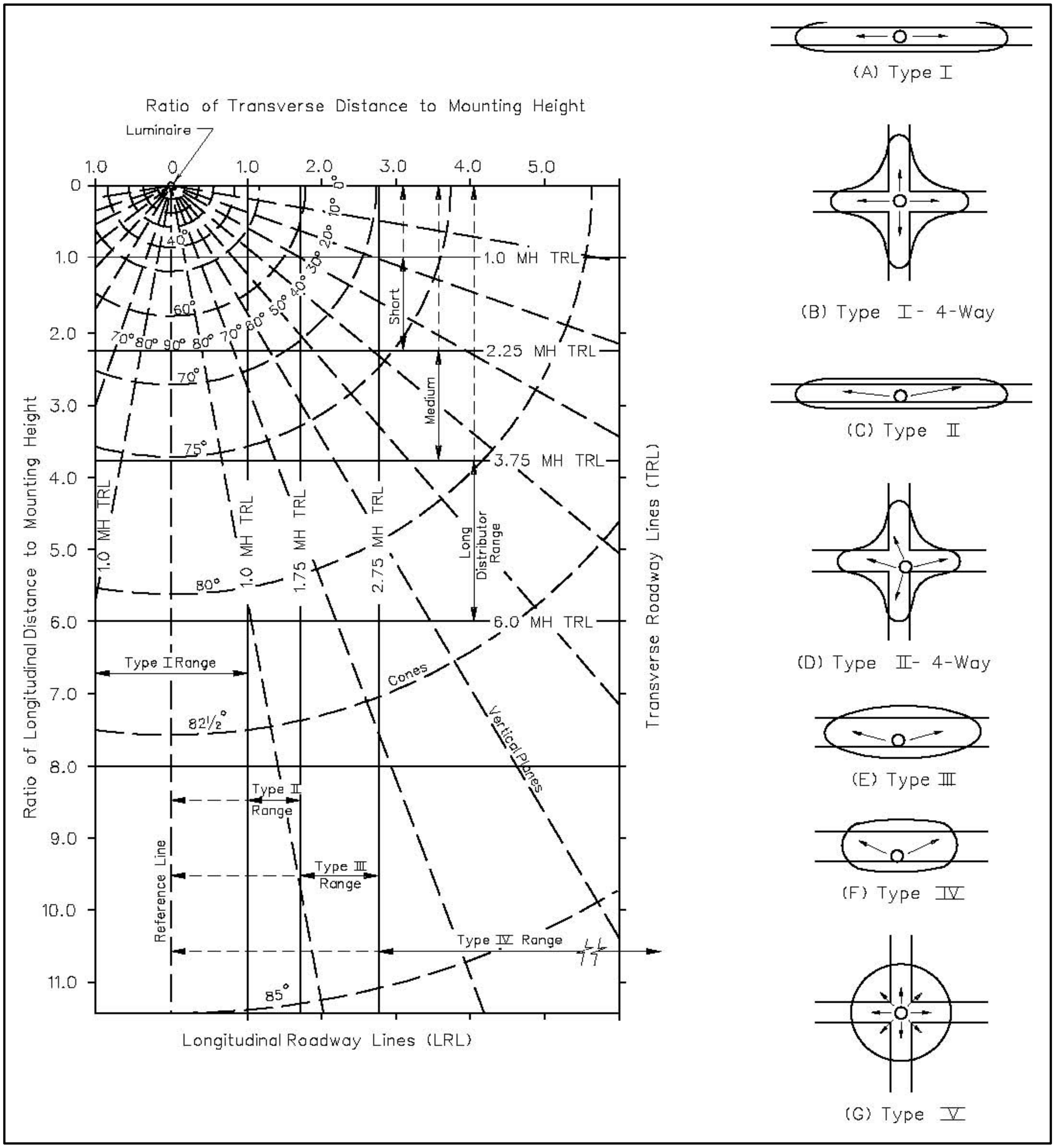
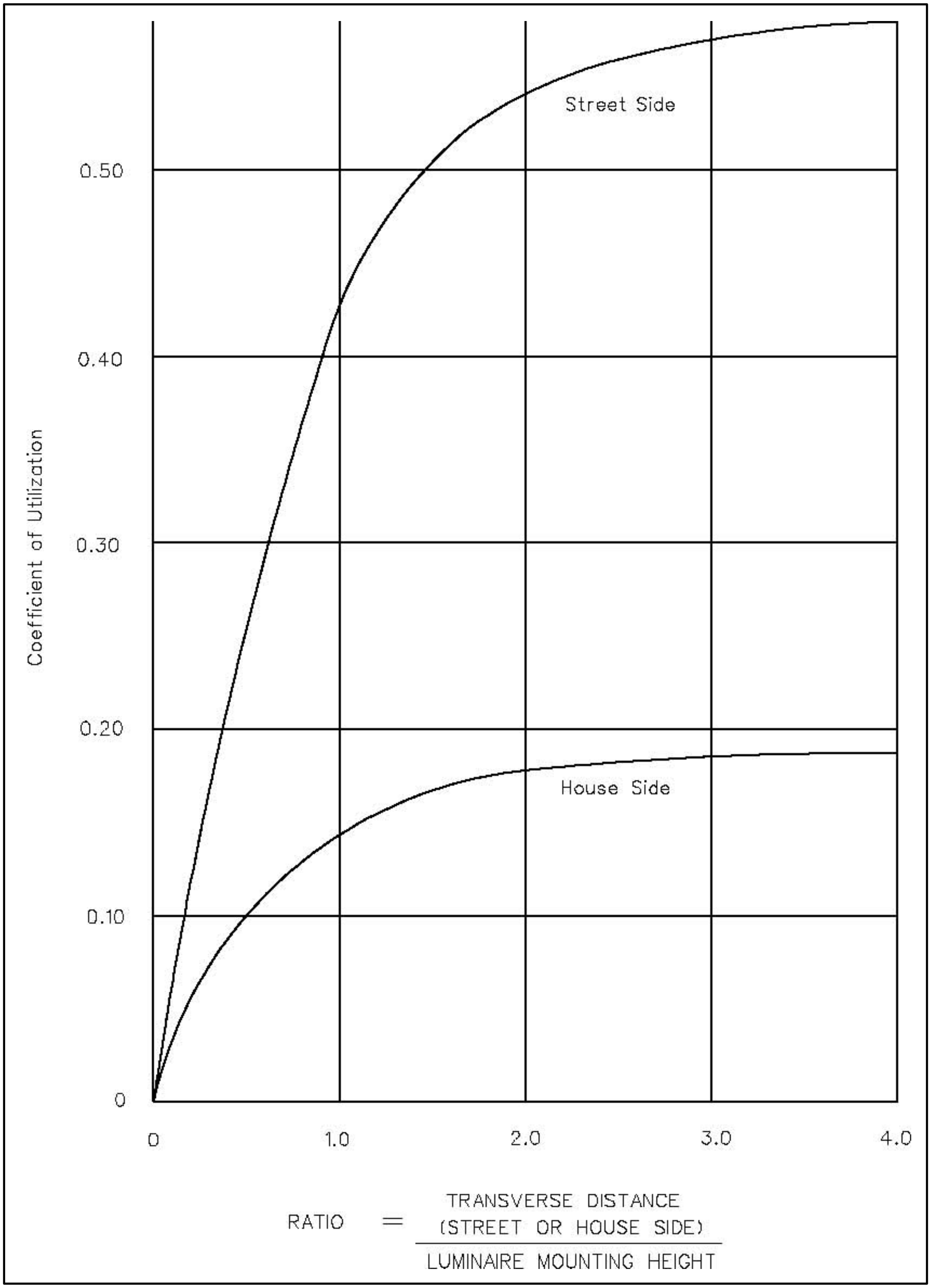


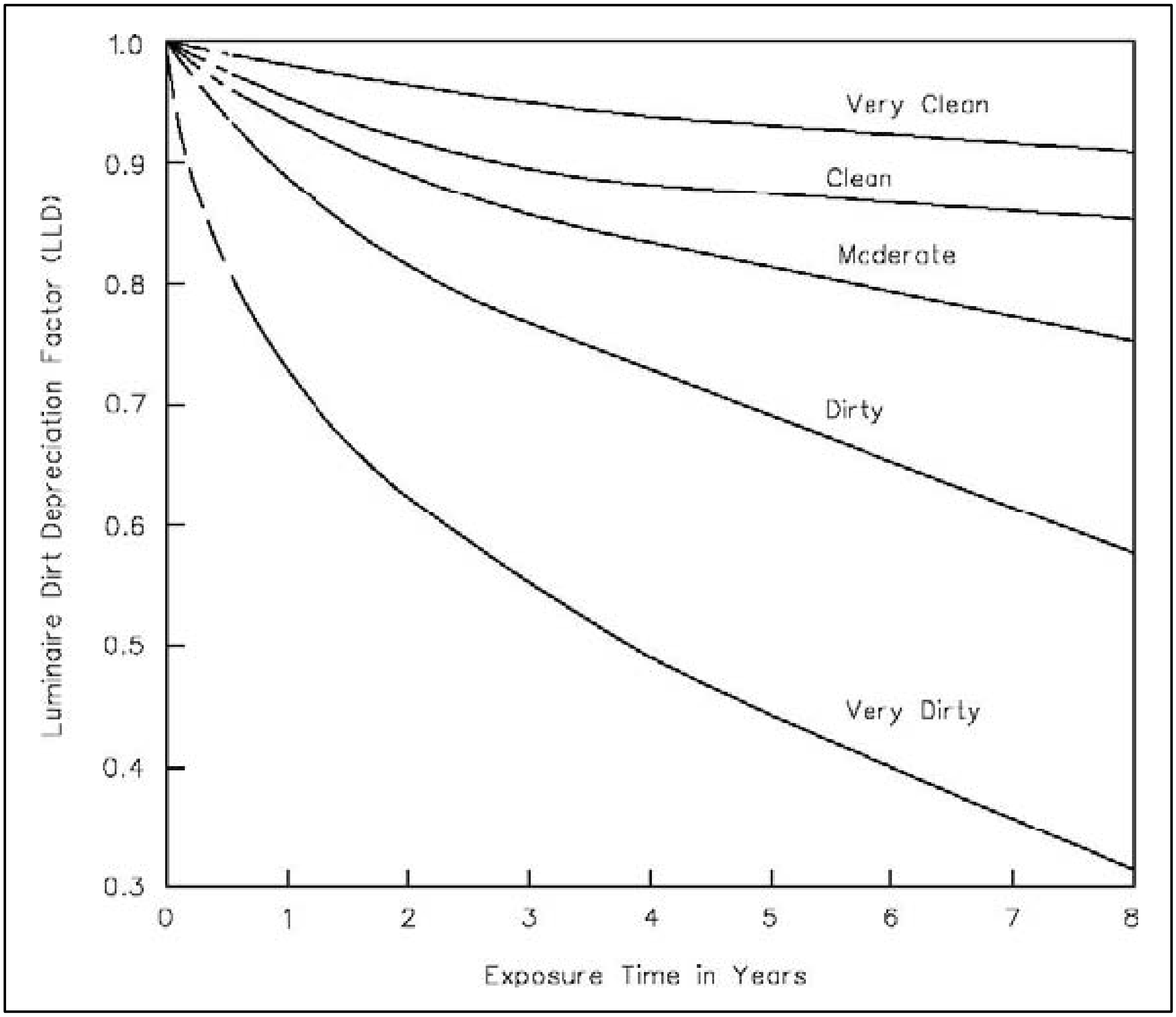
Figure 15.5 – Sample Utilization Curve



Note: The utilization curve will vary with each manufacturer and luminaire type.

- **Light Loss Factors:** The efficiency of a luminaire depreciates over time. The designer must estimate this depreciation to properly estimate the light available at the end of the lamp's serviceable life. The following briefly discusses these factors:
    - **Lamp Lumen Depreciation Factor:** As the lamp progresses through its serviceable life, the lumen output of the lamp decreases. This is an inherent characteristic of all lamps. The initial lamp lumen value is adjusted by a lumen depreciation factor to compensate for the anticipated lumen reduction. This assures that a minimum level of illumination will be available at the end of the assumed lamp life. This information is usually provided by the manufacturer.
    - **Luminaire Dirt Depreciation Factor:** Dirt on the exterior and interior of the luminaire, and to some extent on the lamp itself, reduces the amount of light reaching the pavement. Various degrees of dirt accumulation may occur depending upon the area in which the luminaire is located. Industrial areas, automobile exhaust, diesel trucks, dust and other environs all affect the dirt accumulation on the luminaire. Higher mounting heights, however, tend to reduce the vehicle-related dirt accumulation. The relationship between the ambient environment and the expected level of dirt accumulation is shown in Figure 15.6.
    - **Equipment Factor:** Equipment factor is a general factor encompassing luminaire losses due to all other factors such as ballast factor, manufacturing tolerances, voltage drop, lamp position, ambient temperature, and luminaire component depreciation.
    - **Light Loss Factor:** The reduction factor, referred to as the total LLF (Light Loss Factor is a combination of LDDF, LLDF, and EF including voltage drop. Values in the range of 60 to 80 percent (of initial design value) are used for high-pressure sodium (45 to 65 percent for MH) general application such as regularly maintained outdoor luminaires installed on lighting poles. The use of realistic luminaire depreciation, dirt, and equipment factors, is essential in lighting design to achieve the expected lighting levels on the roadway after the lighting system is installed. Values for these factors are obtained from manufacturers' product data.

Figure 15.6 – Roadway Luminaire Dirt Depreciation Curve

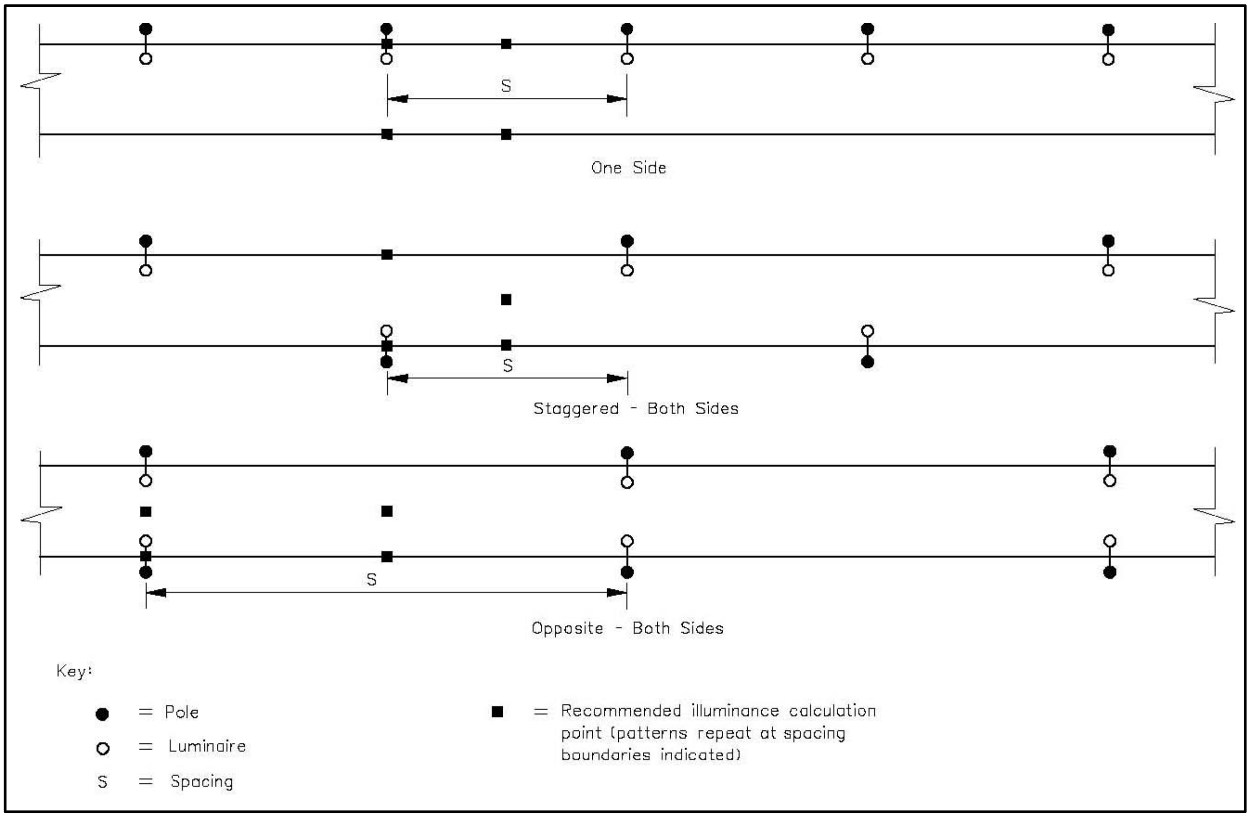


Notes:

- **Very Clean:** No nearby smoke or dust-generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is not more than 150 micrograms per cubic meter.
- **Clean:** No nearby smoke or dust-generating activities. Moderate to heavy traffic. The ambient particulate level is not more than 300 micrograms per cubic meter.
- **Moderate:** Moderate smoke or dust-generating activities nearby. The ambient particulate level is not more than 600 micrograms per cubic meter.
- **Dirty:** Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.
- **Very Dirty:** Similar to Dirty, but the luminaires are commonly enveloped by smoke or dust plumes.

- **Luminaire Arrangement:** Figure 15.7 illustrates typical luminaire arrangements for conventional highway lighting designs and the recommended illuminance calculation points for the various arrangements.

Figure 15.7 – Typical Luminaire Arrangements for Conventional Highway Lighting Design



15.3.5 Other Design Considerations

In addition to the items discussed in the previous sections, consider the following when designing the highway lighting system:

- **Signs:** Place light poles to minimize interference with the driver's view of the roadway and any highway signs. Do not permit luminaire brightness to seriously detract from the legibility of signs at night.
- **Structures:** Place light poles sufficiently away from overhead bridges and sign structures to minimize glare and distracting shadows on the roadway surface.
- **Trees:** Insufficiently pruned trees can cause shadows on the roadway surface and reduce the luminaire's effectiveness. Place the light standard and/or design the luminaire with a height and mast-arm length to negate such adverse effects.
- **Location:** Typically, lighting standards should be placed a minimum of 50 feet from overhead sign structures, and a minimum of 50 feet from overhead bridges.

15.3.6 Roadside Safety Considerations

Light poles should be installed so that they will not present a roadside hazard to the motoring public. However, the physical roadside conditions often dictate their placement. It is important to recognize this limitation. Overpasses, sign structures, guardrail, roadway curvature, right-of-way, gore clearances, proximity to roadside obstacles, and lighting equipment limitations are all physical factors that can limit the placement of light poles. The designer also must consider factors such as roadway and area classification, design speed, posted speed, safety, aesthetics, economics, and environmental impacts. In addition, there should be adequate right-of-way, driveway control, and utility clearance. Consider the following when determining the location of light poles:

- **Clear Zone:** Where practical, place light poles outside the roadside clear zone. See the TDOT Roadway Design Guidelines and *TDOT Standard Drawing RD01-S-12* for additional information on roadside clear zone.
- **Breakaway Supports:** Unless located behind a roadside barrier or crash cushion which is necessary for other safety-related reasons, conventional light poles placed within the roadside clear zone shall be mounted on breakaway supports. Poles outside the clear zone also should be mounted on breakaway supports where there is a possibility of them being struck by errant vehicles. Be aware that falling poles and mast arms may endanger bystanders (e.g., pedestrians, bicyclist, motorists). Consider the following during design:
    - **Pedestrians:** In areas where pedestrians, bicyclists, or building structures and windows may be struck by falling poles or mast arms after a crash, evaluate the relative risks of mounting the light pole

on a breakaway support. Examples of locations where the hazard potential of providing a breakaway support to pedestrian traffic would be greater than a non-breakaway support would be to vehicular traffic include transportation terminals, sports stadiums and associated parking areas, tourist attractions, school zones, central business districts, and local residential neighborhoods where the posted speed limit is 30 mph or less. In these locations, non-breakaway supports will be used. Other locations which require the use of non-breakaway supports, regardless of the amount of pedestrian traffic, are rest area and weigh station parking lots and combination luminaire and traffic signal poles.

- **Breakaway Bases:** All breakaway devices will comply with the applicable AASHTO requirements for breakaway structural supports.
- **Breakaway Support Stub:** Any substantial portion of the breakaway support that will remain after the light pole has been struck will have a maximum projection of four inches above the finished grade within a 5-foot chord above the foundation in accordance with AASHTO criteria.
- **Wiring:** All light poles that require breakaway supports will be served by underground wiring and designed with quick disconnect splices.
- **Light Towers:** Light Towers used in high-mast lighting applications will not be mounted on breakaway supports. Also, they will not be located within the roadside clear zone unless shielded by guardrail or crash cushions.
- **Bridge Parapets and Concrete Barriers:** Where poles are mounted atop bridge parapets and concrete barriers, they will be mounted on non-breakaway supports.

➢ **Gore Areas:** Where practical, locate light poles outside the gore areas of exit and entrance ramps. No lighting support should be placed within the clear zone of a gore area.

➢ **Horizontal Curves:** Place light poles on the inside of sharp curves and loops. Where poles are located on the inside radius of superelevated roadways, provide sufficient clearance to avoid being struck by trucks.

➢ **Maintenance:** When determining pole locations, consider the hazards which will be encountered while performing maintenance on the lighting equipment.

➢ **Barriers:** Use the criteria provided in chapters 1-305.25, 3.1, 2-135.00, and 2-135.05 in the TDOT Roadway Design Guidelines and TDOT Standard Drawing RD01-S-12 for additional information on roadside clear zone to design and place light poles in conjunction with roadside barriers. Consider the following additional guidelines:

- **Placement:** Where a roadside barrier is provided, place all light poles behind the barrier.
- **Deflection:** Light poles placed behind a roadside barrier should be offset by at least the deflection distance of the barrier. This will allow the railing to deflect without hitting the pole. If this clearance distance is not available, such as in extreme side slope conditions, designate the stiffening of the rail.
- **Concrete Barriers:** Light poles that are shielded by a rigid or non-yielding barrier do not require a breakaway support.
- **Impact Attenuators:** Locate light poles, either with or without a breakaway support, such that they will not interfere with the functional operation of any impact attenuator or other safety device.

➢ **Protection Features:** Do not use protection features, such as barriers, for the primary purpose of protecting a light pole.

➢ **Longitudinal Adjustments:** Locate light poles to balance both safety and lighting needs. Adjustments on the order of five feet are permissible in the field to accommodate utilities or drainage facilities provided the new location does not constitute a roadside hazard. Larger adjustments need approval by the Traffic Design Office.

➢ **ADA Requirements:** Contact the local agency for their specific ADA requirements.

15.4 Lighting Design

When designing a highway lighting system, there are numerous factors to consider. This section presents design considerations commonly encountered in highway lighting designs and presents TDOT's criteria, policies, and procedures on these issues. Table 15.2 presents typical highway lighting design parameters used by TDOT.

Table 15.2 – Typical TDOT Highway Lighting Design Parameters

Typical TDOT Highway Lighting Design Parameters (TDOT Recommends The Illuminance Method Of Design)	
Light Loss Factor (i.e., LLD • LDD)	0.70 – 0.81 [1]
Percent of Voltage Drop Allowed	3%
Typical Parameters for Conventional Lighting (Interstate — Rural)	Aluminum or Steel Pole, Single (or Twin) Tenon Mounting, 45-foot Mounting Height, 250W or 400W HPS Multi-Mount Luminaire, Breakaway Base where Justified
Typical Parameters for Conventional Lighting (Interstate — Urban)	Aluminum Pole, Off-set (or Mast Arm) Mounting, 45-foot Mounting Height, 250W or 400W HPS Horizontal-Mount Luminaire, IES Classification: Cutoff or Semi-Cutoff
Typical Pavement Classification	Class R1 (Concrete), Class R3 (Asphalt)
Typical IES Luminaire Classification for Conventional Highway Lighting	Type II, Type III, or Type IV Medium Distribution (M) Cutoff (C) or Semi-Cutoff (SC)
Typical Luminaire Pole Arrangement	Staggered, Opposite, or Same Side

[1] The Light Loss Factor may vary as the Dirt Depreciation Factor varies. In urban areas with higher pollution and/or smog, the designer should use the higher range of values. In remote areas the lower range of the Dirt Depreciation Factor may be used. When calculating the light loss factor, the designer should consider the location of the system (e.g. urban, rural areas, remote locations, etc.).

15.4.1 Methodologies

There are three lighting design methodologies available for use in highway lighting design, Illuminance, Luminance, and Small-Target-Visibility. The IES has been a leader in developing these methodologies (see the publication American National Standard Practice for Roadway Lighting, ANSI/IES RP-8-14). Calculations for both the Illuminance and Luminance methodologies along with consideration for Veiling Luminance should be used for all TDOT lighting projects. Both the Illuminance and Luminance methodologies require the designer to consider veiling luminance and limit the ratio to the values listed in Tables 15.3 and 15.4. The following sections briefly describe each of the available design methodologies.

- **Illuminance:** The Illuminance Methodology is the oldest and simplest to use of the three methodologies. Illuminance in roadway lighting is a measure of the light incident on the pavement surface. It is measured in foot-candles (Lux). The illuminance methodology is used to determine the combined amount of light reaching critical pavement locations from contributing luminaires (i.e. a measure of light quantity). This methodology also assesses how uniformly the luminaires' combined luminous flux is horizontally distributed over the pavement surface (i.e., a measure of light quality). An inherent disadvantage of the Illuminance Methodology is that it only accounts for incident light and does not assess the effect on visibility due to reflected light from an object or surface. This sensation is known as "brightness". Components of illuminance design include the average maintained horizontal illumination (Eh), or quantity of light, and the uniformity ratio (Eh/Emin), or quality of light, maximum veiling luminance (Lv), and veiling luminance ratio (Lv to Lave).

- **Luminance:** Luminance in roadway lighting is a measure of the reflected light from the pavement surface that is visible to the motorist's eye. Reflected light from an object or surface is known as brightness. Objects are distinguished by contrast from their difference in brightness. Brightness is expressed mathematically as luminance: the luminous intensity per unit area directed towards the eye. The Luminance Methodology is used to simulate driver visibility by assessing the quantity and quality of light reflected by the pavement surface to the motorist's eye from contributing luminaires. In theory, luminance is a good measure of visibility. However, the results of using the Luminance Methodology in highway lighting applications are greatly affected by one's ability to accurately estimate the reflectance characteristics of the pavement surface, both now and in the future. As such, a computer program is required in TDOT lighting designs to aid and provide consistency in some of these estimations. Factors affecting pavement reflectivity include initial surface type, pavement deterioration, resurfacing material type, assumptions regarding weather conditions, etc. It is difficult to predict or control such factors. Compared to Illuminance, the Luminance methodology is considerably more complicated to understand and use. Components of luminance design include average maintained luminance (Lave), minimum luminance (Lmin), maximum luminance (Lmax), maximum veiling luminance (Lv), and ratios of Lave to Lmin, Lmax to Lmin, and veiling luminance ratio (Lv to Lave).

- **Veiling Luminance Ratio:** In conjunction with the luminance method, the evaluation of glare from the fixed lighting system is relevant and included with the luminance criteria. The disability glare (veiling luminance) has been quantified to give the designer the information to identify the veiling effect of glare as a percent of average overall luminance. A calculation of reflected light toward the eye of the observer is made for each roadway point 272 feet from the observer, summing the luminance from each luminaire. The distance between points should not exceed 15 feet. Calculations should include a minimum of three luminaire cycles downstream and one luminaire cycle upstream from reference (0.0) REF.

Luminance calculations place the observer's (motorist's) eye height at 4.8 feet above grade. The 4.8 feet is a design figure used internationally and does not affect the driver eye height of 3.5 feet. The observer's line of sight is downward at one degree below horizontal and parallel to the edge of the roadway along lines one-quarter roadway lane width from the edge of each lane. As shown in Figure 15.8, the observer is positioned at a point 272 feet before the first point in the cycle to be evaluated. Because of the geometric configuration for analysis, the veiling luminance calculation is only typically required on straight roadways with clear visibility. This is not to say that the veiling luminance calculation is to be eliminated altogether, rather it should be eliminated only for:

- Short roadway sections and Isolated intersections;
- Curved roadway sections where the points of analysis are unachievable; or
- Where visibility of the calculation points are for any reason obstructed.

Veiling luminance ratio requirements are considered using both the luminance and illuminance design criteria. Criteria for veiling luminance ratio can be obtained from Tables 15.3 and 15.4.

Figure 15.8 – Calculation Points for Luminance and Illuminance Design Methods

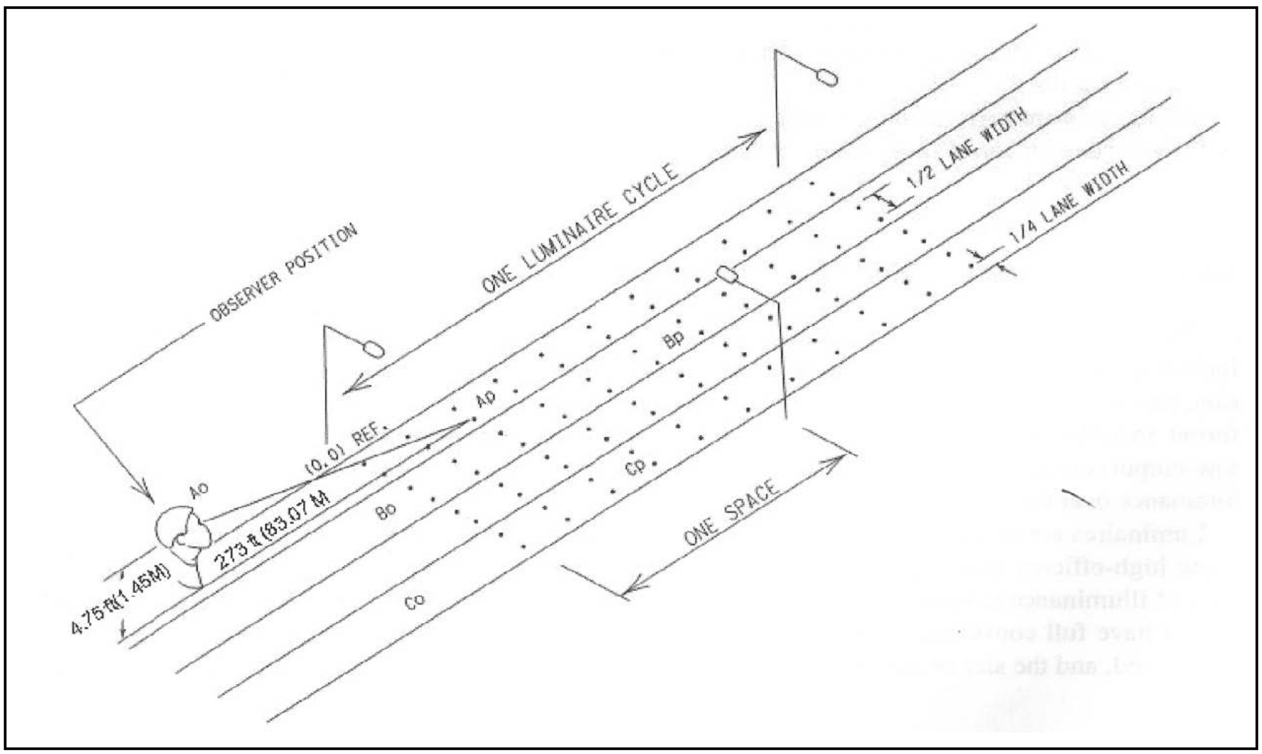


Table 15.3 – TDOT Illuminance Design Criteria

Roadway Facility Classification	Area Classification (Pedestrian Conflict Areas) [(2)]	Average Maintained Horizontal Illuminance (E_h) Foot-candle (lux) [(4)]			Uniformity Ratio [(6)] (Avg/Min.) Max	Veiling Luminance Ratio [(3)] LVmax/Lavg
		Pavement Classification				
		R1 (Min)	R2 & R3 (Min)	R4 (Min)		
Freeway (Interstate)	Class A	0.6 (6)	0.9 (9)	0.8 (8)	3:1 to 4:1	0.3
	Class B	0.4 (4)	0.6 (6)	0.5 (5)		
Expressway	Low	0.6 (6)	0.8 (8)	0.8 (8)		
	Medium	0.8 (8)	0.9 (9)	0.9 (9)		
	High	1.0 (10)	1.1 (11)	1.1 (11)		
Major Arterial	Low	0.6 (6)	0.8 (8)	0.8 (8)	3:1	
	Medium	0.8 (8)	1.2 (12)	1.0 (10)		
	High	1.1 (11)	1.6 (16)	1.4 (14)		
Minor Arterial	Low	0.5 (5)	0.7 (7)	0.7 (7)	4:1	
	Medium	0.8 (8)	1.0 (10)	0.9 (9)		
	High	0.9 (9)	1.4 (14)	1.0 (10)		
Collector	Low	0.4 (4)	0.6 (6)	0.5 (5)		0.4
	Medium	0.6 (6)	0.8 (8)	0.8 (8)		
	High	0.8 (8)	1.1 (11)	0.9 (9)		
Local	Low	0.3 (3)	0.4 (4)	0.4 (4)	6:1	
	Medium	0.5 (5)	0.7 (7)	0.6 (6)		
	High	0.6 (6)	0.8 (8)	0.8 (8)		
Alleys	Low	0.2 (2)	0.3 (3)	0.3 (3)		
	Medium	0.3 (3)	0.4 (4)	0.4 (4)		
	High	0.4 (4)	0.6 (6)	0.5 (5)		
Sidewalks	Low	0.3 (3)	0.4 (4)	0.4 (4)	6:1	
	Medium	0.6 (6)	0.8 (8)	0.8 (8)	4:1	
	High	0.9 (9)	1.3 (13)	1.2 (12)	3:1	
Walkways and Bikeways [(2)]	All	1.4 (14)	2.0 (20)	1.8 (18)	3:1	
Rest Areas And Weigh Stations						
Ramp Gores and Interior Roadways	All	0.4 (4)	0.6 (6)		3:1 to 4:1	0.4
Parking and Major Activity Areas	All	0.8 (8)	1.1 (11)			
Minor Activity Areas	All	0.4 (4)	0.5 (5)		6:1	

Table 15.4 – TDOT Luminance Design Criteria

<table>
<tr><th colspan="2">Road and Pedestrian Conflict Area</th><th rowspan="2">Average Luminance Lave (cd/m2) (Min)</th><th rowspan="2">Uniformity Ratio Lavg/Lmin (Maximum Allowed) (Max)</th><th rowspan="2">Uniformity Ratio Lmax/Lmin (Maximum Allowed) (Max)</th><th rowspan="2">Veiling Luminance Ratio LVmax/Lmin (Maximum Allowed) (Max) [3]</th></tr>
<tr><th>Road</th><th>Pedestrian Conflict Area [2]</th></tr>
<tr><td>Freeway Class A</td><td>N/A</td><td>0.6</td><td rowspan="5">3.5</td><td rowspan="5">6.0</td><td rowspan="11">0.3</td></tr>
<tr><td>Freeway Class B</td><td>N/A</td><td>0.4</td></tr>
<tr><td rowspan="3">Expressway</td><td>Low</td><td>0.6</td></tr>
<tr><td>Medium</td><td>0.8</td></tr>
<tr><td>High</td><td>1.0</td></tr>
<tr><td rowspan="3">Major Arterial</td><td>Low</td><td>0.6</td><td>3.5</td><td>6.0</td></tr>
<tr><td>Medium</td><td>0.9</td><td>3.0</td><td>5.0</td></tr>
<tr><td>High</td><td>1.2</td><td>3.0</td><td>5.0</td></tr>
<tr><td rowspan="3">Minor Arterial</td><td>Low</td><td>0.6</td><td>3.5</td><td>6.0</td></tr>
<tr><td>Medium</td><td>0.9</td><td>3.0</td><td>5.0</td></tr>
<tr><td>High</td><td>1.2</td><td>3.0</td><td>5.0</td></tr>
<tr><td rowspan="3">Collector</td><td>Low</td><td>0.4</td><td>4.0</td><td>8.0</td><td rowspan="6">0.4</td></tr>
<tr><td>Medium</td><td>0.6</td><td>3.5</td><td>6.0</td></tr>
<tr><td>High</td><td>0.8</td><td>3.0</td><td>5.0</td></tr>
<tr><td rowspan="3">Local</td><td>Low</td><td>0.3</td><td rowspan="3">6.0</td><td rowspan="3">10.0</td></tr>
<tr><td>Medium</td><td>0.5</td></tr>
<tr><td>High</td><td>0.6</td></tr>
</table>

Note: Use Illuminance requirements for sidewalks, walkways and bikeways.

The following notes may apply to the Illuminance Method and the Luminance Method:

1. Meet the Illuminance design method requirements and the Luminance design method requirements and meet veiling luminance requirements for both Illuminance and the Luminance design methods.
2. Assumes a separate facility. For Pedestrian Ways and Bicycle Ways adjacent to roadway, use roadway design values. Use R3 requirements for walkway/bikeway surface materials other than the pavement types shown. Other design guidelines such as IESNA or CIE may be used for pedestrian ways and bikeways when deemed appropriate.
3. LV(max) refers to the maximum point along the pavement, not the maximum in lamp life. The Maintenance Factor applies to both the LV term and the Lavg term.
4. There may be situations when a higher level of illuminance is justified. The higher values for freeways may be justified when deemed advantageous by the agency to mitigate off-roadway sources.
5. Physical roadway conditions may require adjustment of spacing determined from the base levels of illuminance indicted above.
6. Higher uniformity ratios are acceptable for elevated ramps near high-mast poles.
7. See AASHTO publication entitled, “A Policy on Geometric Design of Highways and Streets” for roadway and walkway classifications.

- **Small-Target-Visibility:** STV has been proposed as an alternative lighting design methodology to better define actual driver visibility requirements. Both luminance and STV are considerably more complex than illuminance. Luminance designs depend on pavement reflectance characteristics, observer position, and luminaire location and performance. STV designs depend on identical parameters and add the complexity of an array of seven-inch, flat targets placed perpendicularly to the pavement surface. The STV methodology is used to calculate the collective visibility of the targets, expressed as a weighted average, for a given design. Theoretically, STV should closely approximate actual driver visibility; however, there is not yet sufficient field experience to calibrate the STV model. The STV method has not been adopted by AASHTO because it does not adequately describe visibility in the roadway scene.
- **TDOT Design Methodology:** The Illuminance methodology shall be used in roadway lighting design on all TDOT lighting projects. This shall also include the calculations necessary to obtain the veiling luminance ratio. Due to the complexity and the repetitive nature of these calculations, TDOT will require the designer to use computerized design techniques.

15.4.2 Computerized Design

The highway lighting design process is an iterative process that is quite effectively implemented by computer. If criteria are not initially satisfied, it will be necessary to change design parameters (e.g. pole spacing, mounting height, luminaire wattage) until an acceptable alternative is found. This process will be repeated until the design is optimized to meet the selected criteria. For computerized designs prepared by outside consultants, the consultant will provide the program's name and version and the input data and output reports in either printed, or electronic format, or both.

15.4.3 Electrical Design

Roadway lighting is generally bundled with roadway transportation projects which are characterized or defined as civil engineering designs. Often a civil engineer would place emphasis on the photometric portion of the lighting design while the electrical engineer may place chief focus on the electrical components of the design. It is important to note that a sound engineering lighting design consists of two equally important components, the photometric design and the electrical design. The methodology for selecting and designing to a specific photometric design criteria is defined in Section 15.4.1. Upon completion of the photometric design, the electrical design can be initiated.

- **Electrical Design Steps:**
    1. **Determine the service voltage provided for the lighting design:** It is the responsibility of the lighting designer to verify, with the Utility Owner/Maintaining Agency (See Section 15.3.2), the service voltage that shall be provided for the lighting design. The designer

should indicate that the contractor coordinate with the power company to set the service transformer to the proper tap to ensure that the nominal service voltage is achieved. Typically, the single phase, service voltage may be 120 V, 240 V, or 480 V. If requested, the designer might be able to obtain a higher service voltage from the Utility Owner/Maintaining Agency.

2. **Determine the wire size to be used:** It is the responsibility of the lighting designer to verify, with the Utility Owner/Maintaining Agency, the wire size that may be used throughout the project. If no specific wire size is required to meet the specifications of a Utility Owner/Maintaining Agency, the lighting designer shall use sound engineering judgment to select adequate wire sizes for the lighting design.

3. **Circuit breakers:** It is the responsibility of the lighting designer to verify, with the utility owner/maintaining agency, the maximum allowable main circuit breaker size that may be utilized. Maintain standard sized circuit breakers in the control center. A spare circuit breaker should be included in each control center. When determining the size of the breakers an appropriate safety factor should be used.

4. **Establish location for control centers:** The lighting designer shall establish a safe location for the control centers. These locations shall be verified and approved by the Utility Owner/Maintaining Agency and the TDOT Project Manager.

5. **Voltage Drop Calculations:** Items 1 through 4 above are essential in the determination of the voltage drop calculation. The maximum voltage drop should not exceed 3%. However, with consent from the TDOT manager, voltage drop of up to 5% might be considered. The lighting designer should follow the voltage drop calculations as detailed below.

6. **Equipment Selection and Sizing:** The lighting designer shall use recommended safety factors and industry standards when selecting and sizing the electrical equipment.

7. **Wiring Schematic:** The lighting designer shall detail the wire routing for the lighting system.

8. **Inappropriate Equipment Sizing:** It is important to note, that inappropriate equipment sizing can result in major cost overrun. The lighting designer's design shall comply with the latest edition of the National Electric Code.

9. **Electrical Design Quantities:** Once the electrical design is finalized, the electrical design quantities shall be tabulated. The lighting designer shall be responsible for ensuring that the tabulated quantities mirror the final electrical design.

- **Voltage Drop Determination:** The typical highway lighting distribution circuit is 120/240 V or 240/480 V, single phase, 60-cycle alternating current service. The power supply to the lighting system generally consists of two conductors (line to line) and an insulated ground wire. Typically, the lights are connected using both legs of the circuit to obtain 240 V or 480 V at the luminaires. This shall be verified by the Utility Owner/Maintaining Agency. Voltage drop should be determined as follows:

1. Determine the service voltage (VL) provided by the electrical company.
2. Determine the lamp amperes (I) from Table 15.5 based on the lamp wattage and service voltage.
3. Determine the resistance (R) of the wire size to be used from Table 15.6.
4. Determine the distances (L) from each luminaire to the circuit breaker.
5. Use the equations below in determining the percentage voltage drop for a luminaire in a two-wire single phase circuit,
6. Or, use Equation 15.4 in determining the percentage voltage drop between outside conductors and neutral in three-wire single phase circuits. (See Note 3 in Equation 15.4).
7. Use Equation 15.5 to determine the voltage drop for all of the luminaires being connected to the branch circuit breaker.
8. Voltage drop should not exceed 3% as defined in this section.
9. Calculating voltage drop, will determine the total number of luminaires that may be connected to each branch circuit breaker (See Circuit Breaker Size Determination on Page 15-42).

Table 15.5 – Lamp Amperes (HPS Mag Regular Ballast)

Watts	Lamp Amperes (I) 120 Volts	Lamp Amperes (I) 240 Volts	Lamp Amperes (I) 480 Volts
150	1.7	1.0	0.6
250	2.7	1.4	0.8
400	3.9	2.1	1.1
1000	9.1	4.6	2.3

Table 15.6 – Conductor Properties

Wire Size AWG	Circuit Resistance (R) (Ohms/Foot)	Wire Size AWG	Circuit Resistance (R) (Ohms/Foot)
14	0.0032614	2	0.0002009
12	0.0020498	1	0.0001600
10	0.0012899	1/0	0.0001271
8	0.0008089	2/0	0.0001009
6	0.0005099	3/0	0.0000796
4	0.0003210	4/0	0.0000625

$$Vd = (2 \bullet L \bullet I \bullet R) / VL$$

Equation 15.4 – Percentage Voltage Drop for One Luminaire

Where:

Vd = percentage voltage drop for one luminaire in circuit

L = distance of luminaire to circuit breaker (ft)

I = current in conductor (lamp amperes) (See Note 1 below)

R = resistance per foot of conductor (ohms/foot) (See Note 2 below)

VL = service voltage (120 V, 240 V, or 480 V)

Notes:

1. Consult manufacturer's data for ampere for ballasts being considered.
2. Resistances listed in the table below are based on stranded copper conductor at 167°F operating temperature with an insulated covering and located in conduit (resistance in ohms/feet)
3. Voltage drop between one outside conductor and neutral equals one-half of voltage drop calculated by formula above for two-wire circuits.

$$\text{Total } Vd = \Sigma\, Vd$$

Equation 15.5 –Voltage Drop for Each Luminaire

Where:

Total Vd = total percentage voltage drop in one branch circuit

- **Circuit Breaker Size Determination:** The branch circuit breaker size and main circuit breaker size can be determined after the total voltage drop has been calculated. Once the total voltage drop criteria has been satisfied, then the branch circuit breaker and main circuit breaker sizes can be determined as follows:
    1. Determine the total number of luminaires that can be supported on one branch circuit breaker.
    2. Equation 15.6 shows the calculation to determine the size for a branch circuit breaker:
    3. Branch Circuit breaker size should be rounded to the nearest whole number. Standard size circuit breakers of 10, 20, 30, 40 and 60 amperes should be specified. Control Center Cabinets typically use four branch circuit breakers and one spare circuit breaker. However, if more circuits are required and can be supported, the Control Center Cabinet could have up to six branch circuit breakers and a spare circuit breaker.
    4. Equation 15.7 shows the calculation to determine the size for the main circuit breaker.
    5. Typically, the main circuit breaker size may be 60, 100 or 125 Amps. Larger sizes may be used if approved by the Utility Owner/Maintaining Agency.

$$BCB = (\text{Total No. of Luminaires} \times I) / 80\%$$

Equation 15.6 – Branch Circuit Breaker Size

Where:

BCB = Branch Circuit Breaker

I = Current in Conductor (Lamp Amperes) (See Table 15.5)

$$MCB = (\Sigma\ BCB) / 80\%$$

Equation 15.7 – Main Circuit Breaker Size

Where:

MCB = Main Circuit Breaker

BCB = Branch Circuit Breaker

15.4.4 Foundation, Pole Mounting, and Structural Considerations

The *TDOT Standard Specifications* and *TDOT Standard Drawings* provide pole mounting details and details for foundation materials, depth, width, reinforcing, etc. When designing a lighting system, also consider the following:

- **Foundation Height Relative to Final Grade:** For other than high mast (light towers), design pole foundations flush with the high edge of the surrounding grade. This permits drainage necessary to protect the foundation and reduces the likelihood of the foundation intensifying a collision. The foundation also is less likely to be destroyed during a collision. When located within the clear zone, ensure that the foundation and fractured breakaway device does not protrude more than four inches above the finished grade within a five-foot chord.

- **Steel Foundations:** The steel (i.e. helix screw-in type) foundation is one that is commonly used by TDOT for conventional light poles. This foundation is placed in undisturbed earth using a clockwise rotation similar to a common screw. The diameter of the steel tube ranges from eight inches to ten inches and is typically six feet long. Shorter lengths may be appropriate for foundations in areas with shallow bedrock. The steel foundation will accommodate poles with 11.5 inches and 15 inches bolt circles for luminaire mounting heights ranging from 40 feet to 50 feet.
- **Foundations for Temporary Lighting:** Foundations for temporary lighting will be determined on a case-by-case basis. This may include direct embedment of wood poles to a depth of from 5.5 feet, for 30-foot poles, to 12 feet, for 65-foot poles. The use of butt base anchors also may be considered.
- **Pole Mounting on Parapets:** Poles for bridge lighting typically are mounted on specially designed concrete parapet sections. Ensure that the mounting design includes the necessary non-breakaway, high-strength bolts, leveling plate, and vibration pad.
- **Center Median Barriers:** TDOT strongly discourages the installation of light poles on center median barriers. Any installation that requires lane closures on a freeway should be eliminated if at all possible. Lane closures by local power companies are extremely hazardous to both the maintenance worker and the motorist. Consult the TDOT manager before beginning such a layout.
- **Structural Design:** Poles will be designed and fabricated to meet or exceed AASHTO requirements as documented in AASHTO *Standard Specifications for Structural Supports for Highway Signs*, Luminaires, and Traffic Signals and *NCHRP Report 411*. See the TDOT *Standard Specifications* for the appropriate design criteria (e.g. wind loading, gust factor, luminaire mass and effective area).
- **High Mast (Light Tower) Foundations:** Foundations for light towers used in high-mast lighting applications typically require specialized designs and soil surveys to ensure adequate support. A 4-foot diameter reinforced concrete foundation, to a depth as required by the soils analysis, usually is adequate for towers accommodating 80-foot luminaire mounting heights.

15.4.5 TDOT Foundation Design

When high mast interchange lighting is installed, the foundation design at each pole location shall be based on a soil test conducted and certified by a qualified, professional engineer. This certification shall be submitted along with the final construction plans to the TDOT Traffic Design Office for their records. Information from the soils testing may be also included in the plans. TDOT Standard Drawing T-L-1 tabulates estimated foundation depths as a function of pole height. When an outside consultant is used, the consultant will be charged with determining the necessary soils properties required to develop the foundation design. This information will be required at each tentative high mast pole location, as determined by an appropriate lighting design. Boring log information, extending from the surface of the ground to the minimum depth noted on TDOT Standard Drawing T-L-1 plus ten feet or to solid rock, whichever comes first, will be presented in the final design plans for the interchange lighting project. Critical soil parameters will be documented for use in the foundation design. Minimum information required at each boring site are types and depths of each soil strata, 'N' values (numbers of blows per foot using a split spoon sampler), and PP embankment, soil analysis shall be performed after compaction of the embankment. The foundation design will be performed in accordance with the latest version of AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. As a secondary check, Equations 15.8 and 15.9 (presented in the Civil Engineering magazine, May 1969) may also be used:

$$L = \frac{2.13F}{2PpD_{-}} \left\{ \left(\frac{2.13F}{2PpD_{-}}\right)^2 + \frac{3.2M}{PpD_{-}} \right\}^{0.5}$$

Equation 15.8 – Length of Foundation

$$\Delta = \frac{2.16F}{KDL^2} \left\{ 1.33 \left(\frac{H}{L}\right) + 1 \right\}$$

Equation 15.9 – Lateral Movement of Foundation at Ground Line

Where:

L = Length of Foundation, feet

F = Resultant of all Horizontal External Loads, kips

Pp = Passive Pressure, ksf

D = Diameter of Foundation, feet (typically four feet)

M = Moment at Ground Line or Top of Footing, = F x H, feet-kips

Δ = Lateral Movement of Foundation at Ground Line, inches

K = Coefficient of Passive Subgrade Reaction, kcf

H = Distance from Ground Line to Resultant of Horizontal Loads, feet

The consultant will be charged with providing the most cost efficient design, whether it be drilled shaft, rock socket, or spread footing. The consultant shall determine the potential lateral movement of the foundation, and shall design to restrain the lateral movement to no more than 0.5 inches. Manday proposals and costs for the soils study will be reviewed and approved by the TDOT Geotechnical Engineering Office. Manday proposals and costs for the structural design of high mast foundations will be reviewed and approved by the TDOT Structures Division. Final foundation designs will be reviewed by the TDOT Structures Division. These reviews and approvals will be coordinated by the TDOT Traffic Engineering Office.

15.4.6 High-Mast Lighting Design

In general, the design of high-mast lighting systems follows the same design procedures as discussed in Section 15.3 and other sections of Section 15.4. In addition, consider the following:

- **Mounting Heights:** Mounting heights in high-mast lighting applications range from 60 feet to 180 feet. In general, heights of 100 feet to 150 feet have exhibited the most practical designs. Greater mounting heights require more luminaires to maintain illumination levels. However, greater heights allow for fewer poles and provide better light uniformity.
- **Light Source:** LED or HID are to be used for the lamps. The number of luminaires required will be determined by the area to be lighted. As a general starting point, it can be assumed that mounting heights of approximately 100 feet will require a minimum of 400,000 lumens, 600,000 lumens for mounting heights of approximately 120 feet to 130 feet, and 800,000 to 1,000,000 lumens for mounting heights of approximately 150 feet. The number of luminaires per pole typically ranges from four to six luminaires. Luminaires are typically installed in multiples of two in order to balance the lowering device ring.
- **Location:** In determining the location of light towers, review the plan view of the area to determine the more critical areas requiring lighting. In selecting tower locations, consider the following:
  - **Critical Areas:** Locate light towers so that the highest localized levels of illumination fall within the critical traffic areas (e.g. freeway/ramp junctions, ramp terminals, merge points).
  - **Roadside Safety:** Locate light towers outside the roadside clear zone and a sufficient distance from the roadway so that the probability of a collision is virtually eliminated. Do not place light towers on the end of long tangents.
  - **Signs:** Locate light towers so that they are not within the driver's direct line of sight to highway signs.

- **Avoidance Issues:** Special attention should be made to avoid underground utilities, drainage structures, overhead utility lines, and clusters of trees.

➢ **Design:** There are generally two methodologies for checking the adequacy of light uniformity: 1) the point-by-point method; and 2) the template method. The point-by-point method checks illumination by using the manufacturer's isolux diagram. The total illumination at a point is determined by the sum of the contributions of illumination from all mast assemblies within the effective range of the point. Due to the numerous calculations, computer software may be used to make these determinations. The template methodology uses isolux templates to determine the appropriate locations for light towers. The templates may be moved around to ensure that the minimum maintained illumination is provided and the uniformity ratio has been satisfied. TDOT recommends the use of the point-by-point method. Consideration should be given to adjacent land use during the design analysis.

➢ **Navigable Airspace:** Where lighting projects are being considered in close proximity to an active airfield or airport, consider the impact the height of the light tower has on navigable airspace. For additional information, consult the *FAA Advisory Circular AC 70/7460-2J Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace*. Consult the federal regulatory agency for design requirements and coordinate this effort with the TDOT Traffic Engineering Office.

15.4.7 Underpass Lighting

Because of their typical configuration and length-to-height ratio, underpasses generally have good daylight penetration and do not require supplemental daytime lighting. Underpass lighting generally is installed to enhance driver visibility after daylight hours. When the length-to-height ratio of the underpass exceeds approximately 10:1, it usually is necessary to analyze specific geometry and roadway conditions, including vehicular and pedestrian activity, to determine the need for supplemental daytime lighting. TDOT recommends analyzing the need to provide underpass lighting on all highways that are continuously lighted. Favorable positioning of conventional highway luminaires adjacent to a relatively short underpass often can provide adequate illumination within the underpass without a need to provide supplemental lighting. If this action is considered, ensure that shadows cast by the conventional luminaires do not become a visibility problem within the underpass.

15.4.8 TDOT Bridge Lighting Plan

- **General Information:** Luminaires mounted on the bridge supports and bridge piers shall be approved by the TDOT Structures Division to verify that the roadway lighting installations can be adequately supported by the bridge structure. Luminaires mounted 45 feet above the pavement on bridges often become inoperable because of excessive vibration from traffic. Therefore, the mounting height for bridge lighting may vary. The light standards may be installed 30 or 35 feet above the pavement if appropriate uniformity ratios can be achieved for that portion of the design. However, if the lighting design warrants, mountings of 40 to 45 feet may be considered. A Bridge Layout Sheet must be prepared for inclusion in the bridge plans when lighting elements either cross or are installed on a bridge. The information may be provided in electronic format or marked up on a bridge layout sheet and given to the appropriate structural designer for his use in completing the bridge plans. Bridge Lighting should:

  - Be installed near piers where possible to prevent vibration;
  - Show conduit and junction boxes installed in parapet walls;
  - Show details for crossing joints.

  All items to be installed as a part of the construction of the bridge are to be included in the Lump Sum Item 714-01 (Structural Lighting). The quantity of individual materials is to be footnoted on the sheet along with instructions to seal any open conduit to prevent moisture from entering. Pole foundation locations are to be noted in the bridge plan. The cost of the foundations will be included in other bridge items and described by a Bridge Standard Drawing. Elements such as supports, wiring and luminaries will be installed later by the lighting contractor and are included in the lighting plans in the appropriate item for each.

- **Bridge Lighting for Structures Submittal:** For overpass and underpass bridge lighting, the lighting designer shall submit the following to structures for inclusion in the bridge plans (See Figures 15.9 and 15.10 for details):

  - Bridge name, site location, and log mile;
  - Structural lighting quantities for each bridge;
  - Locations of all conduit, junction boxes, footings, etc.

- **Bridge Lighting for Lighting Plans:** For overpass and underpass bridge lighting, bridge lighting detail sheets shall be included in the lighting plans. Overpass and underpass lighting is detailed in separate formats as described below:
  - **Overpass Lighting:** For overpass lighting, the lighting plans shall include the following in the “lighting layout” (See Figure 15.11 for details):
    - Pole number and light pole location;
    - Junction box location in parapet wall;
    - Conduit location in parapet wall.
  - **Underpass Lighting:** For underpass lighting, the lighting plans shall show the bridge lighting as part of the lighting layout. In addition, a detail sheet shall be included for the underpass lighting. The detail sheet shall include the following (See Figure 15.12 for details):
    - 1” = 50‘ scale;
    - Number and luminaire location on bridge;
    - Junction box location in parapet wall;
    - Roadside junction box locations;
    - Conduit location in parapet wall;
    - Strapped conduit location on existing bridge;
    - Electrical connection detailed.

Figure 15.9 – Detail of Overpass Bridge Lighting for Submittal to Structures

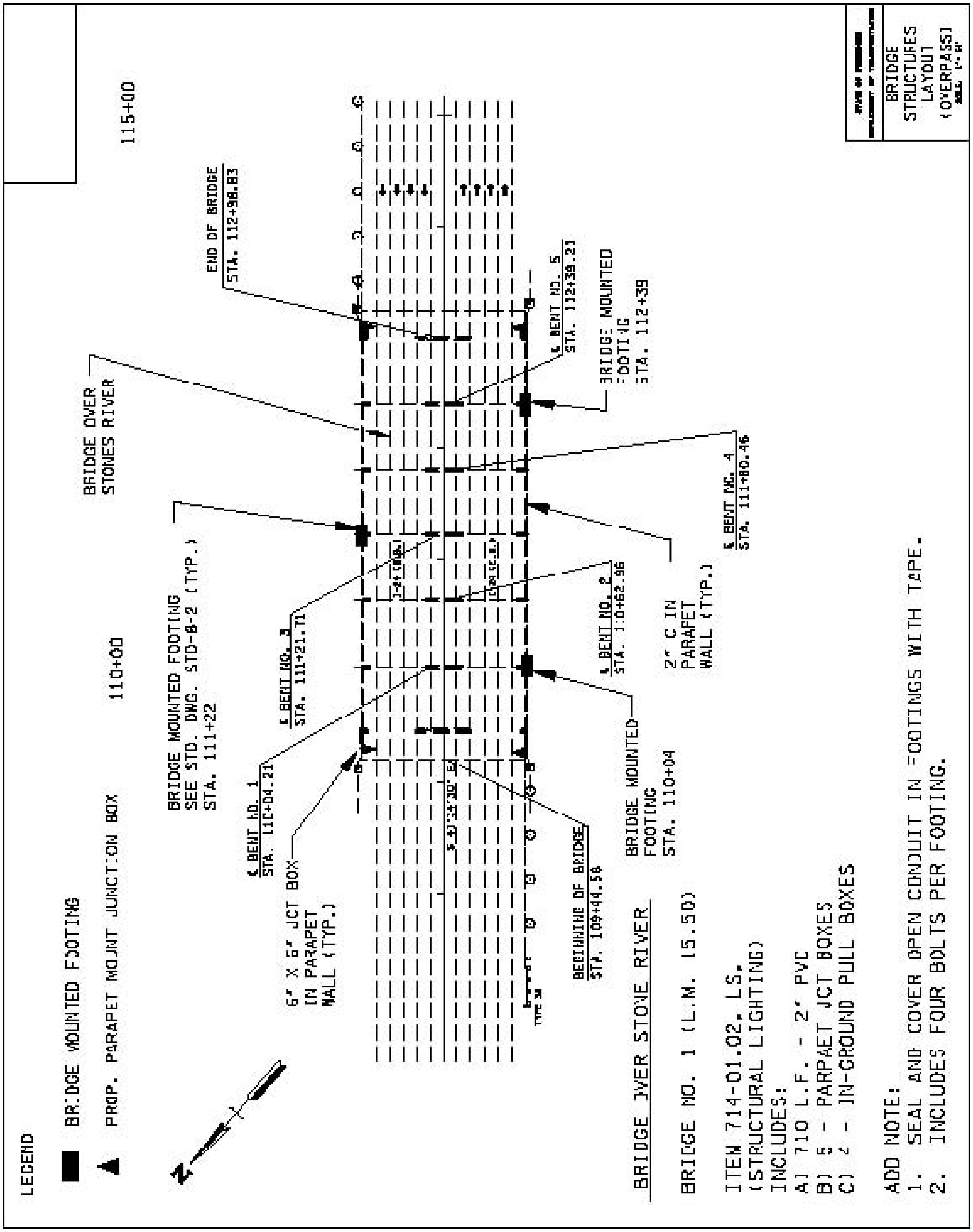


Figure 15.10 – Detail of Underpass Bridge Lighting for Submittal to Structures

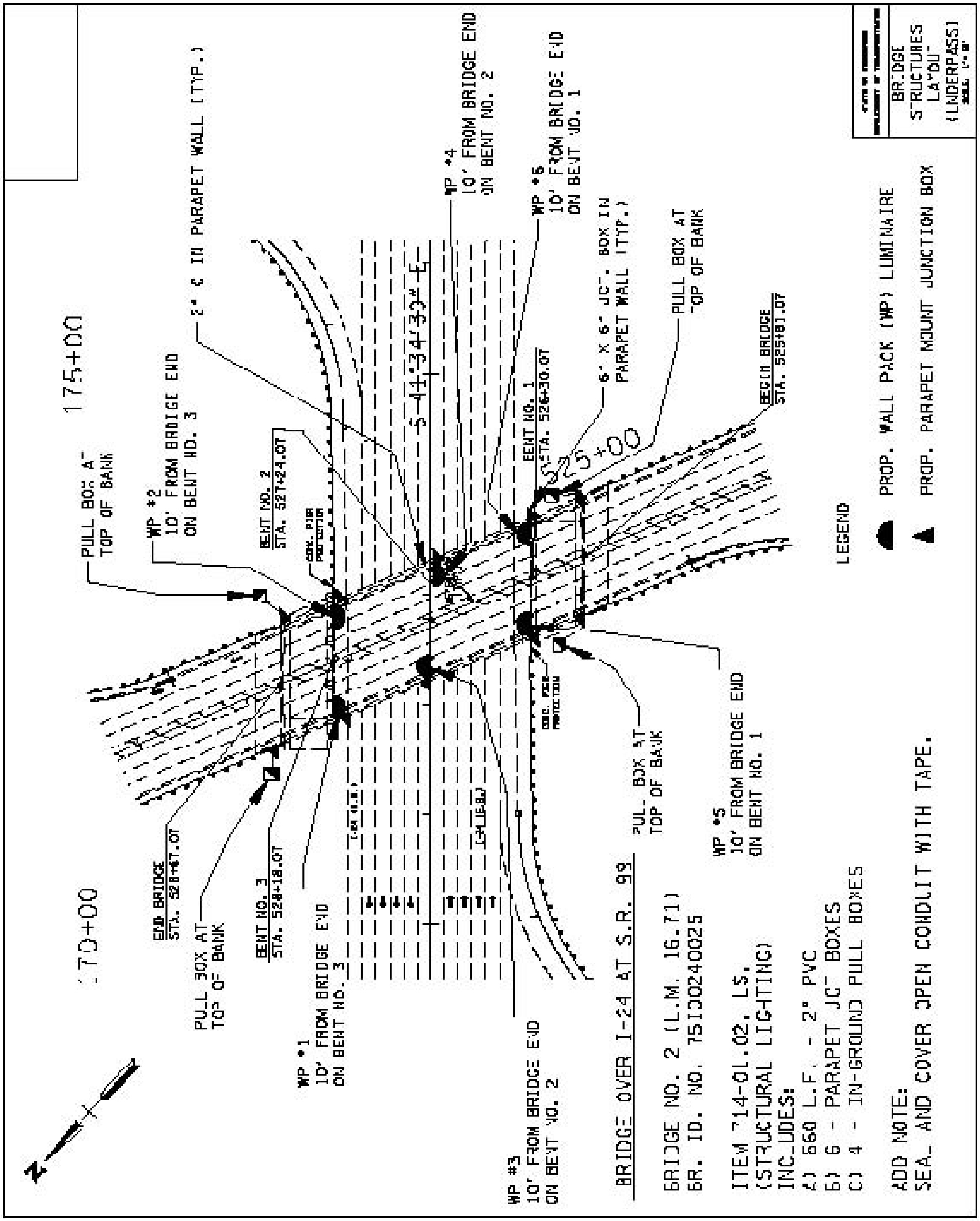


Figure 15.11 – Detail of Proposed Lighting Layout at Bridge Overpass (NTS)

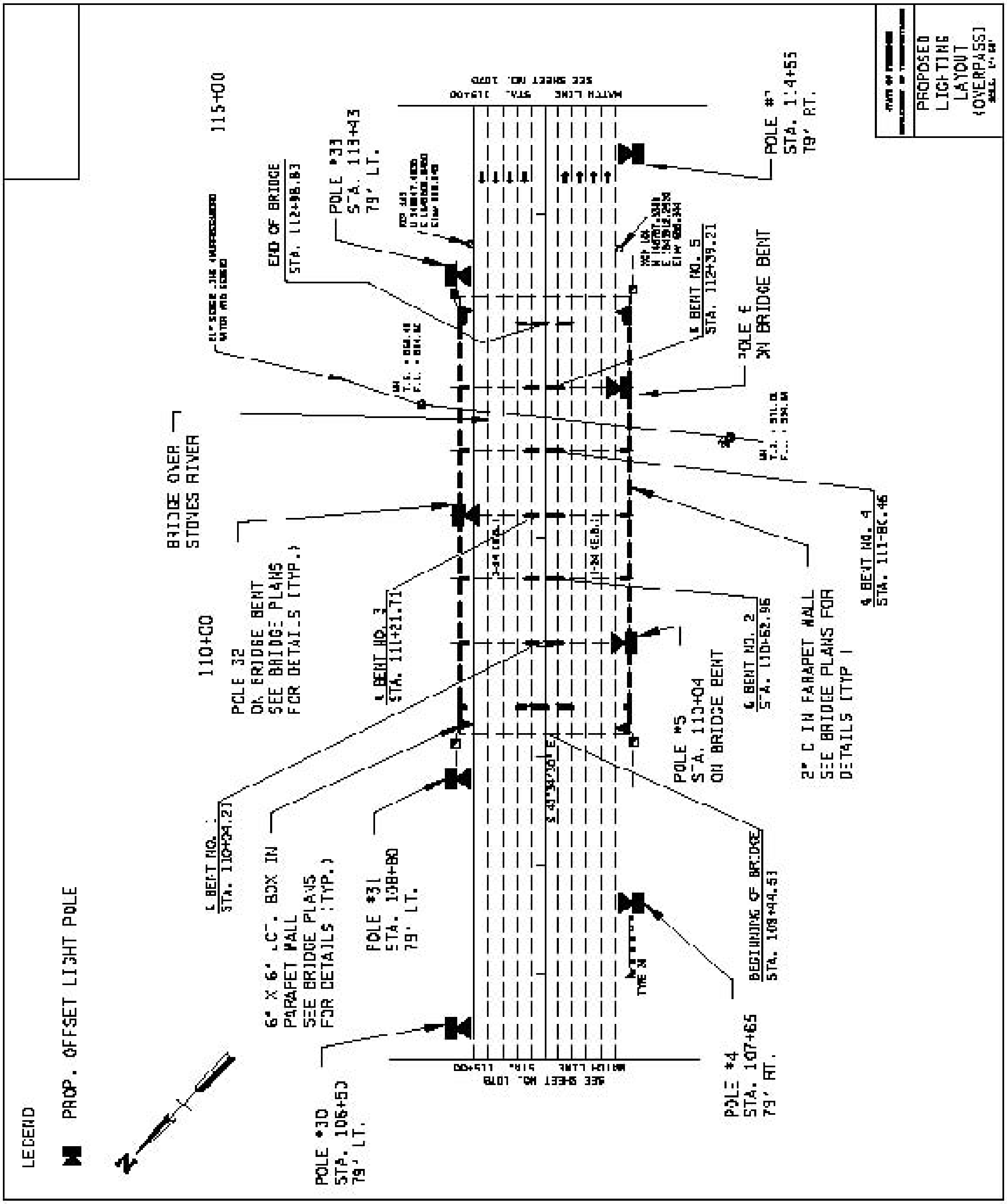
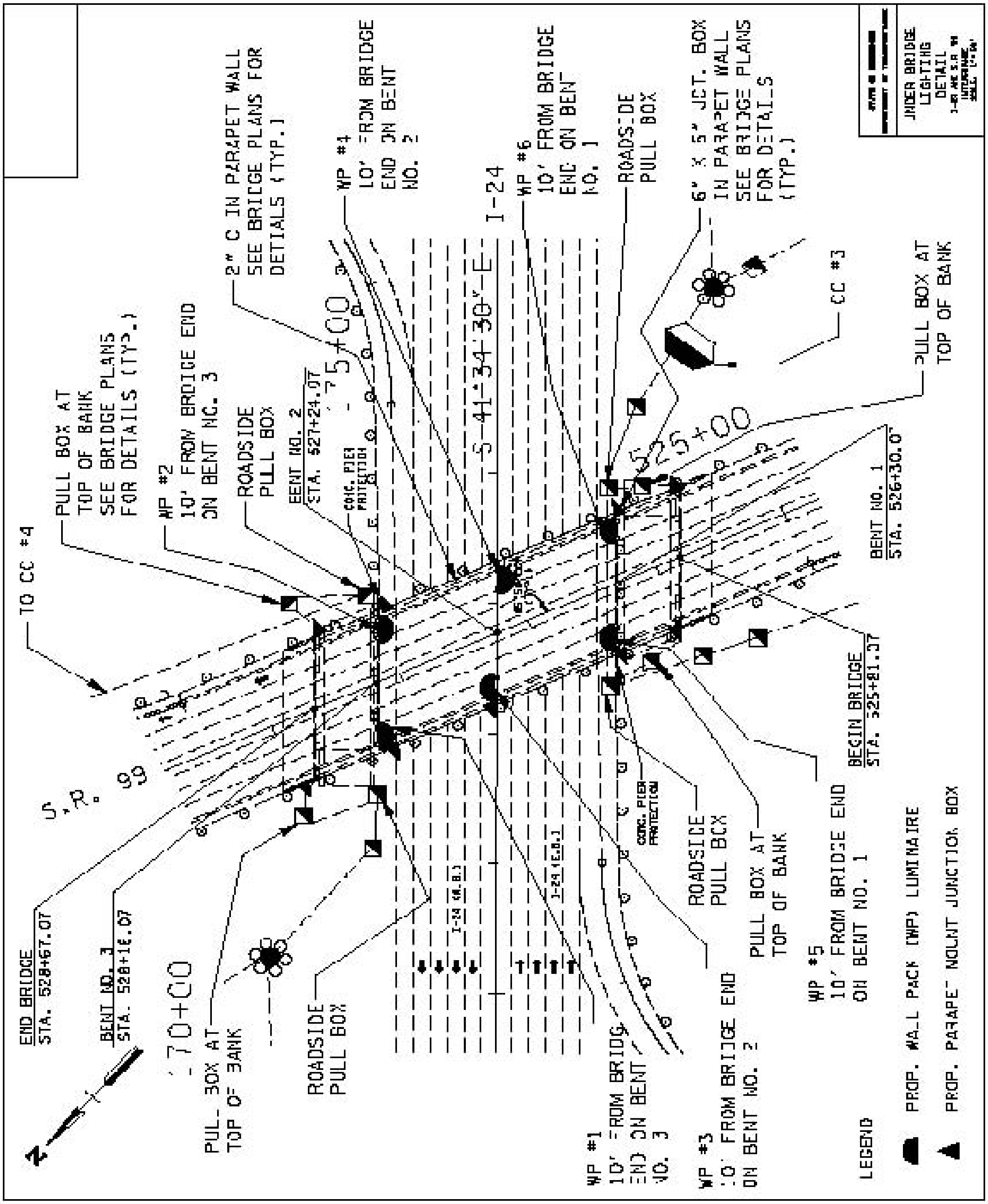


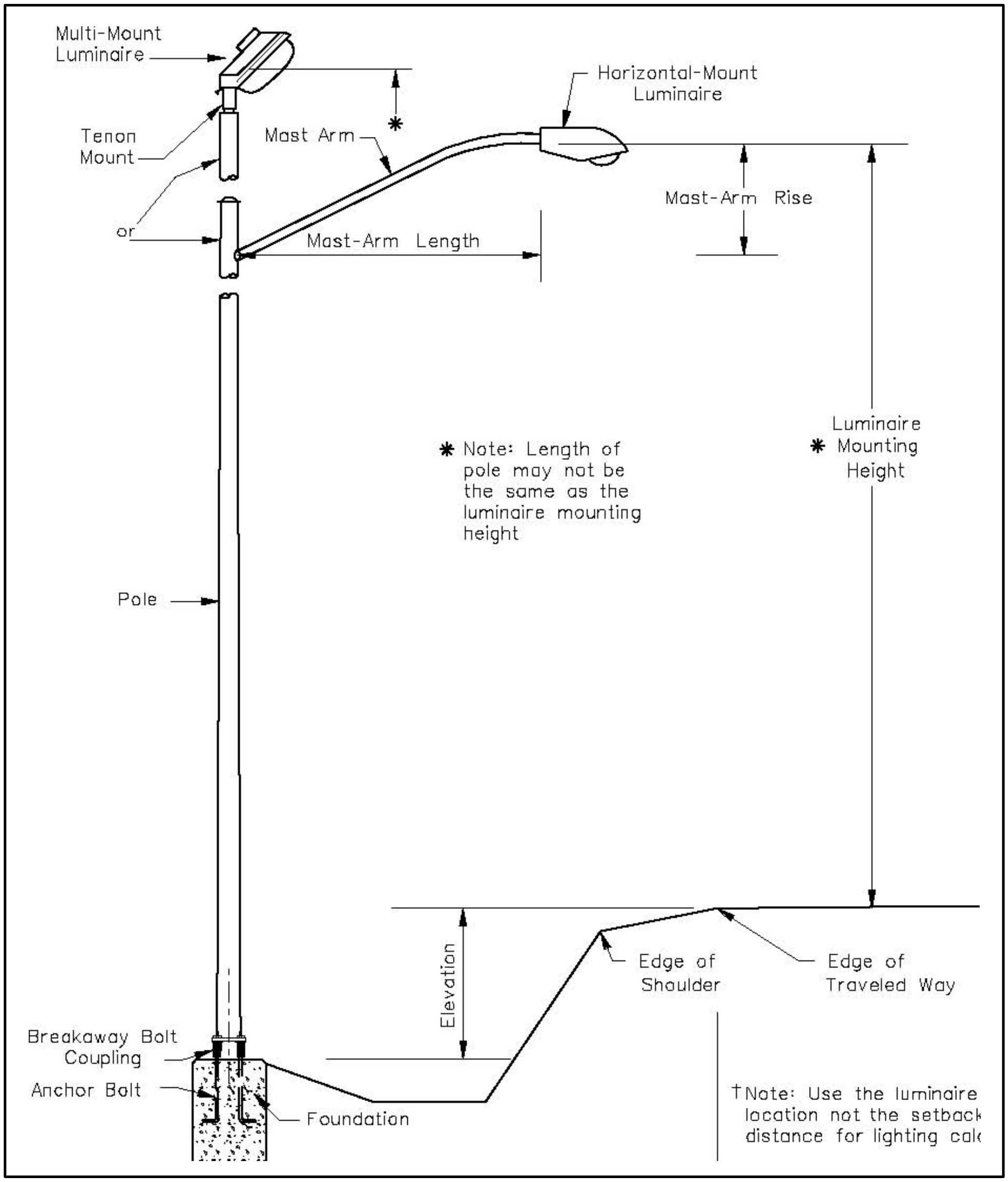
Figure 15.12 – Detail of Proposed Lighting Layout at Bridge Underpass (NTS)



15.5 Materials and Equipment

Because luminaires, electrical devices, and support structures change rapidly with new developments, this section presents an overview rather than an absolute requirement for lighting equipment and materials. See the TDOT *Standard Specifications for Road and Bridge Construction* and TDOT *Standard Drawings* for details on lighting equipment and materials that may be used on projects. This section provides specific design guidance for luminaires, electrical devices, and support structures used by TDOT. Figure 15.13 illustrates the various components of a typical highway lighting structure.

Figure 15.13 – Typical Highway Lighting Structure



Note: Single mast arm/multi-mount luminaire shown for illustrative purposes. For other luminaire mounting types, see the TDOT electric detail sheets, highway standards, and the standard specification.

15.5.1 Foundations and Mounting

In conventional highway lighting applications, luminaire assemblies generally are attached to poles mounted along the roadway either on ground foundations or atop bridge parapets. Supports for conventional light poles may be either reinforced concrete or steel helix foundations and are constructed from typical designs. However, concrete foundations for light towers in high-mast lighting applications require special designs and soil analyses to determine adequate depth and support. Depending on factors such as roadside location, most conventional light poles will be mounted on breakaway devices. Light poles that are mounted atop parapets and barriers are attached using high-strength, non-breakaway bolts. Special vibration isolating materials are used to mount light poles on bridges. At signalized intersections, a roadway luminaire also may be mounted on a combination mast-arm assembly and pole. Luminaires mounted in underpasses and tunnels are either attached directly to the wall adjacent to or hung from vibration-dampening pendants above the travel lanes. Light sources that are used to externally illuminate overhead sign panels typically are fastened to the truss or cantilever support structure. Waterway and aviation obstruction warning luminaires are attached directly to the structures representing the hazard.

15.5.2 Pole Bases

Light poles may be mounted on one of several types of bases (e.g. stainless steel flair base, transformer base, breakaway coupling base, anchor base, butt base). Selection is governed by project need. A very important distinguishing characteristic of the pole base is whether or not it is classified by AASHTO and FHWA as an acceptable breakaway device. If the pole represents a roadside hazard, it will be mounted on a breakaway device (See Section 15.3.5). The following briefly describes the pole bases used by TDOT:

- **Breakaway Bolt Coupling:** Breakaway bolt couplings are connectors or sleeves that are designed to shear when the pole is hit by an errant vehicle. The bottom of each coupling is threaded onto a foundation anchor bolt, and the pole is attached to the top of the coupling. Four couplings are used with each pole. All wiring at the pole base will have quick disconnect splices.
- **Frangible Transformer Base:** The frangible transformer base consists of a cast aluminum apron between the foundation and the base of the pole. It is designed to deform and break away when hit by an errant vehicle. All wiring inside the base will have quick disconnect splices.
- **Anchor Base:** The anchor base consists primarily of a metal plate that is welded to the bottom of the pole. The plate allows the pole to be bolted directly to the foundation using high-strength anchor bolts without an intermediate breakaway connection. The anchor base is not a breakaway device.

15.5.3 Poles

Light poles for conventional highway lighting applications support luminaire mounting heights ranging from approximately 30 feet to 65 feet. They may be fabricated as tapered or straight, single-section poles from materials such as aluminum, galvanized steel, stainless steel, weathering steel, fiberglass, and wood. Light towers for high-mast lighting applications generally range from 80 feet to 160 feet and are designed in multiple sections.

15.5.4 Luminaires

A luminaire is a complete lighting unit consisting of a lamp, or lamps, together with the parts necessary to regulate and distribute the light. The following sections provide some general information on the basic components of the luminaire.

- **Optical System:** The optical system of the luminaire consists of a light source, a reflector, and usually a refractor. The following provides a general discussion on the optical system components:
  - **Light Sources:** There are numerous light sources for highway lighting applications. However, there are only a few practical choices when considering availability, size, power requirements, and cost effectiveness. LED and HID types are used in highway lighting applications. However, fluorescent lamps have been used to illuminate signs. The following provides information on some of the high-intensity light sources used in highway applications:
    - **LED:** LEDs have longer life, saves energy, requires less maintenance, and is environmentally friendly. LED can last for 10 years and longer. Currently, the Department requires a 10 year warranty for all LED luminaires (See Appendix E for LED specifications).
    - **High Pressure Sodium:** HPS lamps have excellent luminous efficiency, power usage, and long life. The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a combination of sodium and mercury vapors.
    - **Low Pressure Sodium:** LPS lamps are considered one of the most efficient light sources on the market. However, the LPS lamp is very long and produces a very pronounced yellow light. Light is produced by passing an electrical current through a sodium vapor.
    - **Metal Halide:** MH lamps produce better color at higher efficiency than MV lamps. However, life expectancy for MH lamps is shorter than for HPS or MV lamps. They also are more sensitive to lamp orientation (i.e. horizontal vs. vertical) than other light sources. MH lamps produce good color

rendition. Light is produced by passing a current through a combination of metallic vapors.MH can be comprised of either probe start or pulse start technologies.

- **Reflector:** The reflector is used to redirect the light rays emitted by the lamp. Its primary purpose is to redirect that portion of light emitted by the lamp that would otherwise be lost or poorly utilized. Reflectors are designed to function alone or, more commonly, with a refractor to redirect the poorly utilized portion of light to a more desirable distribution pattern. Reflectors are classified as either specular or diffused. Specular reflectors are made from a glossy material that provides a mirror-like surface. Diffuse reflectors are used where there is a need to spread light over a wider area.
- **Refractor:** The refractor is another means of optical control to change the direction of the light. Refractors are made of a transparent, clear material, usually high-strength glass or plastic. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light redirected by the reflector. It also can be used to control the brightness of the lamp source.

- **Ballasts:** Some luminaires used in highway lighting applications have a built-in ballast. Ballasts are used to regulate the voltage to the lamp and to ensure that the lamp is operating within its design parameters. It also provides the proper open circuit voltage for starting the lamp. LED has a voltage regulator or driver (See Appendix E for LED specifications).
- **Housing Units:** The housing integrates the lamp, reflector, refractor, and ballast into a self-contained unit. The housing is sealed to prevent dust, moisture, and insects from entering. Air entering the housing for thermal breathing will typically pass through a filter to eliminate contaminates. Housing units are designed to accommodate access for lamp maintenance and adjustment (i.e., light direction and distribution).

15.5.5 Other Materials and Equipment

There are numerous other materials and equipment that are used in a highway lighting system such as quick disconnect fuse holders, controllers, photocells, surge arresters, raceways, ground rods, cabling, transformers, conduit, hand holes, and pull boxes. The use and specification of such ancillary items will depend on the particular highway lighting application and will vary on a project-by-project basis.

15.6 TDOT Lighting Plans Layouts

15.6.1 Plans Preparation

Photometric Plans, Right-Of-Way/Utility Plans, and Construction Plans shall be prepared for all roadway lighting designs. Lighting plans are most often prepared in support of a larger roadway project. It is desirable to have the location of light poles and control centers included in the Roadway Right-Of-Way/Utility Plans submittal. Where it is not feasible, the lighting plans shall be submitted separately through the TDOT Traffic Engineering Office. The lighting designer shall coordinate efforts with the primary roadway designer. The designers shall work together with project scheduling, sheet numbering, review submittals and shall exchange roadway geometric updates throughout all stages of the lighting plans design. All sheets prepared by the lighting designer shall be signed and sealed exclusively by the lighting designer. The following includes sheets that constitute a complete roadway lighting plan and are listed in the order that they should appear in the plans:

- **Title Sheet:** This sheet shall include a reduced scale layout of the overall project showing various circuits, control centers, location of sensitive areas including environmental (streams and wetlands), residential, military and airport facilities.
- **Estimated Roadway Quantities, Notes and Standard Drawings:** For lighting projects prepared in conjunction with a roadway project, the tabulation of quantities, notes and footnotes to quantities, and the listing of standard drawings the shall be included on one sheet. This sheet shall be submitted for inclusion with the roadway plan as a second sheet. For standalone lighting projects, the standard drawings, tabulated quantities, and notes shall be prepared on separate sheets.
- **Special Notes:** Special notes for standard lighting designs may be included on the general notes sheet. Special notes for high mast lighting shall be included on a separate sheet in the second sheet series.
- **Control Center Details:** This sheet shall include details for the wiring schematic, notes, and control center mounting detail (pad or pole mounted).
- **Lighting Details:** This mandatory sheet shall include a separate table for the light pole schedule and wire/conduit schedule. The light pole schedule shall include the pole location, mounting height, number and fixture type, control center number and circuit number. The wire/conduit schedule shall include the quantity and size of each cable running through each conduit. Spare conduit shall also be included in this table.
- **Special Lighting Details:** This sheet shall include details of special fixtures or other non-standard TDOT items clearly identified and detailed.
- **Lighting Layout Sheets:** For large projects, a lighting layout sheet shall be included. This sheet shall show coverage of the entire project with each

proposed lighting layout sheet and the corresponding sheet number identified.

- **Proposed Lighting Layout Sheets:** These sheets should be developed as follows:
    - The plans should be designed for 1 inch = 50 feet scale for straight and curved roadway lengths and 1 inch = 100 feet scale for interchanges;
    - A separate plan sheet with tables showing, but not limited to: the pole mounting height, luminaire type and wattage, conduits, and circuitry shall be provided;
    - The location of lighting standards in relation to the proposed roadway. Each standard shall be flagged to note the pole number, station, coordinates, offset, and pole height if it varies;
    - All conduits and wiring shall be shown and labeled as per the wire/conduit schedule. Special conduit for jack and bore, stream crossings, under road rigid conduit and otherwise shall be clearly identified;
    - All control centers shall be located and numbered, and the power source location shall be identified. A separate plan sheet detailing the control center and its circuitry, wire/conductor size, and the electric feed point shall be provided;
    - Under bridge lighting shall be shown with location of circuitry. A special detail sheet at a larger scale may be required to clarify the under bridge lighting system;
    - North arrow, legend and road names shall be on all layout sheets.
- **Underpass Lighting Details:** This sheet shall be done at a larger scale to clearly depict the underpass lighting system. The detail shall label the underpass fixture and number, conduit and junction boxes in bridge parapet, and the service connection. Refer to Figure 15.12 for under bridge lighting details.
- **Bridge Layout Sheets:** It shall be the responsibility of the structural designer to include the lighting information provided by the lighting designer in the bridge layout sheets. The lighting designer shall provide the lighting design information to the TDOT Structures Division as depicted in Figure 15.9 and Figure 15.10. The bridge layout sheets shall be signed and sealed exclusively by the structural designer
- **Bore Locations and Geotechnical Notes:** For lighting designs that include high mast lighting, a bore location and geotechnical notes sheet shall be included in the lighting plans. This sheet shall depict the bore locations and numbers, geotechnical notes, and parameters used for the design of the high mast foundation.

- **Bore Log Details:** For lighting designs that include high mast lighting, a bore log details sheet shall be included in the lighting plans. This sheet shall show information obtained from each bore log, and includes, but is not limited to, bore depth, sample number, blow counts, N-value, soil description, SPT N-value, water levels and any other information pertinent to the design of the high mast pole foundation.
- **Foundation Details:** For lighting designs that include high mast lighting, a foundation details sheet shall be included in the lighting plans. This sheet shall include, but is not limited to, foundation design information such as footing dimensions, notes, materials description, and design criteria used for a complete foundation design. If the foundation can be constructed as per the standard drawings, this sheet may be eliminated.

15.6.2 Photometric/Preliminary Plans Preparation

The Designer shall prepare all components necessary for photometric/ preliminary plan submittal. The Designer shall submit, to the TDOT Design Manager, the plan sheets showing the overall project. Ensure that the photometric/preliminary plans include:

- Stationing at appropriate intervals and stationing of noses and tangent points of ramps which are formed by the roadway proper and not by the shoulder;
- Pavement, shoulder, and median widths at frequent intervals;
- All roadway features which may affect the stationing or setback of poles (e.g., guardrail, barrier median, barrier curb, signs exceeding 50 feet, driveways, culverts, railroads, pipelines);
- The approximate height of any power and telephone lines over the roadway;
- The location of power poles from which service may be obtained;
- If signals are present or proposed, the location of the signal pole, power pole and control cabinet;
- Point-by-point photometric values shown on a layout sheet shall be clearly legible for the reviewer;
  - For conventional lighting, the point-by-point grid size should be a maximum of half the distance of the lane width by ten to 20 feet along the roadway length (e.g. for a 12-foot lane, the grid size should be six feet x ten feet);
  - For high mast lighting, the point-by-point grid size should be a maximum of the lane width by 20 feet along the roadway length (e.g. for a 12-foot lane, the grid size should be 12 feet x 20 feet);

- The photometric/preliminary plans shall be designed to TDOT Survey and Design CADD Standards. Section 15.6.4 describes additional drafting standards;
- Plan preparation checklists are listed in Section 15.6.7;
- Plans and Work File submittals are discussed in Section 15.6.6.

15.6.3 Photometric/Preliminary Plan Review

Upon receipt of the photometric/preliminary plans, the TDOT Design Manager shall verify the location of poles and luminaires. This will include cross-referencing results from the photometric design Input and output work files to the preliminary design work files (MicroStation) and verifying that they match the layout sheets submitted. Once the working files are reviewed and the lighting design is found to meet the lighting design criteria, the TDOT Design Manager shall approve the photometric/preliminary plans. The TDOT Design Manager shall have up to one month to review, evaluate and provide comments on the existing lighting conditions (when applicable) and the proposed lighting design prior to commencement of the right-of-way/utility plans.

15.6.4 Lighting Computer-Aided Design Drafting Standards

Lighting plans shall follow the TDOT Survey and CADD Standards. The following details additional lighting design criteria that will aid to maintain uniformity in all lighting plans submitted to TDOT:

- Lighting plans layout sheets shall be scaled to 1 inch = 50 feet for straight and curved roadway lengths and 1 inch = 100 feet for interchanges;
- Conventional light poles shall be numbered as 1, 2, etc.;
- High mast poles (i.e. tower poles) shall be numbered as HM1, HM2, etc.;
- Control centers shall be numbered as CC1, CC2, etc.

15.6.5 Site and Field Reviews

- **Site Reviews:** A very necessary, but sometimes overlooked, part of a complete lighting design is the need for site reviews. The number of site reviews will be dependent on the complexity of the project. It is prudent that the lighting designer have at least one site review. The following benefits may be obtained through site reviews:
    - Site reviews can provide information that is not always visible from the survey, e.g., structures such as large trees, clusters of trees, ditches and steep slopes. The lighting designer should be aware of the location of these obstacles to avoid pole placement in their vicinity. Removal of vegetation and trees should be considered only as a last resort;

- The lighting designer can get a better idea of the magnitude and proximity of overhead obstructions, hazards or structures to the roadway;
- Site reviews can provide a better understanding of the neighborhood and other environmental issues that may factor into pole/fixture selection and placement;
- Site reviews clearly show the roadway configuration. This will enable the designer to determine the lighting design criteria specific to the roadway configuration;
- Site reviews will enable the lighting designer to select potential service point locations by identifying power sources throughout the immediate project area;
- Site reviews will enable the lighting designer to verify that the locations of proposed poles are not in conflict with existing or proposed utilities, and at-grade and aerial roadway structures.

➢ **Field Review:** Prior to finalizing plans, the lighting designer should conduct a field review to determine if proposed pole and luminaire locations will interfere with existing or proposed underground utilities, and at-grade and aerial roadway structures.

➢ **High Mast Lighting:** On high mast lighting design projects, it may be necessary for both the lighting designer and the geotechnical engineer to simultaneously conduct a field review to finalize pole locations. This will ensure that the lighting designer and geotechnical engineer are in agreement with the location at which the bores will be performed.

15.6.6 Photometric Plans and Work Files Submittal

For Photometric/Preliminary Plan, Utility Plan, Right-of-Way Plan, and Construction Plan submittal, the lighting designer is required to provide specific files such as the AGI32 and Visual electronic files to the TDOT Traffic Engineering Office. These files shall follow the naming convention set forth in the Survey and Design Computer-Aided Drafting Standards. In addition, the working units for all files shall coincide with the working units set forth in the Survey and Design Computer Aided Drafting Standards.

15.6.7 Lighting Design Checklists

In order to reduce plan revisions, errors, and standardize the preparation, format and content of plans, Lighting Design Checklists (See Appendix E) should be used by all designers, consultants, and personnel checking plans. These forms should be used on all lighting projects. The procedure for use of the form is as follows:

- Fill in the heading information on each sheet;
- The designer or project supervisor will check off each blank with their initials (legible) when sure that each item is completed on the plans. N/A may be used if an item is not required in a project;
- Before submitting plans for a field review, the checklist shall be completed down to that particular stage of plans development; and
- These checklists are intended as a design aid.

TRAFFIC DESIGN MANUAL APPENDICES

Traffic Operations Division
Traffic Engineering Office

August 2018

[This page intentionally left blank.]

TRAFFIC DESIGN MANUAL

APPENDIX A

Traffic Impact Study Forms

Traffic Operations Division
Traffic Engineering Office

Traffic Study Report Recommended Outline

- **Title Page**
- **Table of Contents**
- **Executive Summary**
- **Introduction**
  - Figure with Study and Development Location
- **Study Analysis Considerations**
  - Figure Showing Study Area Limits
- **Existing Traffic Conditions**
  - Figures Showing Geometrics
  - Figures Showing Peak Hour Traffic Volumes
  - Figures Showing LOS Results
- **Background Traffic Development and Growth Calculations**
  - Figures Showing Background Traffic Volumes (Optional)
- **Future Traffic Conditions Without Project**
  - Figure Showing Future Traffic Volumes Without Development
  - Figures Showing Los Results
- **Site Traffic Conditions**
  - Table Presenting Trip Generation Methodology
  - Figures Showing Trip Distribution and Assignment Methodology
- **Future Traffic Conditions with Development**
  - Figures Showing Traffic Volumes with Development
  - Figures Showing LOS Results
- **Summary Of Findings**
  - Table Presenting the Comparison Results Between Future Traffic Results
  - Table Presenting Mitigation Measures
- **Recommendations**
  - Table Presenting Mitigation Methods with Percentage Responsibility
- **Typical Appendices**
  - Appendix A - Traffic Study Screening Evaluation Form
  - Appendix B - Traffic Study Scoping Meeting Minutes
  - Appendix C - Existing Traffic Counts
  - Appendix D - Proposed Development Support Information
  - Appendix E - Multi-Way Stop Control Warrants Analyses (if Applicable)
  - Appendix F - Traffic Signal Warrants Analyses (if Applicable)
  - Appendix G - Other Traffic Analyses (if Applicable)
  - Appendix H – Software Analysis Results

TN TDOT Department of Transportation

TDOT TRAFFIC IMPACT STUDY SCREENING EVALUATION FORM

In advance of requesting a Traffic Study Scoping Meeting, this form shall be submited to the TDOT Regional Traffic Engineer to help determine if a traffic study is warranted, and if so, the type of traffic study that is required. If required, the TDOT Regional Traffic Engineer will notify the applicant/project developer to schedule a traffic study scoping meeting.

Note: The gray areas on this form are to be completed by TDOT.

Proposed Development			
Name:		Date Submitted:	
Location:		Reference Number(s):	

Applicant/Project Developer		Traffic Study Preparer	
Name:		Name:	
Phone:		Phone:	
Email:		Email:	

Has another traffic study been prepared at this location within the past 3 years?		Yes	If Yes →	Date:	
		No		Reference Number(s):	

Note: If needed, use additional sheet & attach	Zoning District (List Each District)	Land Use (List Each Use)	Project Size (SF, Units, Etc.)	Peak Hour Trips AM	Peak Hour Trips PM	Daily Trips
Existing						
Total						
Proposed						
Total						
Proposed Net Increase/Decrease (+/-) →						

Traffic Study Screening Thresholds	Level 1 Traffic Impact Study	Level 2 Traffic Impact Study	Level 3 Traffic Impact Study	Level 4 Traffic Impact Study
	50-99 new pkhr trips or 250-499 new daily trips	100 to 249 new pkhr trips or 500 to 2,999 new daily trips	250-399 new pkhr trips or 3,000-5,999 new daily trips	≥400 new pkhr trips or ≥6,000 new daily trips

Evaluated By						
Recommendation (Circle One)	Traffic Study Not Required	Level 1 - Traffic Impact Study	Level 2 - Traffic Impact Study	Level 3 - Traffic Impact Study	Level 4 - Traffic Impact Study	
Printed Name:			Comments:			
Signature:						
Date:						

[This page intentionally left blank.]

TRAFFIC DESIGN MANUAL

APPENDIX B

Traffic Signal Forms

Traffic Operations Division
Traffic Engineering Office

CONTROLLER TIMINGS	TIMING FUNCTION							
TIMING INTERVAL	1	2	3	4	5	6	7	8
MINIMUM GREEN (INITIAL)								
EXTENSION (PASSAGE)								
MAXIMUM GREEN I								
MAXIMUM GREEN II								
YELLOW CLEARANCE								
ALL RED CLEARANCE								
PEDESTRIAN WALK								
PEDESTRIAN CLEARANCE								
PREEMPTION MINIMUM GREEN								
PREEMPTION CLEARANCE								

COORDINATION UNIT

DIAL NO.	CYCLE LENGTH	OFFSET 1	OFFSET 2	OFFSET 3	CYCLE SPLIT	SECONDS / TIME INTERVAL															
					1																
					2																
					1																
					2																
					1																
					2																
					1																
					2																
					INTERVAL FUNCTION																
					INT. NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

INTERSECTION:____________________

____

FORCE OFFS

F.O. 1 =____________________

F.O. 2 =____________________

F.O. 3 =____________________

BASE DAY ____ PROGRAM

CHANGE POINTS	OUTPUT									
HOUR-MIN	1	2	3	4	5	6	7	8	9	0
MIDNIGHT 00-00										

OUTPUT ASSIGNMENTS

X = ON

1) FLASH OR AUX
2) DIAL 2
3) DIAL 3
4) DIAL 4
5) INBOUND OFFSET
6) HEAVY INBOUND
7) OUTBOUND
8) HEAVY OUTBOUND
9) USER PROGRAMMABLE - SEE LIST OF OPTIONAL MODES.
0) FREE OR AUX.

DIAL 5 = 2) + 4)

DIAL 6 = 3) + 4)

NOTE: NO OUTPUT = DIAL 1, AVG. SPLIT, AVG. OFFSET.

WEEKLY PROGRAM PLAN

PLAN NO.	DAY OF WEEK						
	SUN	MON	TUES	WED	THU	FRI	SAT
	1	2	3	4	5	6	7
0							
1							
2							
3							
4							
5							
6							
7							
8							
9							

INSERT BASE DAY NUMBER IN APPROPRIATE BOX

WEEK OF YEAR ASSIGNMENT

WK. OF YEAR	*WEEKLY PLAN	WK. OF YEAR	*WEEKLY PLAN
1		27	
2		28	
3		29	
4		30	
5		31	
6		32	
7		33	
8		34	
9		35	
10		36	
11		37	
12		38	
13		39	
14		40	
15		41	
16		42	
17		43	
18		44	
19		45	
20		46	
21		47	
22		48	
23		49	
24		50	
25		51	
26		52	

NOTE: WITH NO PLAN LOADED, UNIT WILL AUTOMATICALLY ASSIGN PLAN 0.

* ONLY ONE PLAN NUMBER PER WEEK OF YEAR.

CONTROLLER TIMINGS

TIMING INTERVAL	TIMING FUNCTION 1	2	3	4	5	6	7	8
MINIMUM GREEN (INITIAL)								
EXTENSION (PASSAGE)								
MAXIMUM GREEN I								
MAXIMUM GREEN II								
YELLOW CLEARANCE								
ALL RED CLEARANCE								
PEDESTRIAN WALK								
PEDESTRIAN CLEARANCE								
PREEMPTION MIN. GREEN								
PREEMPTION CLEARANCE								

COORDINATION UNIT

DIAL NO. TIME	CYCLE LENGTH	OFFSET 1	OFFSET 2	OFFSET 3	CYCLE SPLIT	TIME INTERVAL (SECONDS)															
1					1																
AM PEAK					2																
2					1																
OFF PEAK					2																
3					1																
PM PEAK					2																
4					1																
					2																

INTERSECTION

____

____

____

FORCE OFFS	
1	
2	
3	
4	

INTERVAL FUNCTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

TRAFFIC SIGNAL REMOVAL ANALYSIS WORKSHEET

SECTION I - INTERSECTION INVENTORY

Intersection: ______________________ **Date:** ____________

City/County/State: ______________________

Major St.: ______________ **Lanes/Approach:** ______ **ADT:** ________

Minor St.: ______________ **Lanes/Approach:** ______ **ADT:** ________

Major Street Speed Limit (mph): ________ **Direction (circle one)** NB/SB EB/WB

Side-Street Sight Distance (feet): ________ **Direction (circle one)** NB SB EB WB

Side-Street Sight Distance (feet): ________ **Direction (circle one)** NB SB EB WB

SECTION II - PRELIMINARY SCREENING

1. **Minimum Required Intersection Sight Distance Required (feet):**

   Turning Left ________ Crossing Thru ________ Turning Right ________

   Is the Intersection Sight Distance Less Than Minimum?
   ☐ Yes ☐ No

2. **Do Special Site Conditions Make Signal Removal Institutionally Infeasible?**
   ☐ Yes ☐ No

   Comments: ______________________

   ____

3. **Does Existing (or Future) Traffic Satisfy the MUTCD Signal Installation Warrants?**
   ☐ Yes ☐ No **At Least 50% Volume Warrants Satisfied?** ☐ Yes ☐ No

4. **Did Any Special Reasons Justify Signal Installation?**
   ☐ Yes ☐ No

   Are These Reasons Still Valid?
   ☐ Yes ☐ No

   Comments: ______________________

   ____

TRAFFIC DESIGN MANUAL

APPENDIX C

Traffic Signal Installation Inspection Forms

Traffic Operations Division
Traffic Engineering Office

SHEET 1 OF 3

TRAFFIC SIGNAL INSTALLATION - PRELIMINARY HARDWARE INSPECTION CHECKLIST

AGENCY / CONTRACTOR LOGO	
	INTERSECTION LOCATION:
	DATE:
	CONTRACTOR:
	INSPECTOR:

PULL BOXES

ACCEPT	DECLINE	N/A	
			1 Check size, type and location as detailed in the plans and specifications, or "as builts"
			2 Check pull box is leveled, flush with ground or sidewalk (not on street or driveway)
			3 Check for at least 12 inches of gravel in the bottom of the box (drainage)
			4 Check pull box cover – metal or fiberglass
			5 Check pull box cover – labeled "TRAFFIC SIGNAL"
			6 Check for spare length of cables inside pull box
			7 Check for sodding or seeding around pull boxes being completed
			8 Check if splice wires (if spliced) in pull boxes are labeled
			9 Check if proper splicing method used in each pull box
			10 Check for no splices in any pull box for video or opticom cabling (if used)

CONDUITS

ACCEPT	DECLINE	N/A	
			11 Check size and type as detailed in the plans and specifications
			12 Check if conduits are at proper height inside pull box
			13 Check for conduit terminations to be free of sharp edges
			14 Check for bushings, if metal conduit

POLES AND PEDESTALS

ACCEPT	DECLINE	N/A	
			15 Check for proper type as detailed in the plans
			16 Check for proper position as detailed in the plans
			17 Check for proper grade as detailed in the plans
			18 Check for proper height as detailed in the plans
			19 Check that the load face of the pole is oriented towards the load
			20 Check for proper clearance from overhead utilities and cables
			21 Check anchor bolt size, number and placement
			22 Check that anchor bolts are cut with footcovers installed and secured
			23 Check for extra conduit being placed in pole foundation
			24 Check for concrete being completed around poles and pedestals
			25 Check for caps being in place to prevent water from entering the poles/pedestals
			26 Check for all openings on pole/pedestal being plugged if not used
			27 Check for wiring inside handholes with proper splicing method
			28 Check for all handhole covers being in place for pole/pedestals
			29 Check for ground rod being installed at each pole/pedestal
			30 Check for monkey face to be installed on each weatherhead
			31 Check for loop & signal wiring being labeled (only if spliced) inside handholes
			32 Check for no splices in opticom cabling or video cabling (if used)

COMMENTS

SHEET 2 OF 3

LOOP DETECTION

ACCEPT	DECLINE	N/A	
			75 Check if loops are located as per plan
			76 Check if loops are correct size as per plan
			77 Check if loops are sealed properly in roadway
			78 Check for correct wiring and splicing (if spliced) at pull boxes

VIDEO DETECTION

ACCEPT	DECLINE	N/A	
			79 Check if detection zones are located as per plan
			80 Check if video cameras meet minimum height requirements (24 ft)
			81 Check if equipment is securely fastened
			82 Check if correct IMSA cabling is used
			83 Check that video cable is routed neatly and secured properly

SIGNS

ACCEPT	DECLINE	N/A	
			84 Check if span and pole mounted signs are located as per plan
			85 Check if span and pole mounted signs have correct lettering and/or symbols as per plan
			86 Check if sign saddles are tight with lockwasher(s) in place
			87 Check if signs are properly attached to tethers with lockwasher(s) in place
			88 Check if signs are in alignment with proper lane(s)
			89 Check if signsdo not restrict view of any signals

PREEMPTION EQUIPMENT

ACCEPT	DECLINE	N/A	
			90 Check if detectors, confirmation lamps, and beacons are located as per plans
			91 Check if detectors have weep holes opened on each unit
			92 Check if detectors are aligned properly, both horizontally and vertically with roadway
			93 Check if the correct attachment hardware is used on all detectors and confirmation lamps
			94 Check if locking rings on confirmation lamps and detectors are tightened

PAVEMENT MARKINGS

ACCEPT	DECLINE	N/A	
			95 Check if correct material is used on stripping (Thermoplastic)
			96 Check if all crosswalks are located as per plan
			97 Check if all stop lines are located as per plan
			98 Check if all lane stripping are located as per plan
			99 Check if gore markings, if used, are located as per plan

FIBER OPTIC CABLING

ACCEPT	DECLINE	N/A	
			100 Check if fiber optic routing located as per plan
			101 Check if overhead cabling (if routed) is secured with proper hardware
			102 Check if cabling meets minimum bend radius requirements throughout according to specifications
			103 Check if specified cabling is used as per plan and marked on outer jacket
			104 Check if proper splicing method used in each pull box (if used)
			105 Check if proper amount of slack is provided in pull boxes and at cabinet
			106 Check if proper tracer is provided (minimum 14 gauge) on in ground conduits

MISCELLANEOUS

ACCEPT	DECLINE	N/A	
			107 Check that overhead service wire meets the pole at a point that is less than 2 feet from the weatherhead
			108 Check if overhead cabling (if routed) is secured with proper hardware

COMMENTS

INSPECTOR SIGNATURE: ____________________

SHEET 3 OF 3

CABINET

ACCEPT	DECLINE	N/A	
			33 Check that cabinet is leveled and sealed at the base
			34 Check that concrete is completed around cabinet base and pad
			35 Check that cabinet bolts are tight
			36 Check that ground rod is present and wired to ground buss
			37 Check that future conduit is installed in cabinet base (one required)
			38 Check that all cabling entering and exiting the cabinet meets IMSA specs
			39 Check that conduits, if metal, have bushings installed
			40 Check that service wires are neatly routed and phased properly to neutral buss and breaker
			41 Check that serviced wires are phased properly at top of pole or from pull box
			42 Check that AC power is present at breaker in the cabinet
			43 Check that banana plug is present inside police panel
			44 Check that conflict monitor is inside the cabinet
			45 Check that cabinet wiring is neat and all wires from the field are labeled
			46 Check that cabinet has sticker "Call Before You Dig"

SIGNALS AND SPANS

ACCEPT	DECLINE	N/A	
			47 Check that signal heads are located as per plans
			48 Check that signal heads are no lower than 17'6" & plumbed with ground
			49 Check for proper clearance from overhead utilities and cables
			50 Check that pole/pedestal mounted signals are no lower than 10' and aligned with appropriate lanes
			51 Check that pole/pedestal mounted signals are banded properly
			52 Check that no open holes on any signal sections exist
			53 Check that rubber grommets are in place on all goosenecks
			54 Check that saddles are tight with lockwasher(s) in place
			55 Check that goosenecks are tight with cotter pin and set screw in place
			56 Check for correct drip loops for goosenecks
			57 Check that metal plates have been installed and bolted in red sections on span mounted signals
			58 Check that tether bracket(s) in green sections are tight with lockwasher in place
			59 Check that pipedowns are painted and all associated hardware is tight, set screws in place
			60 Check that backplates are properly installed
			61 Check that correct lashing rods are used throughout installation
			62 Check that signal heads are wired and terminated properly
			63 Check that drip loops are in place neatly with tie wraps
			64 Check that span wires are attached properly at poles
			65 Check that insulators (if used) are installed below utility primary lines
			66 Check that spans are grounded to poles and terminated properly
			67 Check that deadends are closed at tethers and spans
			68 Check that thimbles are used at tether brackets mounted to poles
			69 Check that tethers are tighten with minimum slack

PEDESTRIAN SIGNAL HEADS AND PUSHBUTTONS

ACCEPT	DECLINE	N/A	
			70 Check if pedestrian displays are mounted at the proper height (minimum 8')
			71 Check if pedestrian pushbuttons are the proper type according to plans
			72 Check if pedestrian pushbuttons are mounted at the proper height (minimum 3'6")
			73 Check if pedestrian placards are the correct type and positioned properly
			74 Check for no open holes on pedestrian indications

COMMENTS

SHEET 1 OF 2

TRAFFIC SIGNAL INSTALLATION - ACTIVATION DAY INSPECTION CHECKLIST

AGENCY / CONTRACTOR LOGO	INTERSECTION LOCATION:	
	DATE:	ACTIVATION TIME:
	CONTRACTOR:	
	INSPECTOR:	

CABINET

ACCEPT	DECLINE	N/A		
			1 Signal timing received from Traffic Engineer	DATE:
			2 Signal timing properly installed on traffic signal controller	DATE:
			3 Check that cabinet prints are provided and in place in the cabinet	
			4 Check that equipment manuals are provided and in place in the cabinet	
			5 Check that intersection plans or "as built" plans are provided and in place in the cabinet	
			6 Check that timing directives are provided and in place in the cabinet	
			7 Check that program card has all jumpers soldered in proper place	
			8 Check that conflict monitor flash time is set for 10 seconds	
			9 Check that cabinet has been "flashed out" for conflict monitor verification	
			10 Check that all load switches are in place	
			11 Check that cabinet fan is operational via thermostat	
			12 Check that special detectors are wired correctly on "D" connector	
			13 Check that all wires are routed neatly, tie wrapped and labeled properly (signal, detection, etc)	
			14 Check that signal wiring is terminated properly on field terminal strip and at busses	
			15 Check that battery backup system is operational with utility power failure	
			16 Check that cabinet keys have been provided	
			17 Check that cabinet lights are working properly	
			18 Check that all cabinet door switches operate properly	

SIGNALS AND SPANS

ACCEPT	DECLINE	N/A	
			19 Check that the correct indications are displayed
			20 Check that intersection flashes as per print/time sheet

PEDESTRIAN SIGNAL HEADS AND PUSHBUTTONS

ACCEPT	DECLINE	N/A	
			21 Check that pedestrian indications are clearly visible at any point within appropriate crosswalk area
			22 Check that pedestrian detection is calling proper phase

LOOP DETECTION

ACCEPT	DECLINE	N/A	
			23 Check that detection loops lead in is twisted in the cabinet
			24 Check that vehicle detection is calling proper phase

COMMENTS

SHEET 2 OF 2

VIDEO DETECTION

ACCEPT	DECLINE	N/A	No.	Item
			25	Check that field of view is horizontal to roadway with no horizon
			26	Check that field of view is focused clearly with sufficient area for "down" algorithm
			27	Check if fog zones are drawn for each camera view
			28	Check that detection zones call proper vehicle phases when occupied
			29	Check that surge supression is in place for each coaxial line within cabinet
			30	Check that surge supression is used for AC power line on camera power panel
			31	Check that stop line detection zones set up for each direction via "D" connector when advanced
			32	detection is used
			33	Check that BNC connectors are crimped properly and surge supression installed on coax cables

PREEMPTION EQUIPMENT

ACCEPT	DECLINE	N/A	No.	Item
			34	Check if preemption box is grounded and detector wires are labeled as per direction
			35	Check that equipment communicates to all detectors
			36	Check that preemption calls proper phase when activated from field
			37	Check that proper Hi/Lo is displayed based on preempt received
			38	Check that confirmation lamps are operational for specified direction
			39	Check that beacons work properly on all preempts

FIBER OPTIC CABLING

ACCEPT	DECLINE	N/A	No.	Item
			40	Check that fiber optic cabling is terminated properly at WIC box
			41	Check that fiber jumpers are provided within cabinet
			42	Test fiber optics from nearest intersection

MISCELLANEOUS

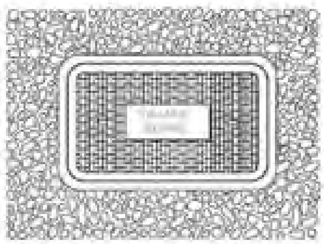
ACCEPT	DECLINE	N/A	No.	Item
			43	Check that Stop signs have been removed
			44	Check that police equipment operates properly
			45	Check that vehicular signal heads and pedestrian signal heads work properly at nighttime
			46	Check if entire construction site is clean of debris

COMMENTS

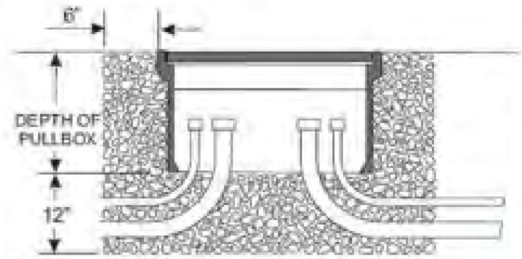
INSPECTOR SIGNATURE: ______________________________

PULL BOXES

TRAFFIC SIGNAL PULL BOX DETAILS



TOP VIEW



SIDE VIEW

Extend the end of the conduit in the pull box above the drainage material by 1 to 2 inches, but don't go all the way to the top!

TYPE	MIN. DIMENSIONS		
	LENGTH	WIDTH	DEPTH
A	12"	12"	6"
B	28"	16"	12"

Type "A" Pull Boxes are used for splicing loop lead-ins.
Type "B" Pull Boxes are used for all signal cable routing.

PULLBOX NOTES:

1. GRAVEL, 12" DEEP, IS REQUIRED UNDER PULLBOXES FOR DRAINAGE
2. TRAFFIC SIGNAL, TRAFFIC OR SIGNAL LEGEND REQUIRED.
3. COVERS SHALL BOLT DOWN.
4. PULL BOXES AND COVERS SHALL MEET TIER 15 REQUIREMENTS PER ANSI/SCTE 77 2002 STANDARDS.
5. TYPE A PULL BOXES TO BE USED FOR SPLICING LOOP LEAD IN WIRES TO SHIELDED CABLE ONLY.

   TYPE B PULL BOXES TO BE USED FOR ALL OTHER TRAFFIC SIGNAL APPLICATIONS.
6. RIGID CONDUIT TO BE GROUNDED WITH NO. 6 SOLID BARE COPPER WIRE ATTACHED TO GROUNDING BUSHINGS IN PULL BOX.

Considerations

Approximately 3 feet (1 meter) of slack cable must be left in each handhole that houses a cable run and approximately 2 feet (600 millimeters) of slack cable must be left in each mast arm pole base, light standard base and pedestal base.

CONDUITS

Material

- Rigid Nonmetallic Conduit (RNMC or RNC)
  - PVC (Polyvinyl Chloride)
    - Schedule 40 – belowground applications
    - Schedule 80 – above and belowground (roadways) applications
- Rigid Galvanized Steel Conduit (RGSC) – aboveground applications
- High-density Polyethylene (HDPE)

Note: do NOT use schedule 40 and schedule 80 conduit together on the same run – different inside diameter!

Use multiple conduit runs if larger conduit capacity is needed; The sizing of conduit should be such as to not fill over 40% internal area of the conduit.

NEC Usable area of conduit:
- 1 conductor: 53%
- 2 conductors: 31%
- 3 or more: 40%

POLES AND PEDESTALS

The access door of the base must be oriented away from traffic to allow maintenance personnel to see the intersection while servicing the base.

Weatherhead

Pedestal cap

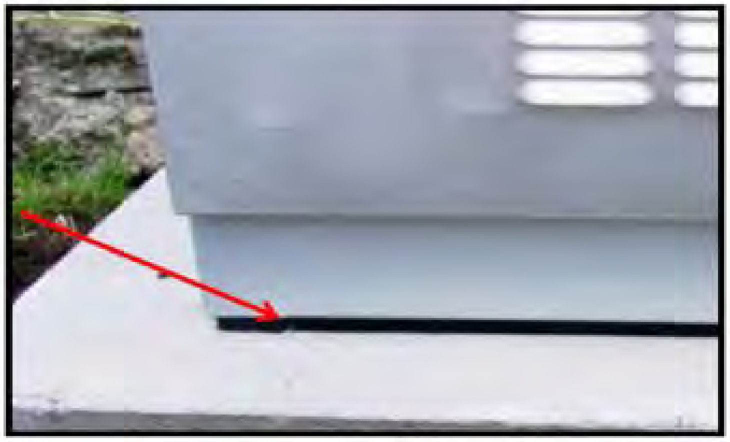
CABINETS

Before the cabinet is installed, make sure that all proper conduits are in place and the anchor bolts fit the cabinet. Refer to the Contract Documents for details. Clean any dirt and debris from the top of the foundation.

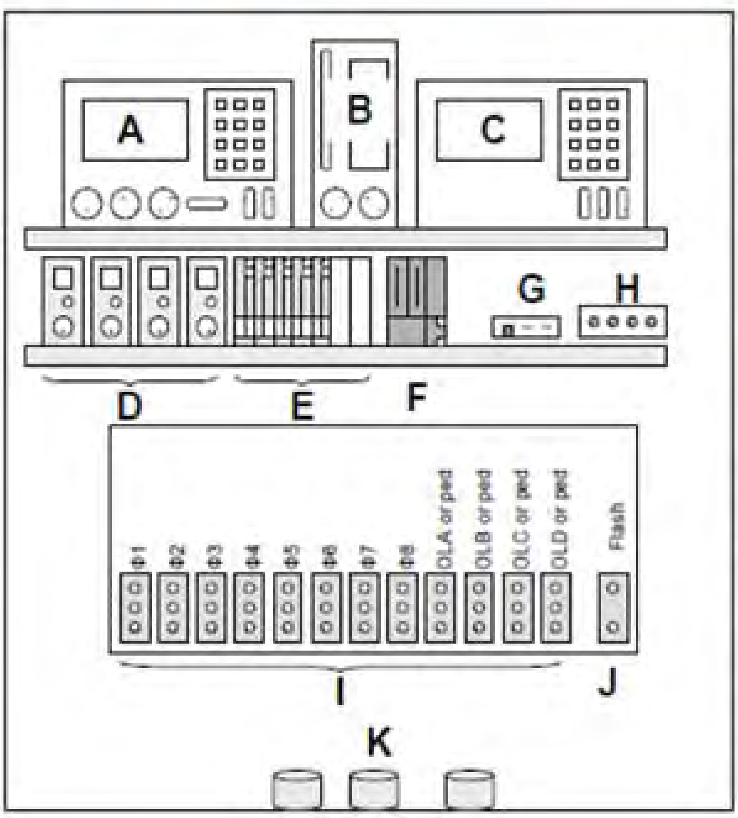
- A four Section Rubber Gasket, and four Anchor Bolts including nuts and stainless steel washers.

Lay the rubber gasket carefully in place and set the cabinet on top of the gasket, making sure the gasket is neatly positioned under the cabinet.

The cabinet must be securely bolted to the cast in-place pad with anchor bolts.



CABINETS



A. Local controller

B. Conflict monitor

C. Master controller

D. Single channel loop detector amplifiers

E. Multi-channel detector rack

F. Pre-emption phase selector

G. Telephone modem

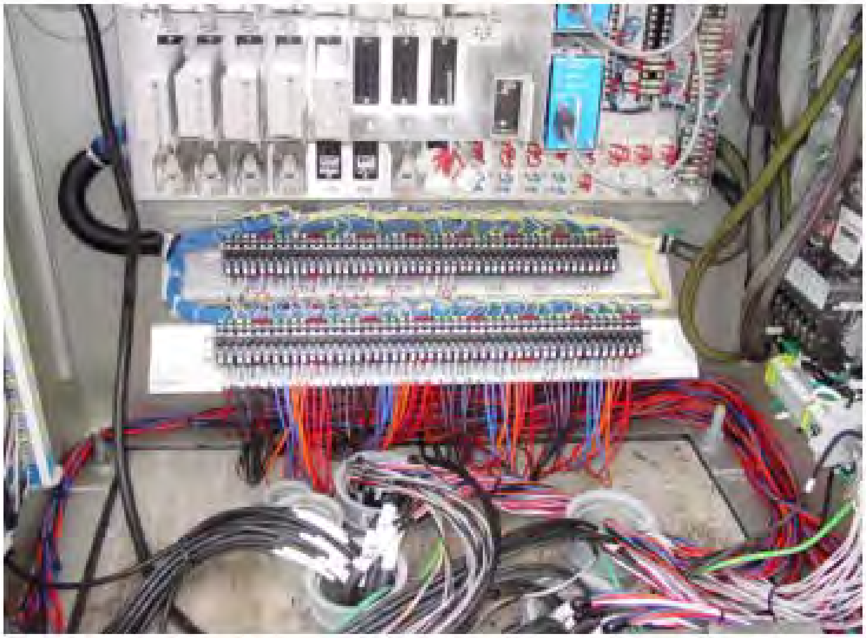
H. Fiber-optic modem

I. Load switches

J. Flasher

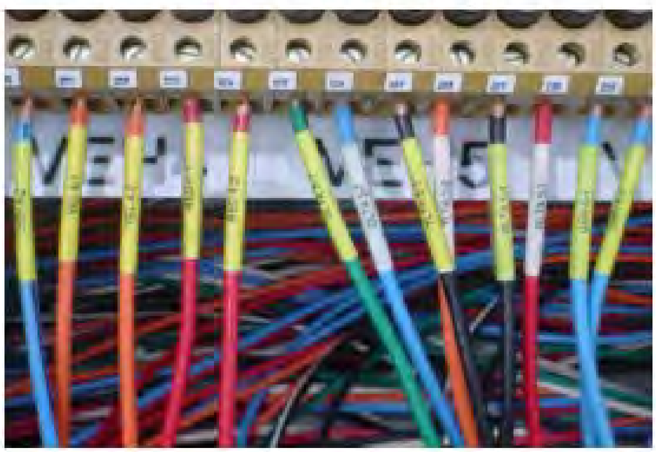
K. Conduits

CABINETS



Neatly wired

Labeling



SIGNALS AND SPANS

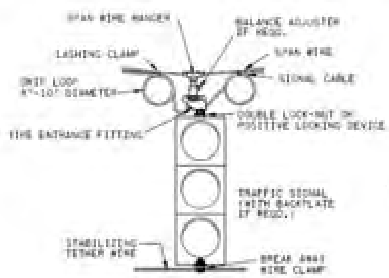
The LED signal indication must operate on a nominal 120 VAC power source.

Spanwire Cable Clamps

Disconnect Hangers

Drip Loops

Used to avoid water to get into electrical connections inside the signal head.



TYPICAL SIGNAL MOUNTING HARDWARE DETAIL

[This page intentionally left blank.]

TRAFFIC DESIGN MANUAL

APPENDIX D

Traffic Signal Maintenance Forms

Traffic Operations Division
Traffic Engineering Office

MUTCD TEMPORARY TRAFFIC CONTROL PLANS FOR TYPICAL MAINTENANCE TASKS

	MUTCD Typical Application						
MAINTENANCE TASK	Figure 6H-21 Lane Closure Near Side of Intersection (TA-21)	Figure 6H-22 Right Lane Closure Far Side of Intersection (TA-22)	Figure 6H-23 Left Lane Closure Far Side of Intersection (TA-23)	Figure 6H-24 Half Road Closure Far Side of Intersection (TA-24)	Figure 6H-25 Multi Lane Closures at Intersection (TA-25)	Figure 6H-26 Closure in Center of Intersection (TA-26)	Figure 6H-27 Closure at Side of Intersection (TA-27)
Knockdown of support structure / span or tether wire	X	X	X	X	X	X	X
Foundation repair / replacement	X	X		X			X
Adjust aim bulb or LED replacement for traffic signal indic. or head		X	X	X		X	X
Adust / aim detector mounted over the roadway		X	X				
Replace in-pavement or loop detector	X				X		
Adjust / aim side fire detector	X						
Open roadway manhole or junction box	X	X	X	X	X	X	X

Source: ITE

SHEET 1 OF 3

TRAFFIC SIGNAL PREVENTIVE MAINTENANCE CHECKLIST

AGENCY / CONTRACTOR LOGO	
	INTERSECTION NAME:
	DATE:
	TIME:
	TECHNICIAN NAME:

SIGNAL HEADS

YES	NO	N/A	1	Height of signal heads (See TDOT Traffic Design Manual section 4.14.7)
YES	NO	N/A	2	Clean lenses and reflectors
YES	NO	N/A	3	Check heads are properly aligned
YES	NO	N/A	4	Check for water in heads
YES	NO	N/A	5	Check for wear of signal housing
YES	NO	N/A	6	Check for wear on signal cables
YES	NO	N/A	7	Check for wear on span wire and mechanical hardware
YES	NO	N/A	8	Check for bent visors / hoods, wing nuts and hinges
YES	NO	N/A	9	Check condition of backplates
YES	NO	N/A	10	Check nighttime visibility
YES	NO	N/A	11	Are signal heads clear from obstructions (tree branches, etc)
YES	NO	N/A	12	Check for tightness of signal heads to mast arms / poles
				Overhead sign hangers on span wire and upper tether
YES	NO	N/A	13	Are they wearing the messenger cable
YES	NO	N/A	14	Sign bolts tight

MAST ARM AND POLES

YES	NO	N/A	15	Check for rust and spot paint as required
YES	NO	N/A	16	Check joints for rust and cracks
YES	NO	N/A	17	Check anchor bolts for rust and tightness
YES	NO	N/A	18	Check for structural damage
YES	NO	N/A	19	Check horizontal and vertical angle of arm
YES	NO	N/A	20	Check for water accumulation
YES	NO	N/A	21	Handhole covers in place and secure

SPAN WIRES AND POLES

YES	NO	N/A	22	Check for rust and spot paint as required
YES	NO	N/A	23	Check joints for rust and cracks
YES	NO	N/A	24	Check anchor bolts for rust and tightness
YES	NO	N/A	25	Check clamps and hardware
YES	NO	N/A	26	Check guy wire anchors and guards
YES	NO	N/A	27	Check for water accumulation
YES	NO	N/A	28	Handhole covers in place and secure

COMMENTS

SHEET 2 OF 3

CABINET

GOOD	BAD	N/A	29 Check cabinet light
GOOD	BAD	N/A	30 Check operation of fan
GOOD	BAD	N/A	31 Check operation of thermostat
GOOD	BAD	N/A	32 Check cabinet circuit breaker
GOOD	BAD	N/A	33 Check main circuit breaker
GOOD	BAD	N/A	34 Test / reset GFCI
GOOD	BAD	N/A	35 Check condition of conduits
YES	NO	N/A	36 Lubicate hinges and locks
YES	NO	N/A	37 Check for water accumulation
YES	NO	N/A	38 Check door gasket for weather tight seal
YES	NO	N/A	39 Caulk against water if needed
YES	NO	N/A	40 Vaccum all dust and dirt accumulated in cabinet
YES	NO	N/A	41 Replace control cabinet filter
YES	NO	N/A	42 Remove graffiti, stickers as needed
YES	NO	N/A	43 Apply insecticide
YES	NO	N/A	44 Traffic signal plan drawings in the cabinet
YES	NO	N/A	45 Approved timing directives in the cabinet
YES	NO	N/A	46 Logbook in the cabinet

47 Voltage at service connection inside cabinet ________________VAC

48 Amperage on service inside cabinet AC+:_________ AC-:_________

Chassis:

CONTROL PANEL

GOOD	BAD	N/A	49 Activate vehicle recall switch for active phases
GOOD	BAD	N/A	50 Activate ped recall switch for active peds
GOOD	BAD	N/A	51 Check stop timing switch for proper operation
GOOD	BAD	N/A	52 Check Max II switch for proper operation
YES	NO	N/A	53 Titghten loose screws on terminal connections
YES	NO	N/A	54 Check all harness for secure and tight connection
YES	NO	N/A	55 Verify load switches & flasher are firmly inserted in sockets
			Police door operation
YES	NO	N/A	56 Check hand controller for proper operation
YES	NO	N/A	57 Flash operation
GOOD	BAD	N/A	58 Mercury relay operation
GOOD	BAD	N/A	59 Flash transfer relay operation
YES	NO	N/A	60 Flash outputs correct
YES	NO	N/A	61 Update controller firmware to latest approved version

COMMENTS

SHEET 3 OF 3

VEHICLE DETECTION

GOOD	BAD	N/A	62	Check loops functionality (turning on/off on detector amplifiers without faults)
GOOD	BAD	N/A	63	Check sealant on saw-cut loops
YES	NO	N/A	64	Video / radar detection aimed properly and secure
YES	NO	N/A	65	Other types of detection working properly
YES	NO	N/A	66	Video detection camera lenses cleaned
GOOD	BAD	N/A	67	Verify extensions (passage time) by detector actuation
GOOD	BAD	N/A	68	Verify detection within designated zone of detection
GOOD	BAD	N/A	69	Verify no adjacent lane detection
YES	NO	N/A	70	Update firmware to latest approved version

PEDESTRIAN SIGNAL HEADS AND PUSHBUTTONS

YES	NO	N/A	71	Activate ped buttons on each crosswalk
YES	NO	N/A	72	Verify pedestrian signal operation
GOOD	BAD	N/A	73	Pushbutton sign alignment and condition
YES	NO	N/A	74	Signal heads working and free of obstructions

MISCELLANEOUS

YES	NO	N/A	75	Check / clean preemption equipment
YES	NO	N/A	76	Check UPS functionality
YES	NO	N/A	77	Street name / lane use control signs in place, clean, and free of obstructions
YES	NO	N/A	78	Stop lines (bars) visible for motorists
YES	NO	N/A	79	Crosswalks visible to pedestrians
YES	NO	N/A	80	Check pull boxes for damage
YES	NO	N/A	81	Logbook completed
YES	NO	N/A	82	Intersection needs revisit

SIGNAL TIMING

YES	NO	N/A	83	Check current timings against approved timing directives

CONFLICT MONITOR / MMU

			84	Tested by:
			85	Certified on (date):
YES	NO	N/A	86	Firmware updated to the latest version

COMMENTS

TECHNICIAN SIGNATURE: ____________________

AGENCY / CONTRACTOR LOGO	CUSTOMER: (if services are contracted out)	NAME OF CALLER:	NAME OF RECEIVER:		
LOCATION:		DATE:	TIME		
			CALL RECEIVED	ARRIVED LOCATION	LEFT LOCATION

REPORTED TROUBLE	KNOCK OVER	DARK	FLASH	LAMP OUT	TIMING	OTHER:	WORK COMPLETED
							YES
CAUSE OF TROUBLE	WEATHER	ACCIDENT	VANDALISM	CONTRACTOR	EQUIP FAIL	OTHER:	NO
TECHNICIAN NAME:							
VEHICLE USED:							

CONDITION UPON ARRIVAL:

ACTION TAKEN / WORK PERFORMED:

MATERIAL / TYPE / QUANTITY USED:

ADDITIONAL WORK / MATERIAL NEEDED:

TECHNICIAN SIGNATURE:	

TRAFFIC DESIGN MANUAL

APPENDIX E

TDOT LED Specifications/ Roadway and Intersection Lighting Forms

Traffic Operations Division
Traffic Engineering Office

SECTION 714-10 [Excerpt] – TDOT HIGHWAY LIGHTING LED SPECIFICATIONS

714-10-B Light Emitting Diode (LED) Luminaires:

A. Description:

LED (Light Emitting Diode) is an evolving technology and can change very rapidly in terms of luminous efficacy, color quality, optical design, thermal management and cost. Light Emitting Diode (LED) luminaire consists of two components: mechanical and the electrical. Additional materials (i.e. warranty) to support the operation of the luminaire will be discussed in these pages.

1. Mechanical parts:

a. Housing: LED luminaire shall be furnished as a complete unit manufactured according to ANSI C136.37-2011 (or recent version). All luminaires shall utilized LED's from well know and reputable LED manufacturers. As part of the submittal package, the designer shall supply all testing and data sheets for the proposed LED's and these should include-but not limited to- the following: Illuminating Engineering Society of North America (IESNA): LM-79-08, LM-80-08, RP-8-00, TM-3-95 and TM-15-07 (all should be up-to-date versions). LM-79-xx deals with Electrical and Photometric Measurements of Solid-State Lighting Products. LM-80-xx deals with Measuring Lumen Maintenance of LED Light Sources.

1) All internal components shall be assembled and pre-wired using modular electrical connections. Luminaires shall accept a designated voltage range as specified in the plans and operate normally with an input voltage that is within 10 percent of the specified voltage. The luminaires must have a Calculated L70 life at a minimum range of not less than 90,000 but can be more than 100,000 hours. All highway luminaires must be equipped with a "Bird Spike" option to deter nesting on the fixtures.

2) Finished surface: Furnish luminaires with the color mentioned in the plans. The surface of luminaire housing shall meet UL-1598 listed for wet locations, ASTM B117 for salt chamber exposure, and ASTM D1654 for rust creepage.

3) Thermal Management: the luminaire shall start and operate in the ambient temperature range of -40C to +40C.

4) Optical Assembly: The LED optical assembly-consisting of LED packages-shall have a minimum Ingress Protection rating of IP 66 according to ANSI/IEC 60529. The luminaire shall have a standardized refractor/reflector to meet the required optical distribution as required by the plans. The optical assembly shall utilize high brightness, long life, minimum 70 color rendering index (CRI), (3000 K-4000 K) color temperature LEDs binned according to ANSI C78.377. Lenses shall be UV-stabilized acrylic or glass. Provisions for house-side shielding shall be provided when specified.

5) Prevent the entrance of wildlife by limiting openings around the pipe tenon mounting area.

2. Electrical Parts and Safety Testing:

   a. Luminaires shall comply with an ANSI C136.41 with 7-pin receptacle that is fully pre-wire for LED driver's control. Furnish and install photo control unit with the specified driver on each LED luminaire. Decorative, wall mounted, and recessed luminaire may be exempted from these requirements.

   b. LED Driver Requirements: The driver shall meet the following requirements:

      1) Rated to operate in -40 degrees C to 40 degrees C ambient.

      2) Total Harmonic Distortion (THD) to be less than 20 percent.

      3) Have minimum power factor of 90 percent.

      4) Comply with the FCC regulations in 47 CRF Part 15.

      5) Rated for outdoor operations with a rating of IP66.

      6) If a dimmable driver is requested then it shall be compatible with IEC 60929.

   c. Surge Protection: If required per plans then it shall comply with FCC regulations in 47 CFR Part 15, Subpart B for the emission of electronic noise.

   Documents for the materials submitted need a certification from a National Voluntary Laboratory Accreditation Program (NVLAP) and that lab must be recognized by the U.S. Department of Energy.

3. Warranty:

   The entire luminaire and all of its component parts shall be covered by a 10 year written warranty. The warranty should cover materials, fixture finish, and workmanship. Failure is when one or more of the following occur:

   a. Negligible light output from more than 10 percent of the LED packages.

   b. Condensed moisture inside the optical assembly.

   c. Driver that continues to operate at a reduced output below 15% of the rated nominal output.

   The warranty period shall begin on the date of final acceptance of the lighting work. The signed warranty certificate shall be submitted prior to final payment.

LIGHTING DESIGN CHECKLIST COVER PAGE
(FOR ALL LIGHTING PLANS SUBMITTALS)

COUNTY: ____________________

FEDERAL PROJECT NO.: ____________________

STATE PROJECT NO.: ____________________

STATE PROJECT IDENTIFICATION NO.: ____________________

ROUTE: ____________________

PROJECT DESCRIPTION: ____________________

DESIGNER: ____________________

TDOT DESIGN MANAGER: ____________________

PROJECTED TURN-IN DATE: ____________________

PROJECTED LETTING DATE: ____________________

PHOTOMETRIC/PRELIMINARY LIGHTING PLANS CHECKLIST

PIN: ______________________________ **SHEET 1 OF 1**

DESIGNER: ________________________

A. LIGHTING CALCULATION SUBMITTALS

___Photometric input File
___Photometric output file (results)
___Survey work file
___Preliminary lighting design work file
___GPK file
___Tin File

B. PHOTOMETRIC DESIGN CALCULATIONS SHEET

Luminaire schedule table:
___Legend, ___Quantity
___Description, ___Catalogue
___Number, ___Lamp wattage
___IES file, ___Light loss factor
___Pole location table, ___Pole
___Numbers, ___Legend, ___Location
___Mounting height, ___Tilt angle

Photometric criteria/design table:
___Avg, ___Max, ___Min
___Max:Min, ___Avg.:Min
___R value, ___L_{avg}, ___L_{min}, ___L_{max}
___L_{Vmax}, ___L_{max}:L_{min}, ___L_{avg}:L_{min}
___L_{Vmax}:L_{avg}, ___Zone symbol
___Utility project number

C. LIGHTING LAYOUT SHEETS (FOR LARGE PROJECTS ONLY)

___Plans layout sheet with sheet number identified
___North arrow and scale
___Legend
___Utility project number

D. PHOTOMETRIC LAYOUT SHEET

___North arrow and scale
___Existing topography and existing
___ROW dimensions
___Location diagram or coordinates for reference points
___Reference points table
___Property owner(s)
___Cross-drains
___All side roads properly labeled
___Proposed horizontal alignment with curve data
___Point by point photometric values
___Legend
___Utilities (Existing)
___Existing light poles to remain
___Existing light poles to be removed
___Proposed light poles and numbers
___Utility project number
___Visual/AGi32 pole locations match proposed pole location in plans
___Photometric calculation zone and zone symbol
___Utility project number

UTILITY/RIGHT-OF-WAY LIGHTING PLANS CHECKLIST

PIN: ______________________ **SHEET 1 OF 2**

DESIGNER: ______________________

A. TITLE SHEET

___Location map showing route to be improved, local roads, streams, railroads and towns
___County, state route and description (include log mile)
___P.E. project number
___North arrow
___Project location identified
___Roadway, bridge, box bridge and project length
___Scale
___Design traffic and design speed
___Designer's name
___Index of sheets (Utility)
___Manager 1 name
___Equations and exclusions
___Type of work (Utility)
___Project county identified on state map
___Signatures in signature block

B. CONTROL CENTER DETAILS SHEET

___Preliminary wiring schematic for each control center
___Preliminary breaker sizes
___Preliminary main breaker size
___Service voltage
___Utility/R.O.W. project number
___Preliminary pole mounted controller construction detail
___Preliminary pad mounted controller construction detail
___Proposed control center location and layout referenced

C. LIGHTING DETAILS SHEET

Pole schedule table:
___Pole number, ___Lamp type
___Wattage, ___Voltage,
___Number of heads,
___Control center number
___Circuit number, ___Mounting height station, ___Offset/side

Wire/conduit schedule table:
___Wire number
___Cable number and size
___Conduit number and size
___Spare conduit
___Utility/R.O.W. project number

D. LIGHTING LAYOUT SHEETS (FOR LARGE PROJECTS ONLY)

___North arrow and scale
___Plans layout sheet with sheet number identified
___Utility list/owner
___Legend
___Utility/R.O.W. project number

UTILITY/RIGHT-OF-WAY LIGHTING PLANS CHECKLIST

PIN: ______________________________ **SHEET 2 OF 2**

DESIGNER: ________________________

E. PRESENT AND PROPOSED LAYOUT SHEET

___North arrow and scale
___Existing topography and existing
___ROW dimensions
___Location diagram or coordinates for reference points
___Reference points table
___Property owner(s)
___Cross-drains
___All side roads properly labeled
___Proposed horizontal alignment with curve data
___Breaks in proposed ROW flagged
___Legend

___Utilities (Existing)
___Utility list/owner
___Existing light poles to remain
___Existing light poles to be removed
___Proposed light poles and numbers
___Proposed lighting conduits and numbers
___Control center
___Proposed jack and bore
___Proposed power source
___Notes
___Utility/R.O.W. project number

CONSTRUCTION LIGHTING PLANS CHECKLIST

PIN: ______________________________ **SHEET 1 OF 4**

DESIGNER: ________________________

A. TITLE SHEET

___New title sheet for Construction plans showing location map with route to be improved, local roads, streams, railroads, and towns
___County, state route and description (include log mile)
___P.E. project number
___North arrow
___Project location identified
___Roadway, bridge, box bridge and project length
___Scale
___Design traffic and Design speed
___Designer's name
___"See sheet no. 1A for index" added to index area
___Manager 1 name
___Equations and exclusions
___Type of work (construction)
___Project county identified on state map
___Signatures in signature block
___Adjacent construction projects labeled

B. INDEX AND STANDARD DRAWINGS SHEET

___Title sheet
___Roadway index sheets
___Estimated roadway quantities sheet
___General notes sheet
___Special notes sheet (high mast only)
___Control center details sheet
___Lighting details sheet
___Lighting layout sheet (for large projects only)
___Present and proposed layout sheets
___Bore locations and geotechnical notes sheet (high mast only)
___Bore log details (high mast only)
___Foundation details sheet (high mast only)
___Utility index, utility owner, and utility sheets
___Standard roadway drawings drawing number, current revision date and title from roadway design standards index for: traffic control appurtenances; erosion control and landscaping
___Construction project number

C. ESTIMATED ROADWAY QUANTITIES SHEET

___Roadway quantity block with all items of construction to bid, including, ___Item numbers, ___ Description, ___Units, ___Quantity
___Footnotes and miscellaneous removal items
___Sign quantities tabulation block
___Lighting quantities
___Quantities on this sheet checked against other tabulation blocks
___Quantities checked and item numbers agree with cost estimate form
___Construction project number

CONSTRUCTION LIGHTING PLANS CHECKLIST

PIN: ______________________________ **SHEET 2 OF 4**

DESIGNER: ________________________

D. GENERAL NOTES SHEET

___Grading
___Utilities
___Construction work zone & traffic control
___Lighting
___Special Notes
___Construction project number

E. SPECIAL NOTES SHEET (FOR HIGH MAST PROJECTS ONLY)

___Special notes (for high mast)
___High mast service voltage
___Step down transformer size (lowering device)
___Construction project number

F. CONTROL CENTER DETAILS SHEET

___Final wiring schematic for each control center
___Final breaker sizes
___Final main breaker size
___Service voltage
___Construction project number
___Final pole mounted controller construction detail
___Final pad mounted controller construction detail
___Proposed control center location and layout referenced

G. LIGHTING DETAILS SHEET

Pole schedule table:
___Pole number, ___Lamp type
___Wattage, ___Number of heads
___Control center number
___Circuit number, ___Mounting height station, ___Offset/side

Wire/conduit schedule table:
___Wire number
___Cable number and size
___Conduit number and size
___Spare conduit
___Construction project number

H. SPECIAL LIGHTING DETAILS SHEET

___Details of non-standard TDOT lighting items
___Notes
___Dimensions
___Construction project number

I. LIGHTING LAYOUT SHEETS (FOR LARGE PROJECTS ONLY)

___North arrow and scale
___Plans layout sheet with sheet number identified
___Utility list/owner
___Legend
___Construction project number

CONSTRUCTION LIGHTING PLANS CHECKLIST

PIN: ______________________________ **SHEET 3 OF 4**

DESIGNER: ________________________

J. PRESENT AND PROPOSED LAYOUT SHEET

___North arrow and scale
___Existing topography and existing
___ROW dimensions
___Location diagram or coordinates for reference points
___Reference points table
___Property owner(s)
___Cross-drains
___All side roads properly labeled
___Proposed horizontal alignment with curve data
___Breaks in proposed ROW flagged
___Legend
___Utilities
___Utility list/owner
___Existing light poles to remain
___Existing light poles to be removed
___Proposed light poles and numbers
___Proposed lighting conduits and numbers
___Proposed jack and bore
___Proposed power source
___Notes
___Construction project number

K. UNDERPASS LIGHTING DETAILS SHEET

___North arrow and scale
___Underpass/bridge labeled
___Existing light poles to remain
___Existing light poles to be removed
___Proposed light poles and numbers
___Proposed lighting conduits and numbers
___Underpass lighting fixture and number
___Conduit size
___Junction box size
___Road side pull box
___Pull box at top of bank
___Electrical connection
___Utilities
___Legend
___Control center and number
___Proposed jack and bore
___Proposed power source
___Notes
___Construction project number

L. BORE LOCATIONS AND GEOTECHNICAL NOTES (FOR HIGH MAST ONLY)

___North arrow and scale
___Existing topography and existing
___ROW dimensions
___Location diagram or coordinates for reference points
___Proposed horizontal alignment with curve data
___Legend
___Bore location and number
___Geotechnical notes
___Geotechnical parameters
___Construction project number

CONSTRUCTION LIGHTING PLANS CHECKLIST

PIN: ______________________________ **SHEET 4 OF 4**

DESIGNER: ________________________

M. BORE LOG DETAILS SHEET (FOR HIGH MAST ONLY)

___Bore log number
___Bore depth
___Sample number
___N-value (blow counts)
___Graphic Log
___Soil description
___SPT N- value (standard penetration test)
___Water levels
___Construction project number

N. FOUNDATION DETAILS SHEET (FOR HIGH MAST ONLY)

___Foundation details
___Foundation dimensions
___Design wind speed
___Foundation notes
___Materials description
___Construction project number

[This page intentionally left blank.]

TRAFFIC DESIGN MANUAL

APPENDIX F

Traffic Operations
Standard Drawings List
and Current Memorandums

Traffic Operations Division
Traffic Engineering Office

TRAFFIC OPERATIONS STANDARD DRAWINGS LIST

Utility Poles/Fiber Optic Standard Drawings:

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-FO-1	07-29-04	FIBER OPTIC AERIAL ENTRANCE DETAILS
T-FO-2	07-29-04	FIBER OPTIC UNDERGROUND ENTRANCE DETAILS
T-FO-3	07-29-04	FIBER OPTIC AERIAL CONNECTION DETAILS
T-FO-4	07-29-04	FIBER OPTIC PULL BOX, CABINET & POLE DETAILS

Roadway Lighting Standard Drawings:

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-L-1	12-04-13	STANDARD LIGHTING FOUNDATION DETAILS
T-L-1SA	09-11-13	STANDARD LIGHTING DETAILS FOR SINGLE ARM SUPPORTS
T-L-1TM	07-29-04	STANDARD LIGHTING DETAILS TENON MOUNTED OFFSET LIGHTING SUPPORTS
T-L-2	12-04-13	FOUNDATION DETAIL FOR LUMINAIRE MOUNTED ON A CONCRETE MEDIAN BARRIER
T-L-3	04-15-96	STANDARD LIGHTING DETAILS PULL BOXES
T-L-4	05-25-11	STANDARD LIGHTING DETAILS CONDUIT, CABLE INSTALLATION

Railroad Crossings Standard Drawings:

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-RR-1	11-01-11	TYPICAL PAVEMENT MARKING AT RAILROAD-HIGHWAY GRADE CROSSINGS AND RAILROAD ADVANCE WARNING SIGN
T-RR-2	11-01-11	STANDARD DRAWING FOR RAILROAD AND HIGHWAY CROSSING SIGNAL WITH GATE
T-RR-3	11-01-11	STANDARD DRAWING FOR RAILROAD-HIGHWAY CROSSING SIGNAL
T-RR-4	11-01-11	STANDARD DRAWING FOR TYPICAL CURB & GUTTER PLAN FOR RAILROAD-HIGHWAY CROSSING WITH OR WITHOUT GATES
T-RR-5	11-01-11	STANDARD DRAWING FOR RAILROAD-HIGHWAY CROSSING SIGNAL TYPICAL CANTILEVER SIGN
T-RR-6	10-25-13	TYPICAL SIGNING AND MARKING AT PASSIVE RAILROAD-HIGHWAY GRADE CROSSINGS

Sign Standard Drawings:

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-S-6	02-12-91	STANDARD MOUNTING DETAILS- BOLTED EXTRUDED PANELS
T-S-7	02-12-91	HIGHWAY SHIELDS USED ON INTERSTATE AND U.S. NUMBERED ROUTES
T-S-8	07-15-91	HIGHWAY SHIELDS USED ON STATE NUMBERED ROUTES AND ARROWS
T-S-9	06-10-14	STANDARD LAYOUT GROUND MOUNTED SIGNS

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-S-10	04-04-12	STANDARD MOUNTING DETAILS FLAT SHEET SIGNS ALUMINUM-STEEL DESIGN
T-S-11	06-06-11	DELINEATOR AND MILEPOST DETAILS
T-S-12	07-10-17	STANDARD STEEL GROUND MOUNTED SIGNS, BREAK-AWAY TYPE POST FOOTING DETAILS, SQUARE TUBES
T-S-13	07-20-12	STANDARD STEEL GROUND MOUNTED SIGNS, BREAK-AWAY TYPE POST FOOTING DETAILS, I-BEAMS
T-S-14	08-17-12	STANDARD STEEL GROUND MOUNTED SIGNS, BREAK-AWAY TYPE POST FOOTING DETAILS, WF-BEAMS
T-S-15	12-07-90	STANDARD CONDUIT & GROUND DETAILS FOR OVERHEAD & CANTILEVER SIGN STRUCTURES
T-S-16	07-02-15	GROUND MOUNTED ROADSIDE SIGN AND DETAILS
T-S-16A	07-02-15	GROUND MOUNTED ROADSIDE SIGN PLACEMENT DETAILS
T-S-17	07-11-17	STANDARD GROUND MOUNTED SIGN USING PERFORATED/KNOCKOUT SQUARE TUBE
T-S-18	02-14-14	END OF ROADWAY AND DEAD END SIGNS, METAL BARRICADES (TYPE III) & WORK ZONE SPEED SIGNS
T-S-19	07-11-17	STANDARD STEEL SIGN SUPPORTS
T-S-20	07-11-17	SIGN DETAILS
T-S-21	07-02-15	DETAILS FOR SIGNS MOUNTED ON CONCRETE MEDIAN BARRIERS

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-S-22	09-12-13	SIGN LAYOUT FOR HOV LANES
T-S-23A	07-11-17	MULTI-DIRECTIONAL SLIP BASE BREAKAWAY SQUARE TUBE SIGN SUPPORT
T-S-23B	07-19-13	MULTI-DIRECTIONAL SLIP BASE BREAKAWAY STRUCTURAL PIPE SIGN SUPPORT
T-S-23C	07-02-15	BREAKAWAY U-POST SIGN SUPPORTS
T-S-24	08-02-13	DETAILS OF SIGN WITH SOLAR FLASHING ASSEMBLY

Signal Standard Drawings:

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-SG-1	06-27-16	WOOD POLE DETAILS FOR SPAN MOUNTED SIGNALS
T-SG-2	06-27-16	LOOP LEAD-INS, CONDUIT, AND PULL BOXES
T-SG-3	07-11-17	STANDARD NOTES AND DETAILS OF INDUCTIVE LOOPS
T-SG-3A	06-27-16	ALTERNATE DETECTION DETAILS
T-SG-4	06-27-16	SPAN WIRE AND MESSENGER CABLE DETAILS
T-SG-5	06-27-16	CONTROLLER CABINET DETAILS
T-SG-6	06-27-16	PEDESTRIAN SIGNAL DETAILS
T-SG-7	07-11-17	SIGNAL HEAD ASSEMBLIES

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-SG-7A	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: APPROACHES WITH NO THROUGH MOVEMENTS
T-SG-7B	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: APPROACHES WITH NO THROUGH MOVEMENTS
T-SG-7C	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: ONE-LANE AND TWO-LANE APPROACHES
T-SG-7D	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: TWO-LANE APPROACHES
T-SG-7E	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: THREE-LANE APPROACHES
T-SG-7F	07-11-17	TYPICAL SIGNAL HEAD PLACEMENT: THREE-LANE APPROACHES
T-SG-7G	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: THREE-LANE APPROACHES
T-SG-7H	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: THREE-LANE AND FOUR-LANE APPROACHES
T-SG-7HH	07-13-17	TYPICAL SIGNAL HEAD PLACEMENT: FOUR-LANE APPROACHES
T-SG-7J	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: FOUR-LANE APPROACHES
T-SG-7K	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: FOUR-LANE APPROACHES
T-SG-7L	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: FOUR-LANE APPROACHES
T-SG-7M	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: FIVE-LANE APPROACHES

DRAWING NUMBER	CURRENT/ REVISION DATE	DESCRIPTION
T-SG-7N	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: FIVE-LANE APPROACHES
T-SG-7NN	07-13-17	TYPICAL SIGNAL HEAD PLACEMENT: FIVE-LANE APPROACHES
T-SG-7P	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: FIVE-LANE APPROACHES
T-SG-7PP	07-13-17	TYPICAL SIGNAL HEAD PLACEMENT: FIVE-LANE APPROACHES
T-SG-7R	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: SIX-LANE APPROACHES
T-SG-7S	06-27-16	TYPICAL SIGNAL HEAD PLACEMENT: SIX-LANE AND SEVEN-LANE APPROACHES
T-SG-8	06-27-16	STRAIN POLE DETAILS FOR SPAN MOUNTED SIGNALS
T-SG-9	07-11-17	DETAILS OF CANTILEVER SIGNAL SUPPORT
T-SG-9A	07-12-17	MISCELLANEOUS SIGNAL DETAILS
T-SG-10	07-11-17	MAST ARM POLE AND STRAIN POLES FOUNDATION DETAILS
T-SG-11	07-12-17	MAINTENANCE OF EXISTING SIGNALS DURING HIGHWAY CONSTRUCTION
T-SG-12	07-12-17	TYPICAL WIRING FOR SIGNAL HEADS AND DETECTION LOOPS
T-SG-13	06-27-16	FLASHING BEACON DETAIL