TENNESSEE DEPARTMENT

of

TRANSPORTATION

DESIGN DIVISION

ENGLISH

TRAFFIC DESIGN MANUAL

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TENNESSEE DEPARTMENT OF TRANSPORTATION
TRAFFIC DESIGN MANUAL

TABLE OF CONTENTS

Page

CHAPTER 1 - INTRODUCTION

Section 1.0 About this Manual……. 1-1
Section 1.1 Traffic Control Devices……. 1-2
Subsection 1.1.1 Traffic Signs…….. 1-2
Subsection 1.1.2 Markings…… 1-2
Subsection 1.1.3 Traffic Signals…… 1-2
Section 1.2 Design of Traffic Control Devices……1-2
Section 1.3 TDOT Traffic Design Section……... 1-3
Section 1.4 TDOT Information……. 1-3
Section 1.5 Governing Laws, Rules and Regulations……... 1-3

CHAPTER 2 – TDOT PROJECT DEVELOPMENT

Section 2.0 Schedule……. 2-1
Section 2.1 Three Party Plans Development……. 2-1
Subsection 2.1.1 TDOT……. 2-1
Subsection 2.1.2 Local Agency……. 2-1
Subsection 2.1.3 Design Engineer……. 2-1
Section 2.2 Plan Development Stages…….. 2-1
Section 2.3 Support Projects…...……. 2-3
Section 2.4 Conformance to TDOT Plans Format……..……2-3
Subsection 2.4.1 Sheet Numbering…… 2-3
Subsection 2.4.2 Plans Scale…… 2-4
Subsection 2.4.3 Aerial Photography…… 2-4
Subsection 2.4.4 Details…… 2-4
Subsection 2.4.5 Notes…….. 2-4
Subsection 2.4.6 Quantities…… 2-4

CHAPTER 3 – NEED FOR TRAFFIC SIGNALS

Section 3.0 Highway Traffic Signals…….. 3-1
Section 3.1 Cooperation with Local Agencies..…….. 3-1
Subsection 3.1.1 Authorization of Installation of Traffic Signals…… 3-2
Subsection 3.1.2 Environmental Requirements..…..…… 3-3
Subsection 3.1.3 Erosion Control……..……..……. 3-3
Section 3.2 Justification of Signal Control.…… 3-4
Subsection 3.2.1 Traffic Signal Study Advance Engineering Data..…… 3-4
Subsection 3.2.2 Traffic Signal Warrants…….. 3-5
Subsection 3.2.3 Right Turn Volume Considerations…..……... 3-8
Subsection 3.2.4 TDOT Signal Justification Guidelines.……... 3-9
Section 3.3 Removal of Traffic Signals…….……3-10

CHAPTER 4 – TRAFFIC SIGNAL DESIGN

Section 4.0 General……4-1
Section 4.1 Traffic Signal Design…… 4-2
Subsection 4.1.1 Intersection Geometrics……..……. 4-2
Subsection 4.1.2 Traffic Signal Movements……..……. 4-3
Subsection 4.1.3 Traffic Signal Mode of Operation…… 4-3
Subsection 4.1.4 Pre-Timed (Fixed Time) Operation..……. 4-3
Subsection 4.1.5 Traffic Actuated Operation……..……. 4-5
Subsection 4.1.6 Fully Actuated Operation……..……4-5
Subsection 4.1.7 Semi-Actuated Operation……..……. 4-7
Subsection 4.1.8 Mode During System Operation……..……4-8
Subsection 4.1.9 Dual Ring Controller Operation……..…… 4-8
Section 4.2 Traffic Signal Intervals (Phases)…… 4-10
Subsection 4.2.1 Need for Left Turn Protection…….…….…… 4-10
Subsection 4.2.2 Left Turn Phase Warrants..…….…….…… 4-10
Subsection 4.2.3 Types of Left Turn Phasing….…….…….……4-11
Subsection 4.2.4 Sequence of Left Turn Phasing…….…….…… 4-15
Subsection 4.2.5 Left Turn “Yellow Trap”…… 4-20
Subsection 4.2.6 Right Turn Indication…… 4-21

Subsection 4.2.7 Phase Numbering Convention……4-21
Section 4.3 Vehicle Detection…… 4-25
Subsection 4.3.1 Locking vs. Non-Locking Memory …….. 4-25
Subsection 4.3.2 Detection for Different Approach Speeds …….. 4-27
Subsection 4.3.3 Stop Line Detection……. ……..…….. 4-27
Subsection 4.3.4 Advance Detection……. …….. 4-27
Subsection 4.3.5 Methods of Detection..…….. 4-27
Subsection 4.3.6 Inductive Loop Detection. ……..…….. 4-31
Subsection 4.3.7 Microwave Detection……. …….. 4-34
Subsection 4.3.8 Video Detection……..…. ……..…….. 4-34
Subsection 4.3.9 Phase Recalls……..…. …….. 4-37
Section 4.4 Pedestrian Signal Interval…… 4-37
Subsection 4.4.1 Pedestrian Signal Warrants……. 4-37
Subsection 4.4.2 Pedestrian Interval Sequence…… 4-38
Subsection 4.4.3 Countdown Pedestrian Signals…… 4-38
Subsection 4.4.4 Pedestrian Actuation..…… 4-40
Subsection 4.4.5 Accessible Pedestrian Signals……. 4-42
Section 4.5 Traffic Signal Timing…… 4-45
Subsection 4.5.1 Type of Signal Timing Data……. 4-45
Subsection 4.5.2 Preset Timing Intervals……. 4-45
Subsection 4.5.3 Pre-Timed Timing Intervals……. 4-45
Subsection 4.5.4 Basic Actuated Timing Intervals……. 4-48
Subsection 4.5.5 Volume Density Timing Intervals……4-51
Subsection 4.5.6 Vehicle Clearance Intervals…… 4-58
Subsection 4.5.7 Pedestrian Phase Timing……..… 4-60
Subsection 4.5.8 Traffic Signal Timing Plans…….. 4-61
Section 4.6 Traffic Signal Coordination…….. 4-63
Subsection 4.6.1 Time Base Coordination……..…….. 4-63
Subsection 4.6.2 Closed Loop Signal System……..…….. 4-64
Subsection 4.6.3 Methods of Communication ……..……4-64
Subsection 4.6.4 Hard Wire Interconnect Installation……..4-65
Subsection 4.6.5 Coordinated Timing Plans……..…… 4-65
Subsection 4.6.6 Offsets…… 4-66

Section 4.7 Preemption and Priority Control of Traffic Signals……4-66
Subsection 4.7.1 Emergency Vehicle Preemption…… 4-67
Subsection 4.7.2 Preemption Justification…… 4-67
Subsection 4.7.3 Preemption Sequence……4-69
Subsection 4.7.4 Multiple Preemption…….. 4-69
Subsection 4.7.5 Methods of Emergency Vehicle Preemption…….. 4-69
Subsection 4.7.6 System Components for Optical and Siren Activated Preemption……. 4-70
Subsection 4.7.7 Priority Control…….. 4-70
Section 4.8 Railroad Preemption…….. 4-70
Subsection 4.8.1 Railroad Preemption Warrant…….. 4-72
Subsection 4.8.2 Pre-Signals…… 4-73
Subsection 4.8.3 Railroad Preemption Sequence……. 4-73
Subsection 4.8.4 Railroad Preemption Warning Timing……... 4-76
Subsection 4.8.5 Blank Out Signs……. 4-76
Section 4.9 Traffic Signal Heads…….. 4-78
Subsection 4.9.1 Lens Size and Type……4-78
Subsection 4.9.2 Signal Housing…….. 4-78
Subsection 4.9.3 Backplates……. 4-78
Subsection 4.9.4 Number of Signal Faces……. 4-78
Subsection 4.9.5 Positioning Relative to the Stop Line……4-80
Subsection 4.9.6 Horizontal Placement……. 4-80
Subsection 4.9.7 Vertical Placement……. 4-80
Subsection 4.9.8 Face Arrangement……..4-80
Subsection 4.9.9 Left Turn Signals…… 4-85
Subsection 4.9.10 Right Turn Signals……. 4-85
Subsection 4.9.11 Pedestrian Signal Indications……. 4-85
Subsection 4.9.12 Signal Head Shielding……. 4-87
Subsection 4.9.13 Programmable Signal Heads…… 4-87
Section 4.10 Signal Controllers and Cabinets……4-87
Subsection 4.10.1 Traffic Signal Controllers…….. 4-87
Subsection 4.10.2 Controller Cabinets…… 4-88
Subsection 4.10.3 Power Supply……. 4-88
Section 4.11 Traffic Signal Supports…….. 4-89

Subsection 4.11.1 Selection of Support Type…….…… 4-89
Subsection 4.11.2 Strain Poles…… 4-92
Subsection 4.11.3 Mast Arm Poles……. 4-96
Section 4.12 Signal Wiring……. 4-98
Subsection 4.12.1 Signal Control Cable…..…… 4-98
Subsection 4.12.2 Copper Communications Cable……4-98
Subsection 4.12.3 Fiber Optic Communications Cable…..……..…..…4-98
Subsection 4.12.4 Inductive Loop Wire…..…… 4-98
Subsection 4.12.5 Loop Detector Lead-In (Shielded Cable)…… 4-98
Subsection 4.12.6 Preformed Loop Detector Wire…… 4-99
Subsection 4.12.7 Cable Lashing…… 4-99
Subsection 4.12.8 Cable Sizing for Conduit…… 4-99
Section 4.13 Conduit…….…… 4-99
Subsection 4.13.1 Conduit Material Type…… 4-99
Subsection 4.13.2 Conduit Installation Methods..…… 4-102
Subsection 4.13.3 Depth Installed (Underground)…… 4-102
Subsection 4.13.4 Conduit Sizing..…….. 4-102
Subsection 4.13.5 Communications Cable Conduit…… 4-102
Subsection 4.13.6 Power Cable Conduit……. 4-103
Subsection 4.13.7 Bored and Jacked Conduit……. 4-103
Subsection 4.13.8 Conduit Radii……. 4-103
Subsection 4.13.9 Spare Conduit…… 4-103
Subsection 4.13.10 Conduit for Road Widening Projects……4-103
Section 4.14 Pull Boxes…….. 4-103
Subsection 4.14.1 Purpose…….. 4-103
Subsection 4.14.2 Type/Size/Use…… 4-103
Subsection 4.14.3 Spacing…….. 4-103
Subsection 4.14.4 Material…….. 4-103
Section 4.15 Street Lighting on Signal Supports at Intersections…… 4-105
Subsection 4.15.1 Justification…… 4-105
Subsection 4.15.2 Design…… 4-105
Subsection 4.15.3 Mounting Height…… 4-105
Subsection 4.15.4 Wiring Requirements…….. 4-105

Section 4.16 Flashing Operations……4-106
Subsection 4.16.1 Types of Flashing Operation…….. 4-106
Subsection 4.16.2 Signal Display…… 4-106
Subsection 4.16.3 Dimming LED Signal Indications…… 4-107
Section 4.17 Stop Signs at Signalized Intersections…… 4-107
Section 4.18 Signal Control for Driveways within Signalized Intersections.. …… 4-107
Section 4.19 New Traffic Signal Inspection……4-108
Section 4.20 Traffic Signal Activation Procedures……. 4-109
Subsection 4.20.1 Advance Flash Period…… 4-109
Subsection 4.20.2 Publicity……. 4-109
Subsection 4.20.3 Activation……..4-109
Subsection 4.20.4 Technical Support……..…… 4-109
Subsection 4.20.5 Signing Adjustments…….. 4-109
Subsection 4.20.6 Police Assistance…… 4-109
Subsection 4.20.7 School Crossing……. 4-109
Subsection 4.20.8 Fine Tuning…… 4-109

CHAPTER 5 – OTHER TYPES OF TRAFFIC SIGNALS

Section 5.0 Highway Traffic Signals……..…….…… 5-1
Section 5.1 Emergency Vehicle Traffic Signals……..…… 5-1
Subsection 5.1.1 Displays…….……... 5-1
Subsection 5.1.2 Control……..……... 5-3
Subsection 5.1.3 Signing……... 5-3
Section 5.2 Flashing Beacons……..…….…… 5-3
Subsection 5.2.1 Intersection Control Beacons…….……...5-3
Subsection 5.2.2 Speed Limit Sign Beacons…….…… 5-5
Subsection 5.2.3 School Zone Speed Limit Beacons…….…… 5-5
Subsection 5.2.4 Stop Beacons (Red)……..…….…… 5-5
Subsection 5.2.5 Warning Beacons (Yellow)……..…. 5-7
Subsection 5.2.6 Signal Ahead Beacons…….…… 5-7

CHAPTER 6 – SIGNING AND PAVEMENT MARKINGS

6.0 GENERAL 6-1

6.1 SIGNING 6-1
Subsection 6.1.1 MUTCD 6-2
Subsection 6.1.2 Application 6-2
Subsection 6.1.3 Sign Layouts 6-2
Subsection 6.1.4 Conventional Highways Signs 6-2
Subsection 6.1.4.1 Directional and Route Signing at Intersections 6-2
Subsection 6.1.4.2 One-Way & Wrong-Way Sign at Median Crossovers .. 6-9
Subsection 6.1.4.3 Roadside Sign Supports 6-20
Subsection 6.1.4.4 Strain Poles 6-20
Subsection 6.1.5 Freeway and Expressway (Access Controlled) Signs.. 6-35
Subsection 6.1.5.1 Overhead Signing 6-35
Subsection 6.1.5.2 Structural Support Foundations 6-37
Subsection 6.1.5.3 Roadside Supports 6-37
Subsection 6.1.6 Sign Vertical Clearances 6-37
Subsection 6.1.7 Traffic Signal Signs 6-40
Subsection 6.1.7.1 Span Wire/Mast Arm Mounted 6-40
Subsection 6.1.7.2 Ground Mounted Signs 6-43
Subsection 6.1.8 Other Traffic Control Signs 6-44
Subsection 6.1.8.1 SPEED LIMIT Signs (R-2 series) 6-44
Subsection 6.1.8.2 Two-Way Left-Turn Lane Signs (R3-9 series) 6-44
Subsection 6.1.8.3 School Signs 6-44
6.2 PAVEMENT MARKINGS 6-45
Subsection 6.2.1 Stop Lines 6-45
Subsection 6.2.1.1 Guidance 6-45
Subsection 6.2.1.2 Placement 6-45
Subsection 6.2.2 Yield Lines 6-48
Subsection 6.2.2.1 Guidance 6-48
Subsection 6.2.2.2 Placement 6-48
Subsection 6.2.3 Crosswalks 6-49
Subsection 6.2.3.1 Guidance 6-49
Subsection 6.2.3.2 Placement 6-49
Subsection 6.2.4 Arrows……..... 6-50

Subsection 6.2.5 Materials..... 6-50

CHAPTER 7 – ROADWAY LIGHTING

Section 7.0 General…… 7-1
Subsection 7.0.1 Need for Engineering Expertise…..…… 7-1
Subsection 7.0.2 Priorities and Funding Guidlines…….… 7-3
Section 7.1 Analyzing Highway Lighting Needs……...……... 7-4
Subsection 7.1.1 Freeways….....…….…… 7-4
Subsection 7.1.2 Streets and Highways Other Than Freeways……...… 7-8
Subsection 7.1.3 Other Locations…….. 7-14
Section 7.2 Lighting Projects New…….……...… 7-16
Subsection 7.2.1 Lighting Design Process Flow Chart….....…… 7-16
Subsection 7.2.2 Design Process…….……...… 7-17
Subsection 7.2.3 Design Considerations…….. 7-19
Subsection 7.2.4 Determine Classifications.……... 7-19
Subsection 7.2.5 Other Design Considerations……..… 7-32
Subsection 7.2.6 Roadside Safety Considerations……. 7-32
Section 7.3 Lighting Design……... 7-35
Subsection 7.3.1 Methodologies….……....7-36
Subsection 7.3.2 Computerized Design.……..… 7-41
Subsection 7.3.3 Electrical Design……. 7-41
Subsection 7.3.4 Foundation, Pole Mounting, and Structural……....7-46
Subsection 7.3.5 TDOT Foundation Design……..7-47
Subsection 7.3.6 High-Mast Lighting Design……...……7-49
Subsection 7.3.7 Underpass Lighting……..…….... 7-50
Subsection 7.3.8 TDOT Bridge Lighting Plan…….. 7-51
Section 7.4 Materials And Equipment……..……... 7-57
Subsection 7.4.1 Foundations and Mounting……..… 7-58
Subsection 7.4.2 Pole Bases…….……. 7-58
Subsection 7.4.3 Poles……... 7-59
Subsection 7.4.4 Luminaires…….. 7-59
Subsection 7.4.5 Other Materials and Equipment……..……..……. 7-61
Section 7.5 TDOT Lighting Plans Layouts……..……... 7-61

Subsection 7.5.1 Photometric/Preliminary Plans Preparation……..…7-63
Subsection 7.5.2 Photometric/Preliminary Plan Review……..…. 7-63
Subsection 7.5.3 Lighting CADD Standards……... 7-64
Subsection 7.5.4 Site Visits and Field Review…….. 7-65
Subsection 7.5.5 Lighting Design Checklist…….…….…… 7-66
Subsection 7.5.6 Photometric Plans and Work Files Submittal……... 7-75

CHAPTER 8 – INTELLIGENT TRANSPORTATION SYSTEMS

Section 8.0 Introduction 8-1
Section 8.1 CFR 940 Compliance.....8-2
Subsection 8.1.1 Introduction and Scope 8-2
Subsection 8.1.2 General Criteria.....8-2
Subsection 8.1.3 High Risk ITS Projects.....8-3
Subsection 8.1.4 Low Risk ITS Projects 8-4
Subsection 8.1.5 Exempt ITS Projects.....8-5
Section 8.2 Architecture 8-7
Subsection 8.2.1 General.....8-7
Subsection 8.2.2 Architecture Conformity.....8-7
Subsection 8.2.3 Project Level ITS Architecture.....8-7
Subsection 8.2.3.1 For Projects Where a Regional or Statewide ITS Architecture Exists.....8-8
Subsection 8.2.4 Interfacing with Planning and the ITS Architecture.....8-8
Section 8.3 Systems Engineering Analysis (SEA) 8-10
Subsection 8.3.1 General.....8-10
Subsection 8.3.2 Level of Documentation.....8-12
Subsection 8.3.3 ITS Standards in the Systems Engineering Process ..8-15
Subsection 8.3.3.1 Required Systems Engineering Analysis Documentation for Low Risk and High Risk Projects……...8-16
Subsection 8.3.4 Additional Requirements 8-19

INDEX..…….…….…….…… I-1

APPENDIX

Glossary…….…….…… A-1

REVISION MEMORANDA

LIST OF TABLES

		Page
Table 1.1	Standard References……..	1-4
Table 2.1	Flow of Work and Typical Timeline……..	2-3
Table 2.2	Typical Project Plan Sheets……..	2-4
Table 4.1	Typical Uses of Locking and Non-Locking Memory..……..	4-26
Table 4.2	Comparison of Vehicle Detection Technologies.……...	4-30
Table 4.3	Pedestrian Signal Head and Pushbutton Needs……...	4-41
Table 4.4	Recommended Volume Density Timing Values.……...	4-57
Table 4.5	Recommended Yellow Change and All Red Clearance Intervals…...	4-59
Table 4.6	Recommended Pedestrian Interval Timing Values……...	4-61
Table 4.7	Typical Wire Sizes……..……..	4-101
Table 6-1	Post Selection for Various Sign Assemblies	6-21
Table 6-2	Estimating Weight of Supports	6-33
Table 6-3	Support Selection for Typical Access-Control Roadside Signs	6-37
Table 7.1	Pavement Classification……..……..	7-22
Table 7.2	Typical TDOT Highway Lighting Design Parameters……..	7-35
Table 7.3	TDOT Illuminance Design Criteria……..……..	7-39
Table 7.4	TDOT Luminance Design Criteria …….……..	7-40
Table 7.5	Lamp Amperes (HPS Mag Reg Ballast)……..	7-44
Table 7.6	Conductor Properties…..……..	7-45
Table 8.1	Risk Assessment for ITS Projects……..	8-6

LIST OF FIGURES

Figure 3.1	Condition Diagram……..	3-5
Figure 3.2	Collision Diagram……..	3-6
Figure 4.1	Basic Four Phase Pre-Timed Operation……..	4-4
Figure 4.2	Basic Four Phase Fully-Actuated Operation……..	4-6
Figure 4.3	Dual Ring Actuated Phasing Sequence……..	4-9
Figure 4.4	Turn Signal Displays…..……..	4-12
Figure 4.5	Left Turn Sight Distances……..	4-14

Figure 4.6 Typical Permitted Left Turn Sequencing…….. 4-16
Figure 4.7 Typical Protected Left Turn Sequencing…….. 4-17
Figure 4.8 Lead-Lag Left Sequencing……... 4-19
Figure 4.9 Recommended Phase Assignments for Four-Leg Intersections…... 4-22
Figure 4.10 Recommended Phase Assignments for T-Intersections……... 4-24
Figure 4.11 Typical Detection Zones……... 4-28
Figure 4.12 Advance Detector Placement……... 4-29
Figure 4.13 Typical Loop Detector Installation Layout……...4-32
Figure 4.14 Preformed Inductive Loop……... 4-33
Figure 4.15 Microwave Detection (Side-Fired Radar)……... 4-35
Figure 4.16 Video Detection……... 4-36
Figure 4.17 Pedestrian Interval Signs and Signals……... 4-39
Figure 4.18 Accessible Pedestrian Signal Pushbutton Locations……... 4-44
Figure 4.19 Actuated Phase Intervals……...4-50
Figure 4.20 Volume Density Timing Variable Initial Interval……... 4-53
Figure 4.21 Volume Density Timing Gap Reduction Feature……... 4-55
Figure 4.22 Vehicle/Pedestrian Interval Timing Relationship……... 4-62
Figure 4.23 Emergency Vehicle Preemption Sequence……... 4-68
Figure 4.24 Emergency Vehicle Preemption Example……... 4-71
Figure 4.25 Railroad Preemption Sequence (2 and 3 Phase Operation)……... 4-74
Figure 4.26 Railroad Preemption Sequence (8 Phase Operation)……... 4-75
Figure 4.27 Railroad Preemption Example……... 4-77
Figure 4.28 Horizontal and Vertical Locations of Overhead Signal Heads)……... 4-79
Figure 4.29 Signal Head Placement (No Left Turn Lanes)……... 4-81
Figure 4.30 Signal Head Placement (One Left Turn Lane)……...4-82
Figure 4.31 Signal Head Placement (Two Left Turn Lanes)……... 4-83
Figure 4.32 Signal Head Placement (Split Phase Operation)……...4-84
Figure 4.33 Typical Pedestrian Signal Details……... 4-86
Figure 4.34 Typical Strain Pole Details……... 4-90
Figure 4.35 Typical Mast Arm Pole Details……... 4-91
Figure 4.36 Typical Strain Pole (Span Wire) Layouts……... 4-93
Figure 4.37 Typical Mast Arm Pole Layouts……... 4-97
Figure 4.38 Typical Traffic Signal Wiring……... 4-100

Figure 4.39 Typical Pull Box Details…….. 4-104
Figure 5.1 Emergency Vehicle Traffic Signal……... 5-2
Figure 5.2 Intersection Beacon and Stop Beacon……... 5-4
Figure 5.3 School Speed Limit Beacons……... 5-6
Figure 5.4 Flashing Warning Sign Beacon.……...5-8
Figure 6.1 Intersection of 2 Major Routes (4-Way Intersections) 6-3
Figure 6.2 Intersection of 2 Major Routes (3-Way Intersections) 6-4
Figure 6.3 Intersection of 2 Major Routes With Overlapping Route Numbers ... 6-5
Figure 6.4 4-Way Intersection Route Signing With a Scenic (Bird) Route 6-6
Figure 6.5 3-Way Intersection Route Signing With a Scenic (Bird) Route..... 6-7
Figure 6.6 3-Way Intersection Route Signing With a Scenic (Bird) Route With Overlapping Route Numbers……..... 6-8
Figure 6.7 Crossroad Signing, Medians Less Than 30 feet, One-Way and Wrong-Way Signing 6-10
Figure 6.8 Signalized Intersections, Medians Less Than 30 feet, One-Way and Wrong-Way Signing..... 6-11
Figure 6.9 “T” Intersection Right, Medians Less Than 30 feet, One-Way and Wrong-Way Signing 6-12
Figure 6.10 “T” Intersection Left, Medians Less Than 30 feet, One-Way and Wrong-Way Signing 6-13
Figure 6.11 Median Crossover, Medians Less Than 30 feet, One-Way and Wrong-Way Signing 6-14
Figure 6.12 Crossroad Signing, Medians 30 feet or Greater, One-Way and Wrong-Way Signing 6-15
Figure 6.13 Signalized Intersection, Medians 30 feet or Greater, One-Way and Wrong-Way Signing 6-16
Figure 6.14 “T” Intersection Right, Medians 30 feet or Greater, One-Way and Wrong-Way Signing 6-17
Figure 6.15 “T” Intersection Left, Medians 30 feet or Greater, One-Way and Wrong-Way Signing 6-18

Figure 6.16 Median Crossover, Medians 30 feet or Greater, One-Way and Wrong-Way Signing 6-19
Figure 6.17 — Estimating Length of Support 6-32
Figure 6.18 — Strain Pole Foundation and Cable Connection Details..... 6-34
Figure 6.19 — Example of Overhead Sign Detail Sheet 6-36
Figure 6.20 — Sign Vertical Clearances..... 6-39
Figure 6.21 — Typical Signal Related Signs 6-41
Figure 6.22 — Stop Line Placement 6-46
Figure 6.23 — Stop Line Locations 6-47

Figure 7.1 Partial Interchange Lighting…….. 7-7
Figure 7.2 Partial Interchange Lighting…….…..…….. 7-7
Figure 7.3 Lighting Design Process Flow Chart……..... 7-16
Figure 7.4 Plan View of Roadway Coverage From IES Luminaires…….. 7-26
Figure 7.5 Sample Utilization Curve……..…….. 7-29
Figure 7.6 Roadway Luminaire Dirt Depreciation Curve…… 7-30
Figure 7.7 Typical Luminaire Arrangements For Conventional HWY Lighting... 7-31
Figure 7.8 Calculation Points For Luminance And Illuminance Design……... 7-38
Figure 7.9 Detail Of Overpass Bridge Lighting For Submittal To Structures..… 7-53
Figure 7.10 Detail Of Underpass Bridge Lighting For Submittal To Structures... 7-54
Figure 7.11 Detail Of Proposed Lighting Layout At Bridge Overpass (NTS)…… 7-55
Figure 7.12 Detail Of Proposed Lighting Layout At Bridge Underpass (NTS)….. 7-56
Figure 7.13 Typical Highway Lighting Structure…… 7-57
Figure 8.1 System Engineering in Relation to the Project Development……. 8-10
Figure 8.2 Steps to ITS Compliance…….. 8-12

CHAPTER 1

INTRODUCTION

1.0 About this Manual – This manual is prepared as a supplement to the Tennessee Department of Transportation (TDOT) Design Division Roadway Design Guidelines to aid in the development of signal, minor intersection improvement, lighting and signing and marking plans. Projects involving grading and drainage improvements and significant right-of-way acquisition should adhere strictly to the Design Division's Design Guidelines where any conflict with this manual may occur in the areas of project management or plans organization. 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 signal, signing, and lighting 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.

The purpose of this manual is to present the concepts and standard practices related to the design of traffic signals systems within the State of Tennessee.

This manual includes the following chapters:

CHAPTER 1 - INTRODUCTION

Chapter 1 introduces this Manual and gives background and the justifications.

CHAPTER 2 – TDOT PROJECT DEVELOPMENT

Chapter 2 discusses the traffic signal project development process.

CHAPTER 3 – NEED FOR TRAFFIC SIGNALS

Chapter 3 discuses the activities required in the preliminary design stages. This includes the procedures for justifying, approving, planning and designing a traffic signal.

CHAPTER 4 – TRAFFIC SIGNAL DESIGN

Chapter 4 details the operation and design of a traffic signal including phasing, detection, displays, timing, preemption, etc.

CHAPTER 5 – OTHER TYPES OF TRAFFIC SIGNALS

Chapter 5 reviews other types of highway traffic signals including emergency vehicle traffic control signals and flashing beacons.

CHAPTER 6 – SIGNING AND PAVEMENT MARKING

Chapter 6 covers the traffic signing and pavement marking related to traffic signals and intersection design.

CHAPTER 7 – ROADWAY LIGHTING

Chapter 7 summarizes the design of roadway lighting projects and design requirements.

CHAPTER 8 – INTELLIGENT TRANSPORTATION SYSTEMS

Chapter 8 addresses policies, guidelines, standard procedures, etc. related to Intelligent Transportation Systems (ITS) and the Systems Engineering Analysis.

1.1 Traffic Control Devices – Defined by the Manual on Uniform Traffic Control Devices (MUTCD) as all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, or bicycle path by authority of a public agency having jurisdiction.[1]

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.[2]

Three common types of traffic control devices are given below:

1.1.1 Traffic Signs – any traffic control device that is intended to communicate specific information to road users through a word or symbol legend.[3]

1.1.2 Markings – devices including pavement and curb markings, object markers, colored pavements, delineators, barricades, islands and channelizing devices used either alone or with other traffic control devices to communicate regulations, warnings, or guidance to road users.

1.1.3 Traffic Signals – any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed.[4]

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[1] MUTCD, 2003, FHWA, p. 1A-14
[2] Ibid. p. 1A-1
[3] Ibid. p. 1A-13
[4] Ibid. p. 1A-14

1.2 Design of Traffic Control Devices – The design of traffic control devices must be carefully prepared by a qualified individual in the civil engineering profession. 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. Traffic engineering is a specialty of the civil engineering discipline.

Traffic control designs must be sealed by a registered professional engineer with specialized training and experience in traffic engineering. Some States (such as California) and some organizations (such as the Institute of Transportation Engineers) provide registration or certification in traffic engineering.

1.3 TDOT Traffic Design Section – The TDOT Design Division, Traffic Design Section, is responsible for the development of traffic signal, roadway lighting and signing and marking plans both as stand alone projects and in support of larger roadway design projects administered by TDOT.

1.4 TDOT Information – General information about the Tennessee Department of Transportation is available on its web site at www.tdot.state.tn.us.

1.5 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 Administrative Procedures Act, the Manual on Uniform Traffic Control Devices (MUTCD) and subsequent revisions became a part of the Rules and Regulations of the State of Tennessee, Department of Transportation as approved by the Secretary of State (Tennessee Rule 1680-3-1.06). 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.

State Standards, References and Specifications include, but are not limited to the following:

Reference	Publisher
Design Guidelines	TDOT
Standard Roadway and Structures Drawings	TDOT
Standard Specifications for Road and Bridge Construction	TDOT
Speical Provisions	TDOT
Survey Manual	TDOT
Manual on Uniform Traffic Control Devices	FHWA
Standard Highway Signs	FHWA
23 CFR 940	FHWA
Standard Specifications for Structural Supports for Highway Signs, Lumiaires and Traffic Signals	AASHTO
A Policy on Geometric Design of Highways and Streets (Green Book)	AASHTO

CHAPTER 2

TDOT PROJECT DEVELOPMENT

2.0 Schedule – Keeping projects on schedule is a shared responsibility. It is imperative that projects involving traffic signal, signing and roadway lighting work are 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 design engineer and the assigned TDOT Manager. The designer should not hesitate to contact the TDOT Manager regarding any questions, difficulties or delays in receiving materials or information.

2.1 Three Party Plans Development – Often, local governing agencies prefer to use local funds to contract with design firms or to use in-house forces for the preparation of contract plans which will be let to contract by TDOT with state and federal funding. Various responsibilities are as follows:

2.1.1 TDOT – The TDOT project manager will be available to provide traffic data, pavement design and other related data as needed, to schedule and conduct field reviews and to review and submit utility, right-of-way and final construction plans. TDOT will submit all plans for Utility/Right-of-way coordination and for letting.

2.1.2 Local Agency – The local agency will hire and approve the consultant or on-staff designer and assure that plans development proceeds in a timely manner. They 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.

2.1.3 Design Engineer – The design engineer will develop a set of plans that adheres to the Department's plans format and is based on the established scope of work. The design engineer will contact the TDOT project manager as needed in a timely manner to settle design issues and answer questions.

2.2 Plan Development Stages – The various stages of development of signal, lighting and signing project plans include:

1 . Selection of design engineer, proposal submittal and approval of proposal

2. Begin work

- Issue work order
- Kick off meeting; although a face to face meeting is not always required, some understanding, in writing, of the various parties duties and responsibilities should be established.

3. Survey

4. Preliminary Design; this would include the preparation of a nearly complete set of plans for utility or right-of-way submittal. This should include all sheets except for the roadway quantities and some detail sheets. Survey Control points should be coordinated with the Regional Survey Offices through the TDOT manager. Where feasible, avoid design features requiring the acquisition of right-of-way or conflicts with utilities to help expedite the project.

5. Preliminary field review

6. Right-of-Way/Utility plans; When ready, preliminary plans should be transmitted to the TDOT Manager on full sized (24”x36”) reproducibles (vellums are acceptable) for field review distribution. If needed, the TDOT Manager will schedule a field review at a time and place most convenient to all reviewing parties involved. The design engineer will take minutes of the meeting and prepare them in a report format for distribution by the TDOT Manager to all attendees. On some smaller projects, a field review is not necessary and the plans will be distributed for comments only. The TDOT manager will summarize all comments in a report for distribution to reviewers. Upon completion of the review, the design engineer will incorporate valid comments into the plans and send a 1/2 sized (12”x18”) set of plans to the TDOT manager for review. Upon approval of the plans, the design engineer will transmit a set of mylar plans to the TDOT manager for Utilities/Right-of-Way incidentals distribution. (Please note that state laws allow utilities a 120-day review period before utility certification can be accomplished).

7. Right-of-Way plans submittal

8. Construction plans development; upon submittal of Utilities/Right-of-Way plans, final construction plans can proceed immediately. Construction plans should also include all roadway quantities sheets, index sheets, notes, tabulations and details as required. If the TDOT manager determines a construction plans review is appropriate, the design engineer will transmit full sized reproducibles for distribution.

9. Construction review

10. Construction plans submittal; upon approval of final plans, the design engineer will submit signed and sealed (on every sheet) mylars for printing and advertising. A floppy disk or CD containing a listing of all the roadway quantities in the proper format should be submitted with the mylars. The design engineer should contact the TDOT manager regarding the proper database format. Often, the TDOT Construction Division requires changes during the advertisement period of the bid letting process. The design engineer should be prepared to make all necessary revisions and

submit on new mylar sheet(s) as soon as possible after receiving instructions to do so.

11. Post letting; Requests for construction revisions will occasionally come from the TDOT manager and should be processed as soon as possible.

A typical time line is shown in Table 2.1 below.

Table 2.1 Flow of Work and Typical Timeline (No ROW Acquisition)

	Months before Letting											
Task	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Kick-Off Meeting												
Preparation of Preliminary Plans												
Submittal for Incidentals												
Preparation of Final Plans												
Submission of Final Plans												
Advertise for Bids												

2.3 Support Projects – are often prepared as part of a larger grade and drain project by a sub- consultant or in-house staff and require just signal, lighting or signing layouts and detail sheets (or sign schedules).

Support projects are often prepared by design engineers not under the direct supervision of the primary P.E. responsible for signing and sealing the plans in general. In this case, quantities and notes should be included on a sheet separate from the project quantities under the seal of the supporting signal design engineer. Coordination between the primary P.E., the supporting design engineer and the TDOT manager should be maintained throughout the design process.

2.4 Conformance to TDOT Plans Format – The Department requires all roadway plans let to contract in the State's bid process to be developed in the particular TDOT format described in the Design Division's Design Guidelines and as adapted for traffic design in this manual. The Department 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 the many designers, inspectors and road contractors have become familiar and comfortable with. Variations from this format could create some confusion and misunderstanding and should be avoided. Plans Layout Requirements:

2.4.1 Sheet Numbering (example shown in Table 2.2 is an intersection widening project with a traffic signal)

2.4.2 Plans Scale for signal layout sheets should be a minimum of 1" = 50' with a desirable scale of 1" = 20' for intersection signal layouts.

2.4.3 Aerial Photography 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 Manager before using aerial photography.

2.4.4 Details –A signal detail sheet will be required for each signal installation and shall display tabulations of phasing, detection and timing requirements (see appendix).

2.4.5 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.

2.4.6 Quantities – Keep items as specific as possible. Avoid "costs to be included in other items" if possible.

Table 2.2 Typical Project Plan Sheets

	Plan Set Type		
Sheet	**Utility Only**	**Utility/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 (next number)	8 (next number)	8 (next number)
Traffic Control	8 (next number)	9 (next number)	9 (next number)
Cross-Sections	9 (next number), 10, etc.	10 (next number), 11, etc.	10 (next number), 11, etc.

CHAPTER 3

NEED FOR TRAFFIC SIGNALS

3.0 Highway Traffic Signals – The MUTCD defines a "highway traffic signal" a power-operated traffic control device by which traffic is warned or directed to take some specific action. These devices do not include power-operated signs, illuminated pavement markers, barricade warning lights, or steady-burning electric lamps.

The term "traffic signal" has been associated with an intersection stop-and-go signal. However, "traffic signals" can apply to other types of power operated devices.

Listed below are the general types of traffic signals that are commonly used today:

A. Traffic Control Signals (Traffic Signals) – any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed. *This is what is normally referred to as a" traffic signal"*. Chapter 4 goes into detail on traffic control signals.

- **Pedestrian Signals –** a part of a traffic control signal to direct pedestrians when to cross a street.

B. Other Highway Traffic Signals (See Chapter 5):

- **Emergency Vehicle Traffic Control Signals –** a special traffic control signal that assigns the right-of-way to an authorized emergency vehicle.
- **Lane-Use Control Signals –** 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.
- **Ramp Control Signal –** a highway traffic signal installed to control the flow of traffic onto a freeway at an entrance ramp or at a freeway-to-freeway ramp connection.
- **Flashing Beacons –** a highway traffic signal with one or more signal sections that operates in a flashing mode.

In this Manual, the term "traffic signals" will assume to apply to intersection stop-and-go signals unless otherwise noted.

3.1 Cooperation with Local Agencies – The Tennessee Department of Transportation (TDOT) does not typically own, operate or maintain traffic signal devices or street lighting installed under Departmental projects or located along state highways. Ownership, along with responsibility for operation and maintenance, reverts to the local governing agency executing either the Right-of-Way agreement or other funding contracts as provided by the Department.

It is TDOT's goal to provide a safe, reliable and economically sound traffic control or street lighting 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. However, the specification of proprietary items will not be allowed except in special pre-approved cases.

3.1.1 Authorization of Installation of Traffic Signals:

A. Authorization of Installation of Signals on TDOT Projects (state or local routes): It shall be the responsibility of the Civil Engineering Manager 1 in charge of the Traffic Design Section, 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.

Recommendations for new signal installations as part of a Final Scoping Report (FSR), Advance Planning Report (APR) or Safety Project report shall be reviewed and approved by the Traffic Design Office before the final report is issued to avoid problems in the Design phase of the project.

Proposed signal operation should safely, economically and efficiently accommodate current and near future traffic and safety needs. Although some local governmental agencies may request certain aesthetic features, enhancement of signal systems with materials or equipment that does not meet basic operational needs should generally be avoided unless the local agency is willing to cover the additional costs with local funds.

Before installations of traffic control devices are approved, an engineering study shall be performed and sealed by a licensed Engineer and approved, in writing, by appropriate TDOT officials as stated above. As required by the Manual on Uniform Traffic Control Devices (MUTCD), an engineering study shall be performed and should indicate "that installing a traffic control signal will improve the overall safety and/or operation of the intersection."[1] If not, a traffic signal should neither be put into operation nor continued in operation.

B. Authorization of Installation of Signals on Non-TDOT Projects (on state routes): All locally initiated signal design projects shall follow procedures and conform to guidelines given in this Manual.

C. Authorization of Installation of Signals on Non-TDOT Projects: (non-state routes): For locally initiated signal designs affecting the

[1] MUTCD, FHWA, 2003, p. 4C-1

intersection of two or more local routes, procedures and guidelines in this Manual are recommended as they represent current best practices.

3.1.2 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:

A. Tennessee Department of Environment and Conservation (TDEC)

- Notice of Intent (NOI)
- Aquatic Resource Alteration Permit (ARAP)
- Class V Injection Well Permit

B. Corps of Engineers: 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.

C. 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.

D. Tennessee Wildlife Resources Agency (TWRA): Any impact on the Reelfoot Lake Basin will require a TWRA permit.

The design engineer shall consult with the Environmental Planning Division for the latest requirements and guidelines for any environmental permits.

3.1.3 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.

3.2 Justification for Traffic Signal Control – Generally, the installation of a traffic control signal is considered only after all of the following conditions are met:[2]

- One or more of the MUTCD traffic signal warrants are met.
- An engineering study shows that traffic signalization will improve the overall traffic operations and/or safety of an intersection.
- The resulting traffic signal will not 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."[3]

3.2.1 Traffic Signal Study Advance Engineering Data – The following engineering data should be included in a traffic signal study.[4]

A. Traffic Counts – Traffic counts should be made on a typical weekday for the location, which would normally be in the middle of the week (Tuesday thru 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. Counts should include cyclists.

- **Machine Traffic Counts –** Twenty-four (24) hour directional machine counts should be conducted on each approach counting all vehicles entering the intersection.
- **Manual Traffic Counts –** Manual traffic counts should be conducted on each approach of the intersection showing all vehicular movements during each 15-minute interval for a minimum of 2 hours in the AM, midday, and PM peak periods. In any case, these hours should include the periods of greatest traffic volumes as revealed by the previously conducted machine traffic counts.
- **Pedestrian Traffic Counts –** If pedestrians are a concern, pedestrian volume counts should be conducted on each crosswalk for the same periods as the manual traffic 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 count data should be submitted in a format that shows hourly pedestrian volumes by approach.

[2] Traffic Engineering Handbook. 1999. p.460
[3] MUTCD, FHWA, 2003, p. 4C-1
[4] Ibid p. 4C-2.

B. **Speed Data –** a speed study showing the 85th percentile speeds on the approaches to the intersection.

C. **Condition Diagram –** a diagram of the intersection showing its geometry, channelization, pavement markings, signs (traffic, business marquees, and billboards) driveways, utility poles, parking conditions, transit stops, sidewalks and handicap ramps, vegetation (if over 3' in height), adjacent land use, nearby railroad crossings and the distance to the nearest traffic signal (if less than 1 mile). See Figure 3.1.

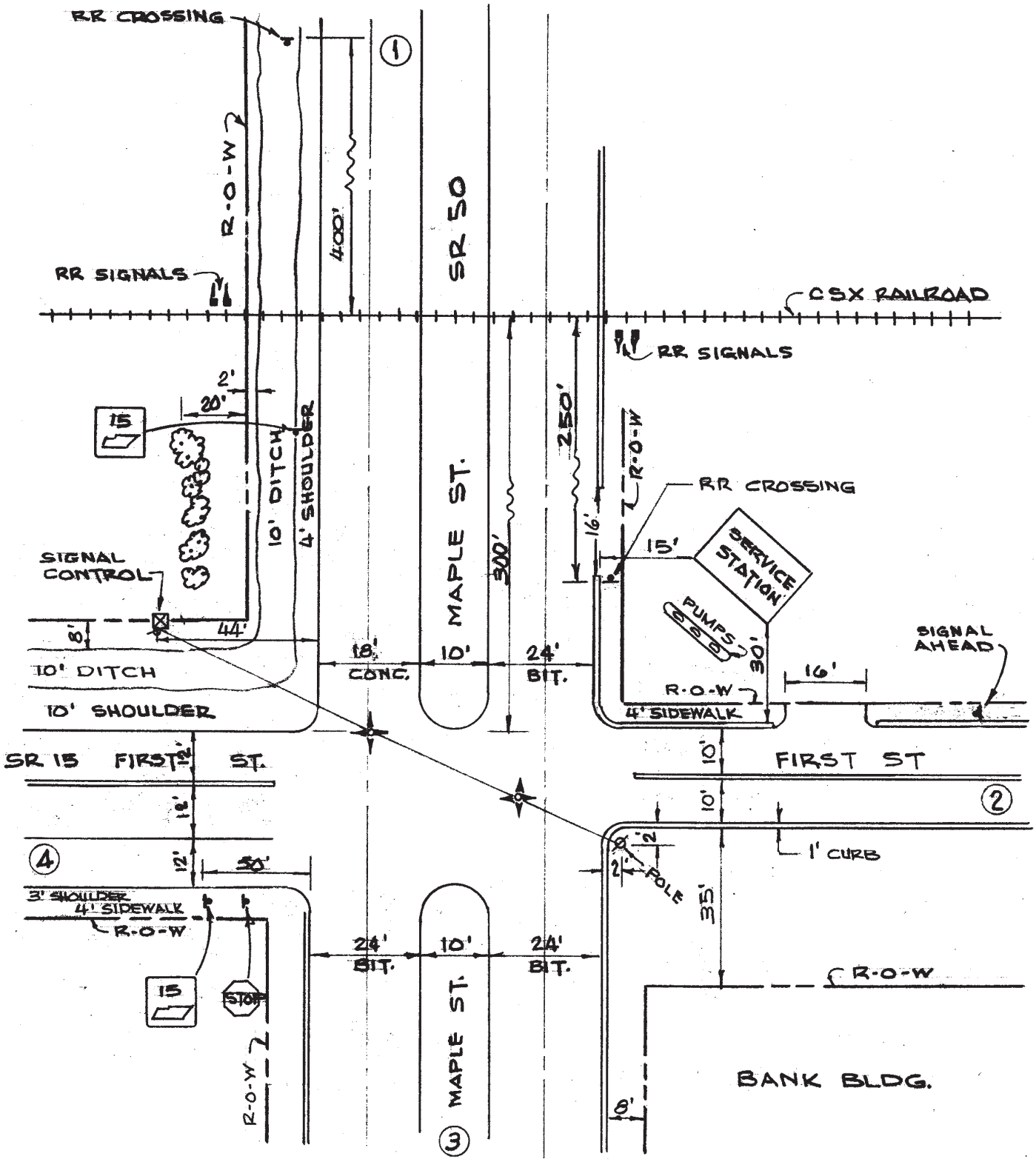
D. **Collision Diagram –** a diagram or listing showing the crash record for the intersection covering the most recent 12 months (as a minimum) for which records are available. Each crash symbol or record should show the crash type, the direction of travel of the vehicles, the severity (injuries/fatalities), time of day, date, pavement condition, weather, and lighting conditions. See Figure 3.2.

3.2.2 Traffic Signal Warrants

A. **Signal Warrants –** Traffic signal warrants define minimum threshold levels for a set of objective traffic and pedestrian operational conditions. If met, they become part of a total engineering study needed to justify signalization.[5] The MUTCD identifies eight traffic signal warrants as follows:

- Warrant 1 – Eight Hours 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

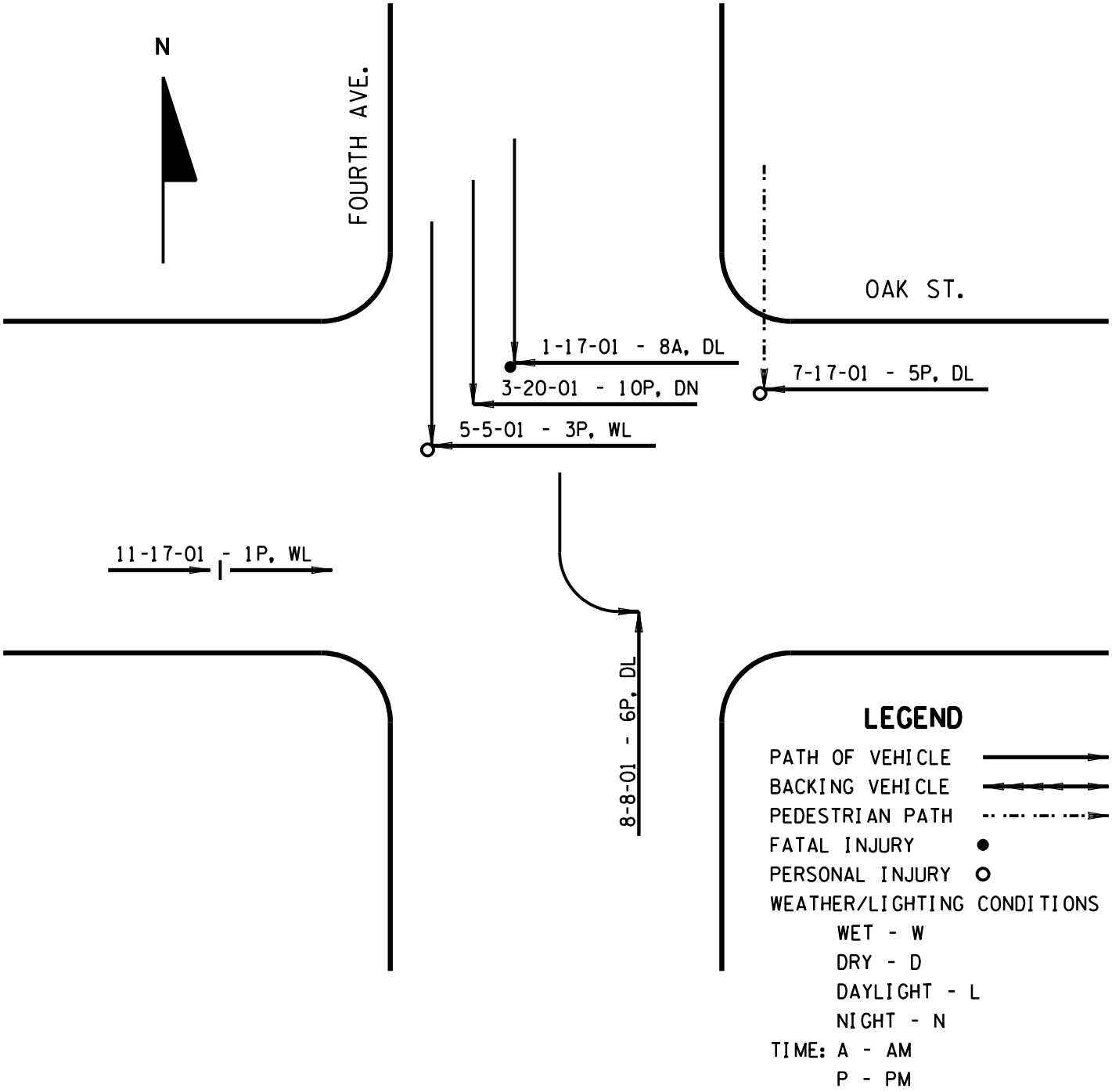
[5] Traffic Engineering Handbook. 1999. p. 460



Tennessee Department of Transportation
Traffic Design Manual

Condition Diagram

Figure 3.1



Tennessee Department of Transportation
Traffic Design Manual

Collision Diagram

Figure 3.2

3.2.3 Right Turn Volume Consideration[6] **–** Engineering judgment should be used as to whether all or part of right turning traffic volumes on the side street should be included when applying signal warrants. If right turns on an intersection approach are in a mixed lane containing through and right turning traffic, they should be included in the analysis. However, the percent of right turning traffic and its conflict with major street traffic must be considered. If the right turns are in their own lane and channelized away from the intersection, they should probably be excluded from the analysis. Engineering judgment should be applied in all cases.

- **Approach Lane Consideration –** Where there are separate turn lanes present on a single lane intersection approach, the question arises as to whether these lanes should be counted as an approach lane for warrant application. The following guidelines are provided:

- **Left Turn Lane –** If a separate left turn lane is present on an approach, it may be considered an approach lane if it carries approximately half the approach traffic volumes and it has sufficient storage capacity to store the left turning traffic.[7] Engineering judgment should be used.

- **Right Turn Lane –** If a separate 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 turns have been eliminated from the approach volumes for warrant analysis, then any separate right turn lane present should not be included in the number of approach lanes. If no separate right-turn lane exists, right-turning traffic should be included in analysis of the warrant. If a separate right-turn lane exists and delays to right-turning vehicles are significant, a capacity analysis may be conducted to determine the impact of the right-turn volume on operation. Engineering judgment should be used.

[6] Ibid p.461
[7] MUTCD, FHWA, 2003, p. 4C-1

3.2.4 TDOT Signal Justification Guidelines

A. Application of Signal Warrants – In investigation of warrants toward signal justification, Warrant 1 (Eight Hour Vehicular Volume) or Warrant 7 (Crash Experience) will be the primary warrants considered for signal 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. Signal justification based on other warrants will be considered only when extenuating circumstances exist.

B. Access to Adjacent Signals – Before new signalization is justified, 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 might be denied based on the access to an existing signal. Such traffic diversions may not be practical, however, if the diversion takes place through residential areas or on substandard streets. Engineering judgment must be exercised.

C. 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 portion of development to be completed at time of signal installation. The following procedures will be used:

- **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 Trip Generation Manual published by the Institute of Transportation Engineers.

Whether calculated based on an existing similar development or estimated using data from the Trip Generation Manual, all assumptions and trip estimates must be approved by the TDOT Mapping and Statistics Office.

D. Signal Operation – A capacity analysis may be required to determine the impacts of signalization at an intersection. If within an existing coordinated system or if progression of the corridor should be considered, a progression analysis should also be completed.

3.3 Removal of Traffic Signals – Although the original installation of a traffic signal may be based on the satisfaction of one or more 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 warrants for the removal of traffic signals[8].

A general rule of thumb is that if a traffic signal does not meet 60% of the values of any of the warrants, the signal should be analyzed for removal. Even though traffic volumes may have decreased, the removal of a traffic signal requires engineering judgement 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:

1. Determine the appropriate traffic control to be used after removal of the signal.

2. Remove any sight-distance restrictions as necessary.

3. Flash or cover the signal heads for a minimum of 90 days, and install the appropriate stop control or other traffic control devices.

4. Remove the signal if the engineering data collected during the removal study period confirms that the signal is no longer needed. 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.

5. Remove traffic signal equipment if the continued analysis finds the intersection

[8] MUTCD, FHWA, 2003, p. 4B-1.

CHAPTER 4

TRAFFIC SIGNAL DESIGN

4.0 General – "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 pedestrians, bicyclists, vehicles, and other conveyances using any highway for purposes of travel. This Chapter 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.[1]

The selection and use of traffic signals should be based on an engineering study of roadway, pedestrian, bicyclist and other conditions.

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 Department Standard Specifications, the following standards shall be consulted:

- Manual on Uniform Traffic Control Devices (MUTCD) – The MUTCD is the basic guide for signing and marking. The requirements of the MUTCD must be met, as a minimum, on all roads in Tennessee.
- Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, AASHTO – This document provides structural design criteria.
- The National Electrical Code, National Fire Protection Association (NFPA) – This code contains provisions that are considered necessary for the practical safeguarding of persons and property from hazards arising from the use of electricity.
- National Electrical Manufacturer's Association (NEMA) Standards for Traffic-actuated Controllers – This publication describes the physical and functional requirements of signal controllers. Two standards, TS-1 and TS-2, are defined. TS-1 dates back to the 1970s but still applies to most of the equipment in current use. TS-2 is an emerging standard that incorporates contemporary computer and communications technology.
- TDOT Design Standards – These standards are composed of a number of standard drawings that address specific situations that occur on a large majority of construction projects.

4.1 Traffic Signal Design – A traffic signal shall be designed for both safe and efficient traffic operations. To accomplish this, the design should incorporate the fewest number of signal phases and the shortest cycle lengths that can efficiently

[1] MUTCD, FHWA, 2003, p. 4B-1.

move traffic without compromising safety. The design and operation of traffic signals shall take into consideration the needs of pedestrians as well as vehicular traffic.[2] The following design criteria set forth TDOT's application of the traffic signal design standards given in the MUTCD.

The key decisions affecting a traffic signal system design include:

- Intersection geometrics (lanes, sight distance, grade, etc.)
- Determination of traffic signal operational mode
- Selection of left turn treatments
- Selection of the traffic signal phasing plan
- Determination of detection needs
- Development of traffic signal timing parameters
- Development of the timing plan(s) for arterial coordination
- Determination of preemption needs
- Location and configuration of all traffic signal displays
- Location and configuration of the controller and cabinet
- Selection of type and location of traffic signal support poles
- Determination of necessary traffic signing
- Location of stop lines and crosswalks
- Determination of wiring, conduit and pull box needs

Future Intersection Expansion – Any planned or anticipated intersection improvements or future phasing needs should be considered. The traffic signal controller type, cabinet type, pole design and traffic signal cable are examples of design features that may be affected by future improvements.

4.1.1 Intersection Geometrics – Intersection geometrics play a pivotal role in designing a traffic signal. In particular, geometrics play just as important a role as traffic volumes in evaluating turn phasing. For example, left turns may be made from shared lanes yielding to the opposing thru traffic; however, the capacity of a shared lane is somewhat limited. The Highway Capacity Manual provides a procedure for assessing the capacity of both shared and exclusive lanes under traffic signal control. The operational advantage of an exclusive lane should be clear from a capacity perspective. Exclusive left turn lanes are normally required when protected left turn movements are provided in the traffic signal phasing.

When left turning volumes are high, multiple exclusive left turn lanes may be required to provide adequate capacity. Dual left turn lanes should be considered when a capacity analysis suggests that overall intersection performance could be improved. Proper attention must be paid to accommodating traffic in multiple left turn lanes as it leaves the intersection. The exit roadway must have enough lanes to accommodate the left turns and pedestrian crosswalks should be clearly marked. Pedestrian signals should always be used for any crosswalk in which pedestrians will encounter protected left turns.

4.1.2 Traffic Signal Movements – A typical four-leg intersection can have up to eight separate movements requiring traffic signal phases (four thru and four left turns). If right turn movements are signalized separately, they are usually operated in conjunction with a protected side street left turn

[2] MUTCD, FHWA, 2003, p. 4D-2.

movement and operated as an overlap (concurrently with another phase). Four-leg intersections can be operated with between two and eight phases. Two phase operation would only provide phases for the two crossing movements, while the eight phase operation would provide separate phases for each movement. An intersection with two to four vehicle phases should use a four phase cabinet facility. An intersection with five to eight vehicle phases should use an eight phase cabinet facility. Newer controllers allow up to 16 phases, but more than eight phases are only used in unusual situations, such as running two intersections from one controller or complex interchanges.

Four phase cabinets should be used for intersections with 2 to 4 phases and eight phase cabinets should be used for those with 5 to 8.

4.1.3 Traffic Signal Mode of Operation – A traffic signal may operate under two basic modes of operation. It may operate as a fixed time signal, in which basic timing intervals are constant, or as an actuated signal, where many of the timing intervals are variable based on demand.

Traffic signals may be operated as independent (or isolated intersections) or as part of a coordinated signal system. Coordinated traffic signal systems are designed to minimize delay. An individual intersection operates most efficiently when it is allowed to respond to traffic demand in an actuated mode. Actuated operation allows the traffic signal to adjust the cycle length and phase split times on a cycle-by-cycle basis. At all intersections, vehicles tend to group into "platoons." Once a platoon is established, delay can be reduced by keeping the platoon moving through adjacent signals. The coordination of traffic signals (operating more than one signal in a system) can provide smooth progression along an arterial. Operating traffic signals in a coordinated mode does have some drawbacks. The coordination of the system may further delay some minor traffic movements.

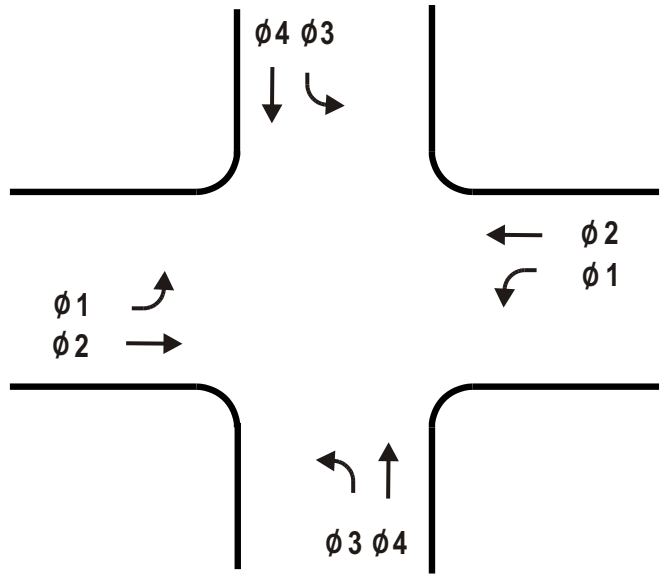
Traffic signals can operate as an independent intersection or as part of a coordinated system. The traffic signals can be set up to operate in the fully or semi-actuated mode, in fixed time mode, or in a flashing mode of operation. How a signal is operated determines its effectiveness in reducing delay and increasing safety. Signal operation also influences public acceptance.

4.1.4 Pre-Timed (Fixed Time) Operation – Pre-timed operation is an infrequently used mode of operation (except in downtown areas) in which a traffic signal operates in a non-actuated mode (no vehicle detectors) and in which both the timing and phasing do not vary from cycle to cycle (see Figure 4.1).

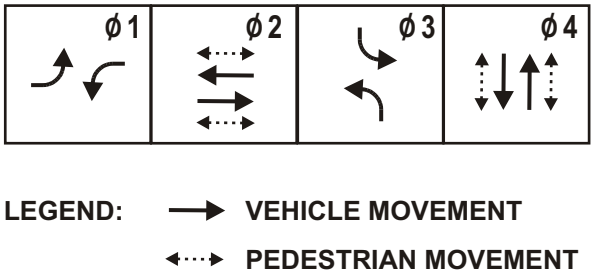
Pre-timed two-phase operation is often used in a central business district, but is infrequently used on major streets.

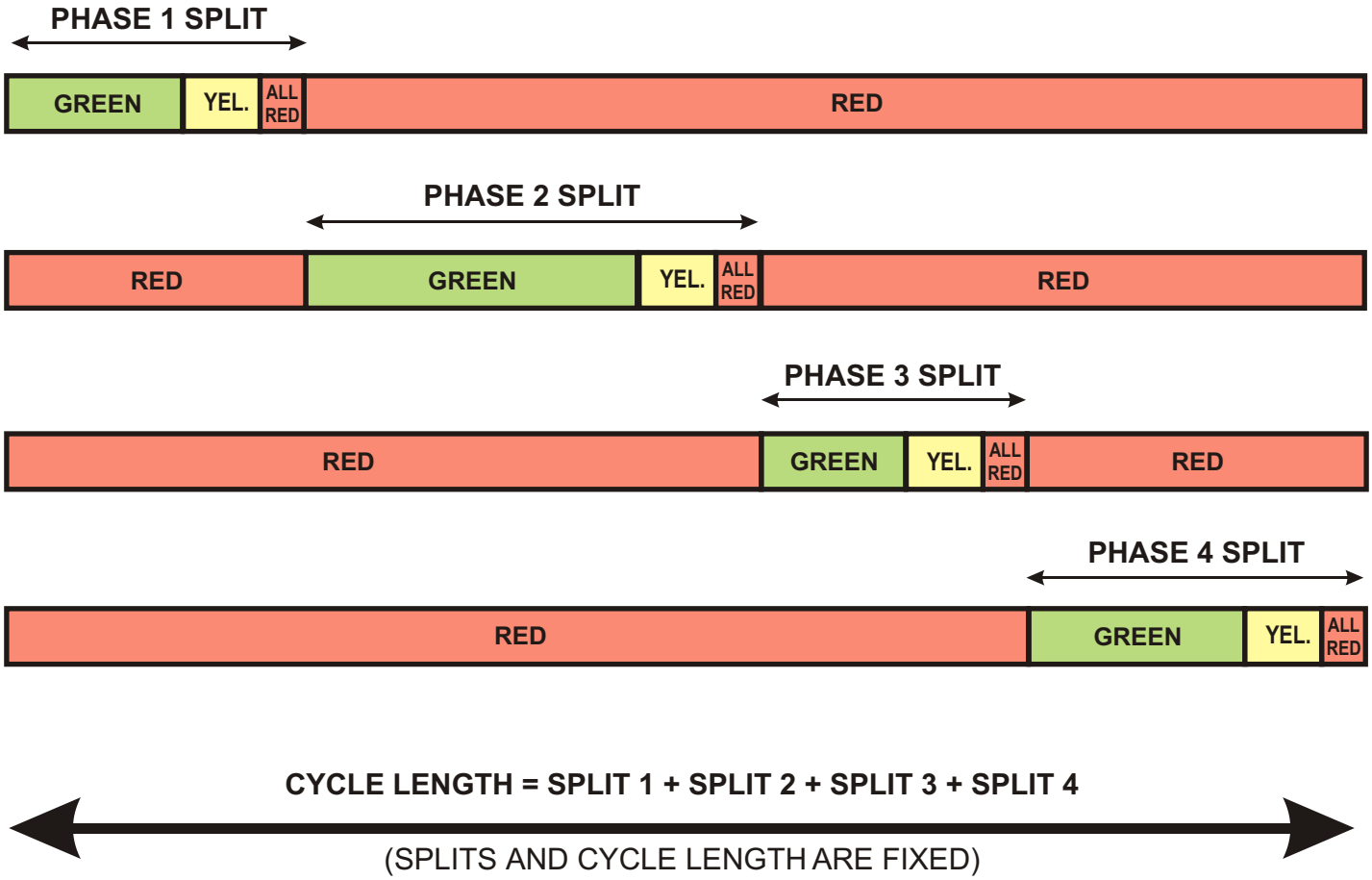
Advantages to pre-timed operation include:

1. Simplicity of equipment
2. Easy to coordinate along a route or in a grid (like a CBD)



FOUR-PHASE





Tennessee Department of Transportation
Traffic Design Manual

Basic Four Phase
Pre-Timed Operation

Figure 4.1

Disadvantages to pre-timed operation include:

1. Can't recognize or adjust to short term fluctuations in traffic
2. Can cause excessive delays to vehicles and pedestrians during off-peak periods

Pre-timed operation is best suited for the following conditions:

- **Uniform Traffic Demand –** where traffic variations and timing requirements are predictable or do not vary significantly.
- **Signal Coordination –** at intersections in which the major street continuously operates in coordinated mode and fluctuations in volumes along the minor street are negligible.
- **Closely Spaced Signalized Intersections –** at intersections where coordination between adjacent intersections is needed to provide consistent interval timing and offsets.
- **CBD Signals and One-Way Streets** – where two-phase operation is utilized to provide a measure of coordination and speed control.
- **Maintenance –** where ease of maintenance is a concern (no vehicle detectors to maintain).

4.1.5 Traffic Actuated Operation – Traffic-actuated operation of isolated intersections attempts to adjust green time on one or more approaches continuously. These adjustments occur based on real-time traffic measures of traffic demand from vehicle detectors placed on one or more approaches to the intersection.

Advantages to actuated operation include:

1. Reduced Delay (if properly timed)
2. Adaptable to short-term fluctuations in traffic flow
3. Increased capacity
4. More effective at multiple phase intersections

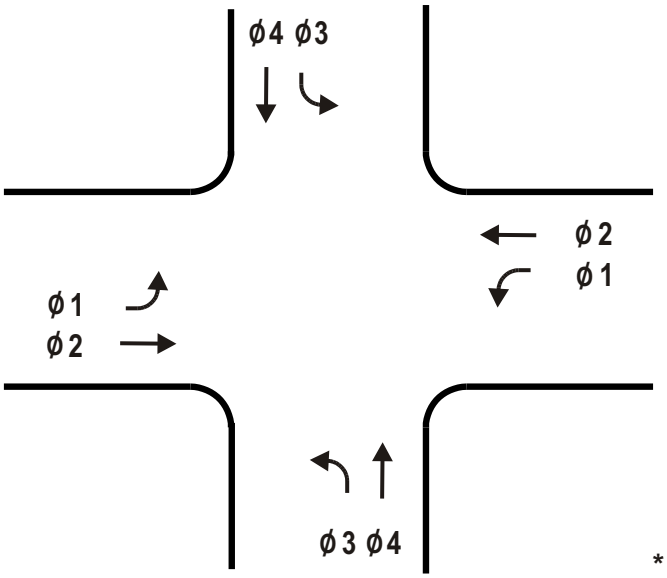
Disadvantages to actuated operation include:

1. Higher cost than pre-timed
2. Long term maintenance of detectors

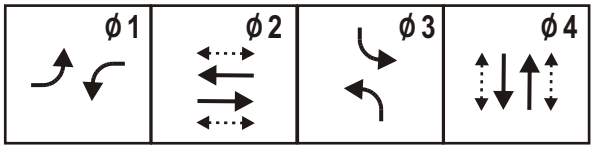
Traffic actuated signal control can be broken into two types of operation (fully-actuated and semi-actuated, or partially activated).

4.1.6 Fully-Actuated Operation – Fully-actuated operation describes the actuated mode of operation in which a traffic signal operates with vehicle detection for all signal phases. Since the traffic signal operation is based on traffic demand, both the timing and phasing can vary from cycle to cycle (see Figure 4.2).

Fully-actuated operation should normally be used at isolated, high speed and heavy volume intersections.



FOUR-PHASE



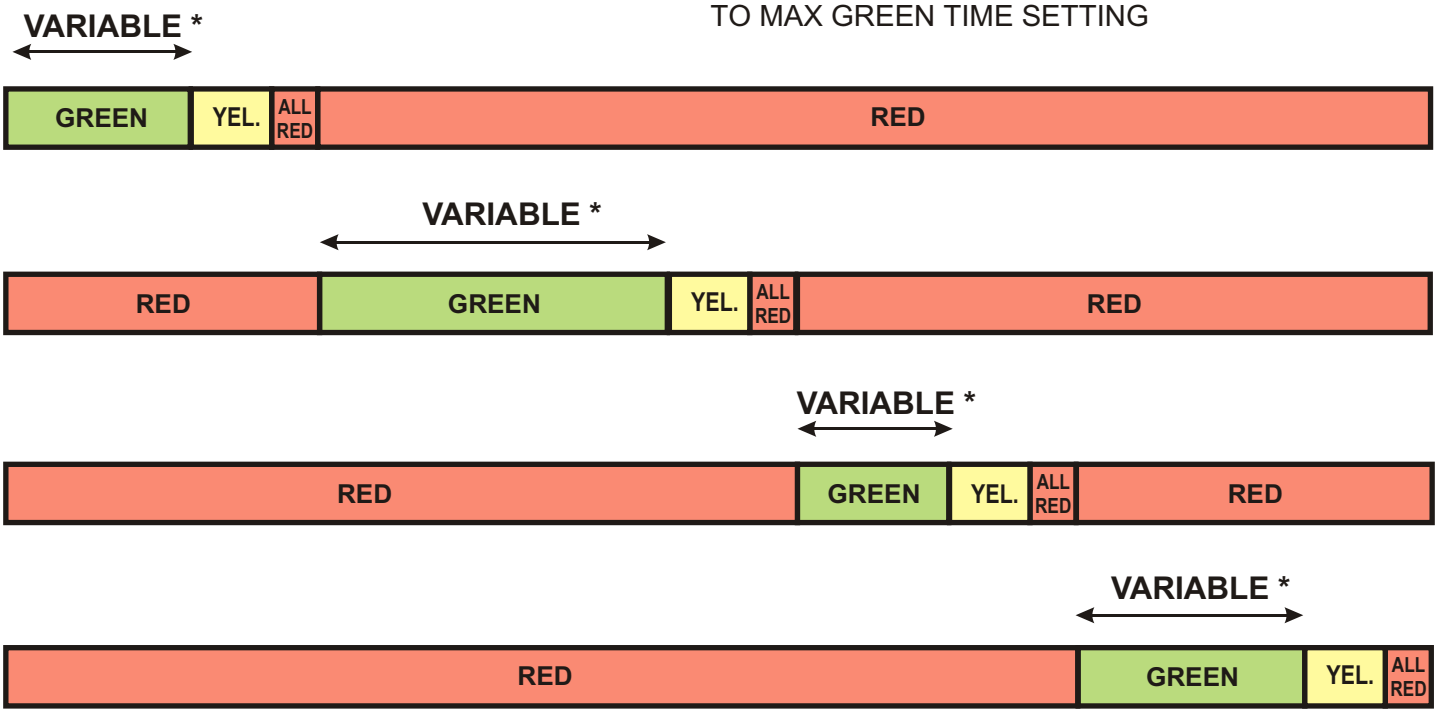
LEGEND: → **VEHICLE MOVEMENT**

↔ **PEDESTRIAN MOVEMENT**

* EACH **GREEN INTERVAL** VARIABLE FROM:

A. MIN GREEN TIME SETTING IF ON RECALL
OR
B. ZERO IF NOT ON RECALL

TO MAX GREEN TIME SETTING



NO TRUE CYCLE LENGTH

(PHASE GREENS VARIABLE - YELLOW AND ALL RED ARE FIXED)

Tennessee Department of Transportation
Traffic Design Manual

Basic Four Phase Fully-Actuated Operation

Figure 4.2

Fully-actuated operation should be considered under any of the following conditions:

- **Isolated Intersections –** where traffic fluctuations cannot be anticipated, fully-actuated operation provides maximum flexibility by allowing the traffic signal controller to skip those phases without traffic present.
- **High Speed Intersections –** to reduce problems caused by arbitrary stopping of the major street thru movement, regardless of demand.
- **Part Time Coordination –** when a traffic signal operates in a system part of the day, but operates in a "free" mode at other times.
- **Efficiency –** where traffic operations require maximum efficiency to adequately accommodate existing traffic volumes at the best possible level of service. Fully-actuated operation allows the traffic signal controller to tailor its timing to each individual signal phase according to its actual traffic demand on a cycle-by-cycle basis.

Volume-density operation is a more sophisticated form of fully-actuated control. It has the ability to calculate the duration of Minimum Green based on actual demand (calls on red) and the ability to reduce the maximum allowable time between calls from the initial Passage Time to a Minimum Gap. This reduction in allowable time between calls (or actuations) generally improves efficiency.

4.1.7 Semi-Actuated Operation – Semi-actuated operation is similar to a fully-actuated traffic signal with but not all signal phases are actuated. Some movements do not have detection and are operated as pre-timed phases. When this type of operation is chosen, it is usually the major street signal phase that is non-actuated. The timing on the phases that are actuated can variable or be entirely skipped from cycle to cycle as traffic demands.

In semi-actuated coordinated systems, the major movement is the coordinated phase. Because the major movement is the coordinated phase, it is in effect on constant recall, and no detection is needed while the system is operating. Minor movements are served only when called (or detected) and only at certain points within the system background cycle. In a system, these points ensure that the major movement will be coordinated with adjacent intersections.

Semi-actuated operation should be used when side street volumes are low and sporadic or when an intersection is operated in coordination 24 hours a day.

In semi-actuated controlled intersections that are not in a system, the major movement is placed on Minimum Recall. The major movement rests in green until a conflicting call (detection) is received. The Minimum Green must be long enough to ensure it is adequate for the major street movement, but not so long as to unnecessarily delay side street traffic.

Semi-actuated operations can work under one of the following conditions:

- **Unpredictable Side Street Volumes –** where side street volumes are sporadic.
- **Limited Traffic Signal Need –** where a traffic signal is needed for only brief periods of the day.
- **Full Time Signal Coordination –** in signal systems that operate in a coordinated mode at all times, where the main street thru traffic phase operates without vehicle detection.

4.1.8 Mode During System Control – Many fully-actuated traffic signals that are in signal systems operate as both fully-actuated and semi-actuated traffic signals. They can be fully-actuated during off peak hours when the system may not running and all intersections to run free, but operate as semi-actuated traffic signals when the system is running.

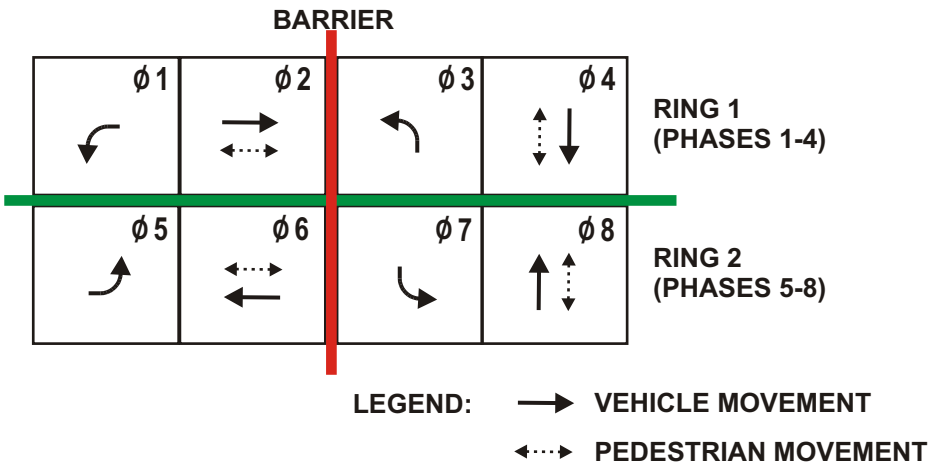
4.1.9 Dual Ring Controller Operation – A traffic actuated controller typically employs a "dual ring concurrent" timing process. This concept is illustrated in Figure 4.3. A dual-ring controller uses eight phases, each of which controls a single traffic movement. The eight phases are required to accommodate the eight movements (four thru and four left turns) at an intersection. Any movements that do not have a separate protected movement are not assigned phases and not used. Phases 1 through 4 are included in ring 1, and phases 5 through 8 are included in ring 2. The two rings operate independently, except that their control must cross the "barrier" at the same time.

The dual-ring concurrent operation of an isolated actuated traffic signal can be the most efficient method of operation.

To avoid conflicts, all of the movements from one street must be assigned to one side of the barrier. Similarly, all movements from the other street must be assigned to the other side. On both sides of the barrier there are four phases (two thru and two left). One phase from ring 1 and one phase from ring 2 may operate concurrently, however the concurrent phases must be on the same side of the barrier (see Figure 4.3). Simultaneous phase operation in each ring is not permitted.

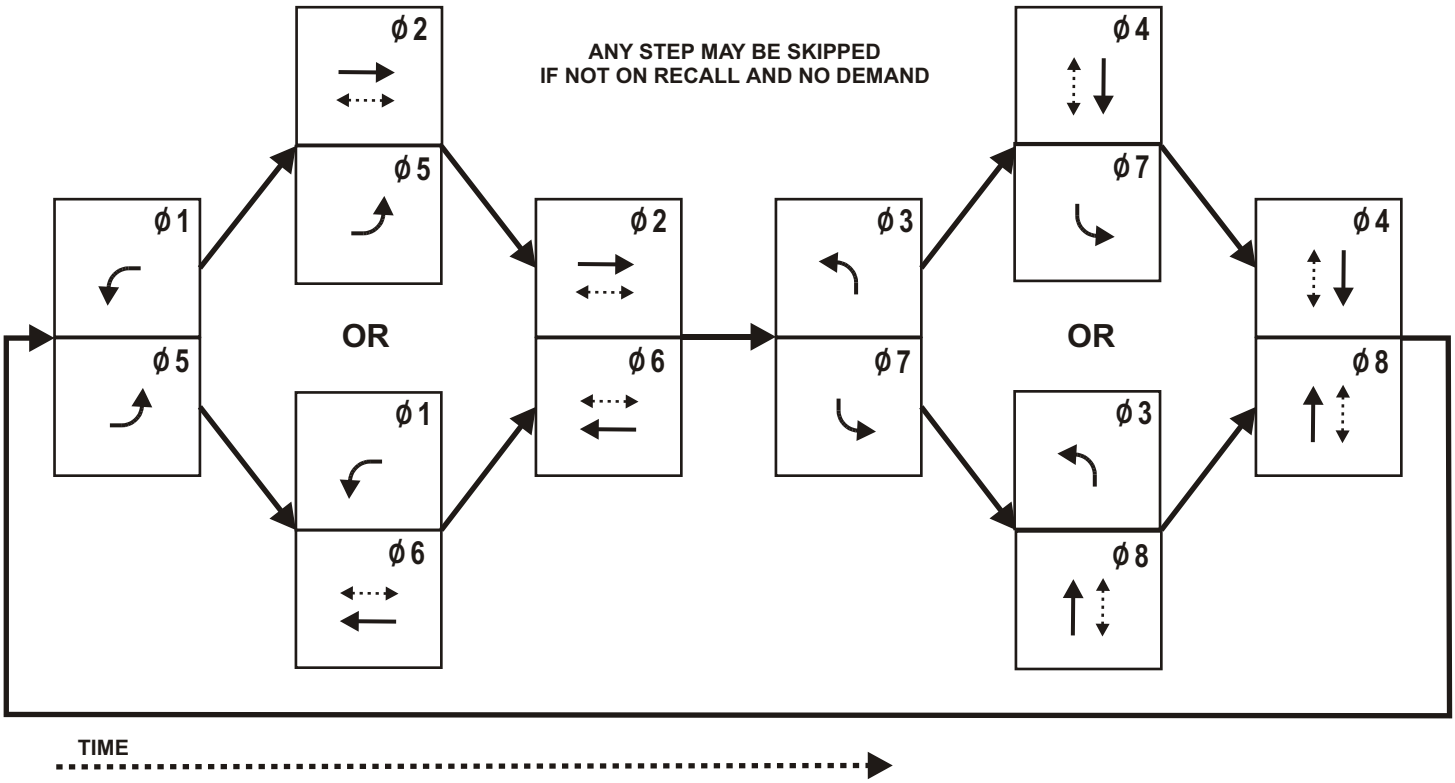
As an example, if phase 2 (in ring 1) is the EB thru movement, it may be displayed concurrently with either phase 5 (EB left turn) or phase 6 (WB thru), both of which are in ring 2. However, phase 2 can never be displayed concurrently with any of the phases across the barrier (phases 3, 4, 7 or 8 – all side street phases). Any allowed combination of phases may be skipped if there is no demand for that movement.

Four phase operation can be achieved using a dual ring controller by only using phases 1-4. This type of controller can be used for pre-timed, semi-actuated or fully-actuated operation. The majority of signalized intersections now employ dual-ring traffic actuated controllers conforming to NEMA standards. Eight phase dual-ring controllers are typically used in all new installations.



NEMA DUAL RING (8-PHASE CONTROLLER)

(ONE PHASE FROM RING 1 AND ONE PHASE FROM RING TWO MUST BE DISPLAYED - EXCEPT THAT SIMULTANEOUS PHASES CAN NOT CROSS THE BARRIER)



NEMA 8-PHASE ACTUATED CONTROLLER PHASING SEQUENCING

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Traffic Design Manual

Dual-Ring
Actuated Phasing Sequence

Figure 4.3

4.2 Traffic Signal Intervals (Phases) – A traffic signal vehicle interval, or phase, can be defined as the part of a cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously (left turn phases, etc.). Generally, the number of traffic signal phases should be held to a minimum. When more than three phases are used to operate a traffic signal, the delay and cycle length usually increase as a result of the increase in start up delays and the increase in signal clearance intervals per signal cycle. When this occurs, the overall intersection efficiency decreases, but the use of fully-actuated traffic signal controllers can sometimes minimize these negative effects .

The number of signal phases used in a traffic signal design is basically a left turn protection issue.

If the need for left turn phasing on an intersection approach has been established, the guidelines in Section 4.2.3 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 (see Section 4.2.5).

4.2.1 Need for Left Turn Protection – 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.

The designer's goal should be to accommodate left turn movements adequately and safely while delaying the heavier thru traffic movements as little as possible.

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:

4.2.2 Left Turn Phase Warrants – The following warrants may be used in the analysis of the need for the installation of separate left turn phases.

1. **Volume Warrant –** Left turn phasing may be considered based on a cross-product threshold as defined by the product of the left turning volume and the volume of opposing traffic (opposing traffic includes both opposing thru and opposing right turning traffic). Left turn phasing should be considered on any approach that meets the following thresholds:
   - **One Opposing Lane – 50,000**
   - **Two Opposing Lanes – 90,000**
   - **Three Opposing Lanes – 110,000**

2. **Delay Warrant –** Left turn phasing may be considered if the left turn delay is greater than or equal to 2 vehicle hours on the critical approach during the peak hour. Also, a minimum left turn volume of two vehicles per cycle must exist with the average delay per vehicle being no less than 35 seconds.[3]

3. **Accident Warrants –** Left turn phasing may be considered on an approach if the following left turn accident experience is documented:[4]

   - **One approach –** 4 left turn accidents in one year or 6 left turn accidents in two years.
   - **Two opposing approaches –** 6 left turn accidents in one year or 10 left turn accidents in two years.

4. **Sight Distance –** Left turn phasing allowing only protected turns should be considered at locations where vertical or horizontal curves restrict visibility and prohibit safe left turn maneuvers.

5. **High Speed, Wide Intersections –** Left turn phasing may be considered at a location in which two or more opposing lanes of traffic having a posted speed limit of 45 miles per hour or greater must be crossed in making the left turn movement.

4.2.3 Types of Left Turn Phasing – Three general types of left turn phasing are possible. Figure 4.4 displays the signal heads for various types of left turn phasing.

A. Permissive Only Left Turn Mode – Left turns are allowed only concurrently with the adjacent thru movement and must yield to opposing traffic.

B. Protected/Permissive Left Turn Mode – This is the most common and generally most efficient type of left turn operation. It allows left turns to be made both on the left turn GREEN ARROW (when they are protected) and on the CIRCULAR GREEN signal indication (when they are permitted, but must yield to opposing traffic). It should be considered when any of the following conditions exist:

- **Capacity –** where intersection capacity is limited and maximum efficiency of the traffic operations is needed.
- **Left Turn Storage –** where left turn lanes are not present or left turn lanes are of inadequate length to store the actual left turn traffic volumes.
- **Left Turn Accidents –** where the left turn signal phase is <u>not</u> justified by the left turn accident warrant described in Section 4.2.2.

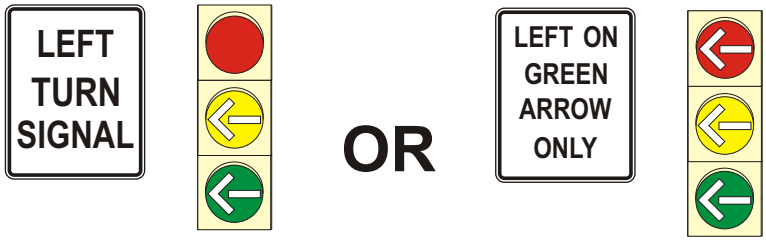
The preferred phasing method is protected/ permissive unless one of the conditions exists requiring protected only left turn phasing. It is generally more efficient than protected only left turn phasing.

[3] <u>Manual of Traffic Signal Design</u>, ITE, 1998, p.32
[4] Ibid. p. 32-33

LEFT TURN SIGNAL DISPLAYS

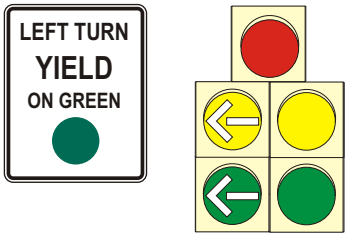
PERMISSIVE ONLY MODE — **NO SEPARATE SIGNAL REQUIRED**

PROTECTED ONLY MODE (ONE PER LEFT TURN LANE)



(SIGN REQUIRED) (SIGN OPTIONAL)

PROTECTED/ PERMISSIVE MODE

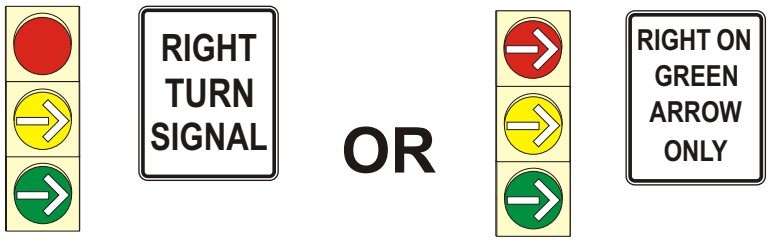


(SIGN OPTIONAL)

RIGHT TURN SIGNAL DISPLAYS

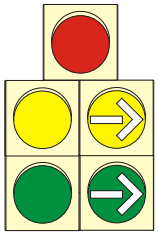
PERMISSIVE ONLY MODE — **NO SEPARATE SIGNAL REQUIRED**

PROTECTED ONLY MODE (ONE PER LEFT TURN LANE)



(SIGN REQUIRED) (SIGN OPTIONAL)

PROTECTED/ PERMISSIVE MODE



NO SIGN

Tennessee Department of Transportation
Traffic Design Manual

Turn Signal Displays

Figure 4.4

C. **Protected Only Left Turn Mode –** This type of left turn operation allows left turns to be made only on a left turn GREEN ARROW display. It should be considered when any of the following conditions exist:

- **Limited Left Turn Sight Distance –** the view of opposing thru and opposing right turn traffic is restricted (see Figure 4.5).

Protected only left turn phasing should always be used for intersections with insufficient sight distance and high approach speeds.

- **Excessive Street Width –** left turning traffic must cross three or more lanes and the speed of the opposing traffic is 45 mph or greater.[5]

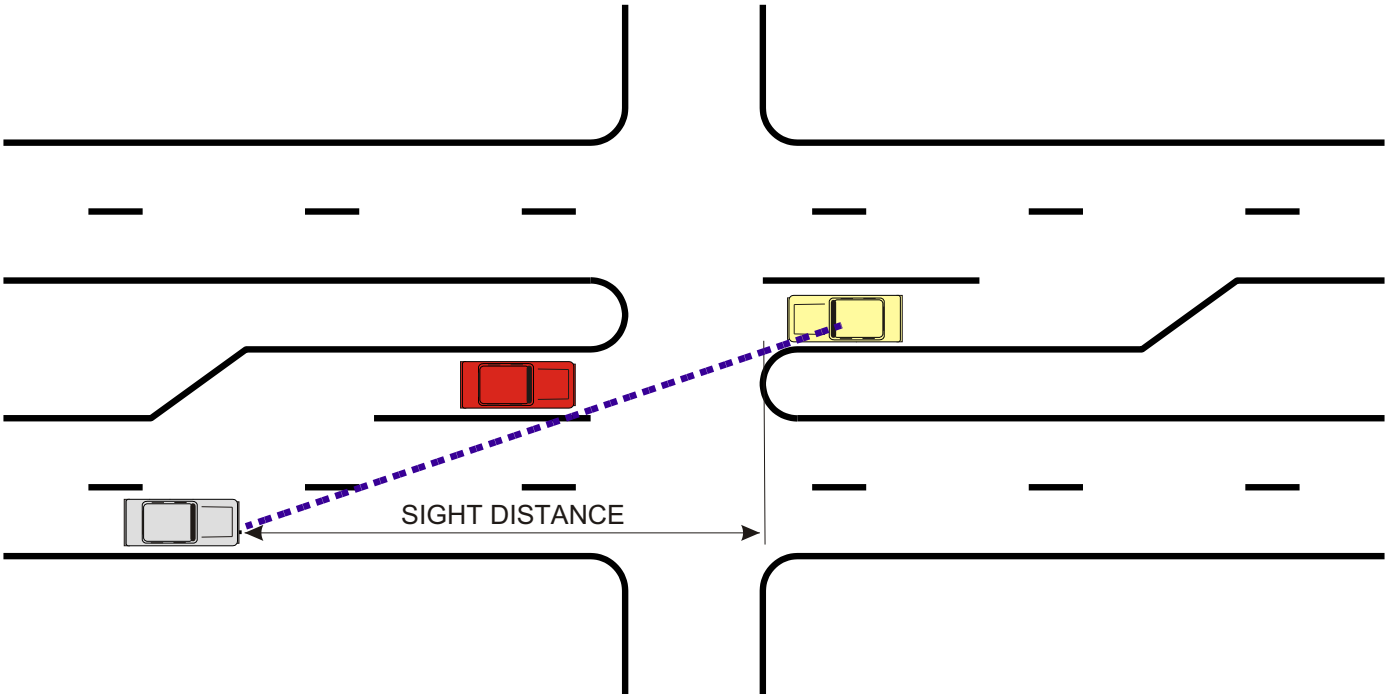
- **Inadequate Geometry –** at intersections where there is inadequate room for opposing left turn movements on the same street to move simultaneously without conflicting or crossing. Either Lead-Lag or split phasing must be used.

- **Left Turn Accidents –** where the left turn signal phase is justified by the left turn accident warrant described in Section 4.2.2 of this manual.

- **Multiple Left Turn Lanes –** on approaches where two or more side by side left turn lanes exist.[6] Protected left turn phasing shall be provided for an approach to an intersection with two or more adjacent left turn only lanes on one approach.

- **Lead-Lag –** Protected only phasing shall be used on the approach with the leading left movement of a Lead-Lag intersection phasing sequence to avoid a "yellow trap" (see Sections 4.2.4-D and 4.2.5).

[5] Traffic Engineering Handbook, ITE, 1999, p. 477
[6] Ibid.



OPERATING SPEED (MPH)	SAFE SIGHT DISTANCE (FT.)		
	2-LANE	4-LANE	6-LANE
20	240	260	280
30	360	390	420
40	470	520	560
50	590	650	700
60	710	780	840

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2001.

Tennessee Department of Transportation
Traffic Design Manual

Left Turning Sight Distances (Urban and Suburban)

Figure 4.5

4.2.4 Sequence of Left Turn Protection – Once the need for and type of left turn protection is determined, it must then be decided where to sequence the left turn phase in the signal cycle. Additionally, if there is more than one left turn phase to be added, it must also be decided how they will sequence in relation to one another.

A. Leading Left Turn – This defines a left turn signal phase that precedes the thru green signal phase on a particular street (see Figure 4.6 and 4.7). Left turning motorists tend to react quicker to a leading left turn than to a lagging left turn.

Leading left turn phasing should be used unless other sequencing is needed for more efficient operation or safety. However, caution should be exercised to avoid a "yellow trap" when using simultaneous leading protected/permissive left turns (see Section 4.2.5).

A leading left turn should be used in the following circumstances[7]:

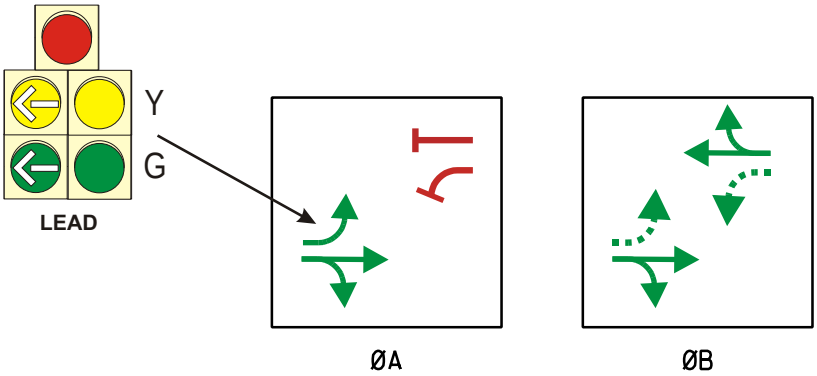
- **Lack of Left Turn Lanes –** a leading left turn signal phase increases the approach capacity on approaches without separate left turn lanes. This assures that all traffic moves on the approach at the beginning of the green signal phase.
- **Signal Coordination –** where a time-space diagram indicates that a leading left turn signal phase will increase the arterial green bandwidth and improve the signal progression.
- **Minimizing Conflicts –** to minimize conflicts between left turn and opposing thru vehicles by clearing the left turns through the intersection first.

B. Split Phase – This defines the situation when each approach on the same street is serviced separately with GREEN signal indications (see Figure 4.7). Typically, it is the side street which is split phased. The major street should almost never be split phased. Split phasing could be used in the following circumstances:

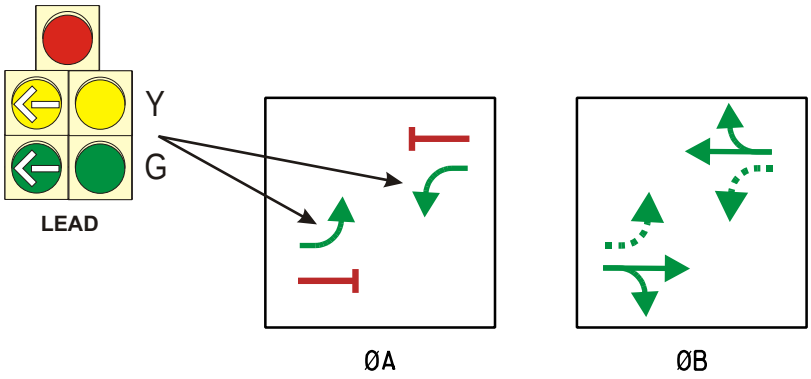
Split phasing typically creates additional overall intersection delays and should only be used in unusual circumstances.

- **Lack of Turn Lanes –** on an approach that lacks left turn lanes and whose left turn and thru volumes are approximately equal. This assures that all traffic moves on an approach at the beginning of the green signal phase.[8]
- **Inadequate Intersection Geometry –** at intersections where intersection turning movements dictate exclusive left turn lanes and shared thru/left turn lanes.
- **Offset Intersections –** where alignment prohibits concurrent left turn and thru movements from opposite approaches.

[7] Traffic Control Devices Handbook, ITE, 2001, p. 274
[8] Traffic Engineering Handbook, ITE, 1999, p. 480.



SINGLE APPROACH LEADING LEFT-TURN WITH PROTECTED-PERMISSIVE OPERATION



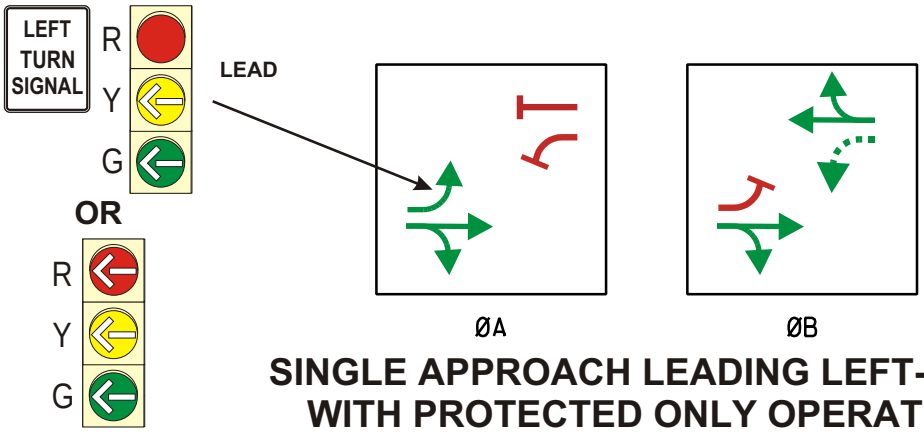
SIMULTANEOUS LEADING LEFT-TURNS WITH PROTECTED-PERMISSIVE OPERATION

NOTE: TO AVOID A "YELLOW TRAP":
1. REQUIRE THE SIDE STREET TO BE SERVICED PRIOR TO RETURNING TO THE LEFT TURN PHASE
OR 2. PHASE OMIT THE LEADING LEFT TURN PHASE WHEN THE OPPOSING THRU GREEN IS DISPLAYED

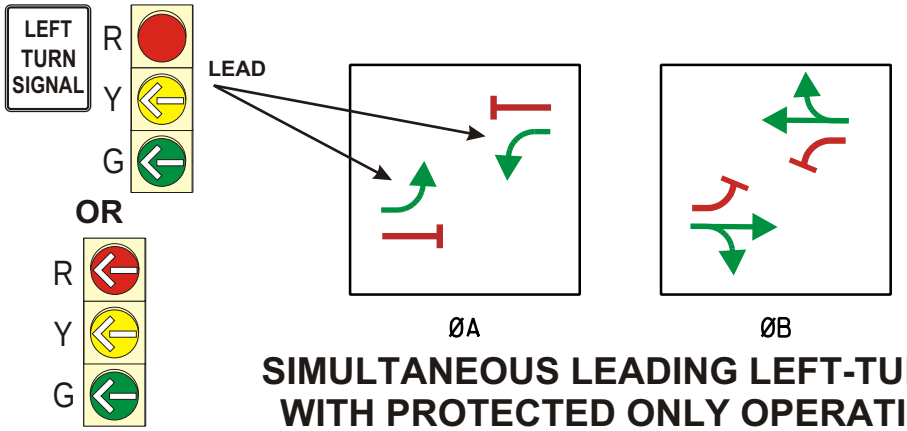
Tennessee Department of Transportation
Traffic Design Manual

Typical Permitted
Left Turn Sequencing

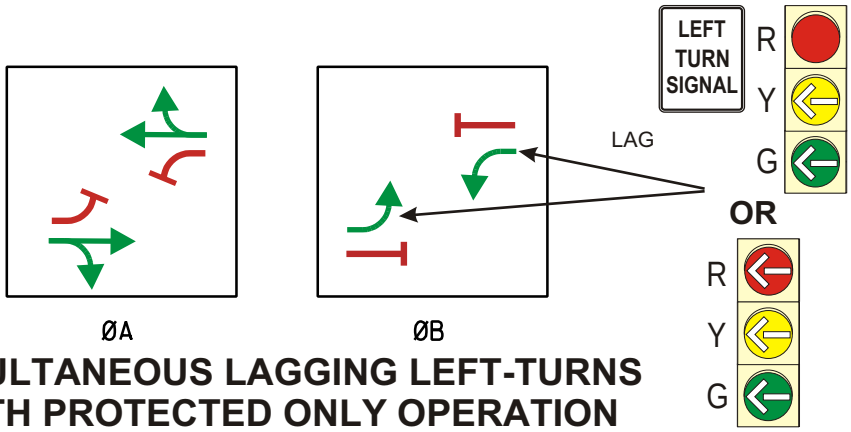
Figure 4.6



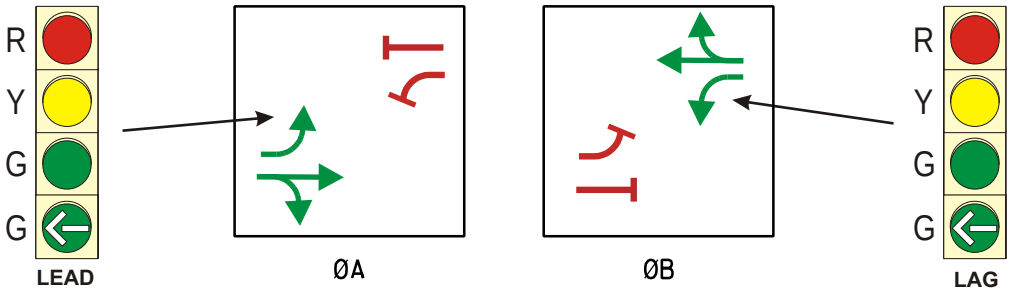
SINGLE APPROACH LEADING LEFT-TURN WITH PROTECTED ONLY OPERATION



SIMULTANEOUS LEADING LEFT-TURNS WITH PROTECTED ONLY OPERATION



SIMULTANEOUS LAGGING LEFT-TURNS WITH PROTECTED ONLY OPERATION



SPLIT-PHASE LEFT-TURNS

Tennessee Department of Transportation
Traffic Design Manual

Typical Protected
Left Turn Sequencing

Figure 4.7

C. **Lagging Left Turn –** This is a left turn signal phase that comes at the end of the thru green phase. This type of sequence is not normally expected by drivers.

Lagging left turn movements should be used cautiously. They are not normally expected by drivers and can lead to a "yellow trap" in certain situations.

A "yellow trap" can occur when a traffic signal controller with a protected/ permissive or protected only lagging left turn initiates its lagging left turn phase (see Figure 4.8). The opposing left turn movement can experience a "yellow trap" (see Section 4.2.5). For these reasons, this phasing sequence is not recommended. Single lagging left turns should only be used if the leading left turn movement is prohibited or is at a T-intersection. Simultaneous lagging left turns should only be used if they are protected only phases (see Figure 4.7)

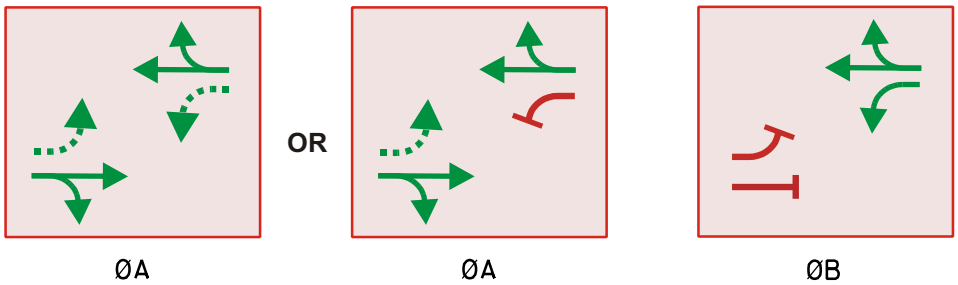
D. **Lead-Lag Left Turns –** This is the combination where both a leading and lagging left turn signal phase is provided on the same street. Figure 4.8 shows this combination operating in a protected/permissive mode as previously described. It may be used in the following circumstances:

- **Lack of Left Turn Lanes –** on one and two lane approaches that lack left turn lanes.
- **Signal Coordination –** where a time-space diagram indicates that a lead-lag left turn combination in the proper direction will increase the arterial green band width and improve signal progression.

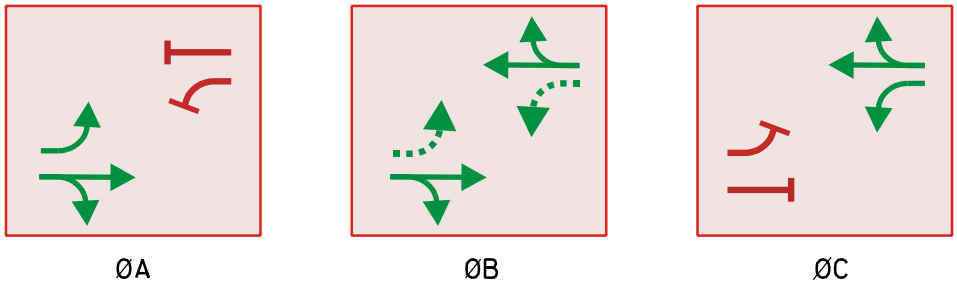
Leading left turn movements in lead-lag signal phasing shall be protected only phases to avoid a "yellow trap".

- **Unequal Left Turn Volumes –** To allow for the separate timing of each left turn phase.
- **Inadequate Intersection Geometry –** At intersections where there is inadequate room for opposing left turn movements on the same street to move simultaneously without conflicting or crossing. Protected only left turns must be used.

DO NOT USE - YELLOW TRAP

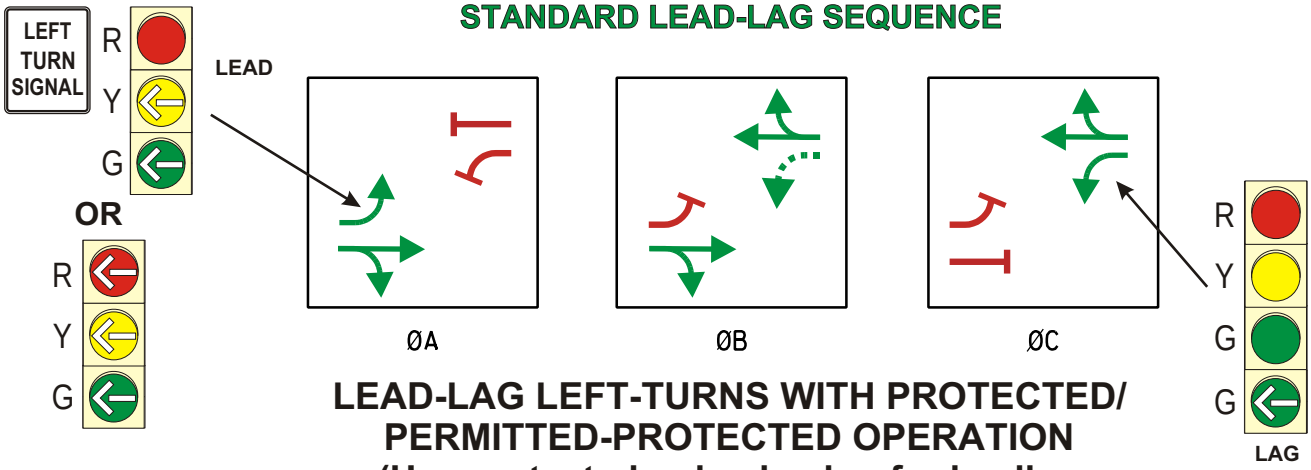


SINGLE LAGGING LEFT-TURN
(Phase A left turn experiences yellow-trap -
Do not use unless Phase A left-turns are prohibited)



LEAD-LAG LEFT-TURNS WITH
PROTECTED-PERMITTED OPERATION
(Phase A left turn experiences yellow trap)

STANDARD LEAD-LAG SEQUENCE



LEAD-LAG LEFT-TURNS WITH PROTECTED/
PERMITTED-PROTECTED OPERATION
(Use protected only phasing for leading
left-turn to avoid yellow trap)

4.2.5 Left Turn "Yellow Trap" – A "yellow trap" can occur when all movements for one approach conclude (permissive or protected-permissive left and thru movement), but the opposing approach movements continue (see Figure 4.8). A driver on the concluding approach waiting to turn left in the permissive portion of the ending movement sees all of the signal indications turn YELLOW and wrongly assumes that the opposing traffic is also receiving YELLOW signal indications (the opposing direction is about to receive a protected left turn in combination with its thru movement). The driver now believes that his left turn can be completed on yellow when, in fact, the opposing thru traffic still has a CIRCULAR GREEN thru signal indication. If the left turn is made under these conditions an accident could occur.

A "Yellow Trap" is a condition in which a permitted left turn phase ends in one direction while the opposing through movement continues through the succeeding phase. A hazard is introduced because the left turning drivers tend to perceive the end of their phase as an opportunity to clear the intersection as a "sneaker," while the green indication in the opposing direction is displayed continuously during the transition from one phase to the next.

A "yellow trap" can occur when:

- **Simultaneous Protected/Permissive Leading Left Turns –** A fully-actuated traffic signal controller with simultaneous protected/permissive leading left turns, in the absence of side street traffic, cycles back and forth between a thru phase and a leading left turn phase.[9] In this case, the "yellow trap" can be eliminated by using protected only left turns, by servicing the side street prior to returning to the left turn phase, "or by phase omitting the protected left turn phase when the opposing thru green is displayed".[10]
- **Single Lagging Protected Only or Protected-Permissive Left Turns –** A "yellow trap" can occur when a single lagging left turn movement begins after completion of an opposing permissive left turn movement. The "Yellow Trap" can be avoided only if leading left turns are prohibited.
- **Lead-Lag Left Turns –** Similar to a single lagging left turn movement, a lead-lag "yellow trap" can occur when a single lagging left turn movement begins after completion of the permissive portion of the protected/permissive phase of the opposing movement. The "Yellow Trap" can be avoided if leading left turns in lead-lag phasing are protected only.

[9] Traffic Engineering Handbook, ITE, 1999, p. 479
[10] Ibid.

4.2.6 Right Turn Indication[11] – Typical right turn signal heads are shown in Figure 4.4.Separate phasing is typically not defined for right turns, but two types of indications may control right turning movements. Three parameters define the right turn treatment for each approach:

Separate right turn signal indications are typically used only when a separate right turn lane exists.

- Lane utilization (shared, exclusive or channelized)
- Right turn on red (allowed or prohibited)
- Right turn movement protection (permissive, protected or both)

It is important to ensure that the lane utilization is compatible with the signal protection and with the accommodations for pedestrians. The three types of right turn phasing are:

A. Permissive Only Mode – A separate signal indication is not required and right turns may be made on red unless prohibited by a traffic sign. Unless otherwise noted, this type of control is in effect.

B. Protected Only Mode – This indication is used when right turns are not allowed concurrently with the adjacent thru movement. The protected right turn cannot occur concurrently with an adjacent Pedestrian Walk phase. A separate right turn signal head is required.

C. Protected/Permissive Mode – This allows right turns to be made both on a right turn GREEN ARROW and on the CIRCULAR GREEN signal indication. Typically displayed as a phase overlap with a protected side street left turn movement, a separate signal face may be used, but is not required.

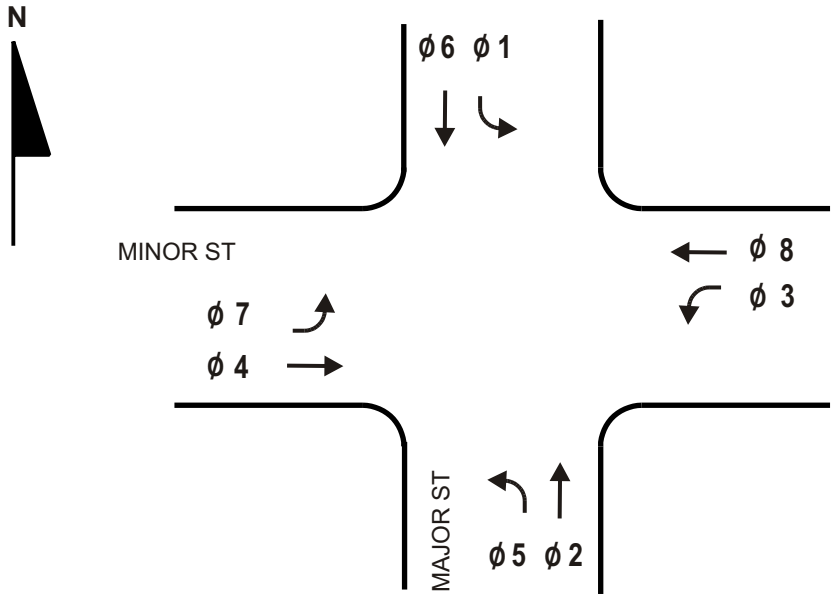
4.2.7 Phase Numbering Convention – Phases for Pre-timed, Semi-Actuated or Fully-Actuated control are numbered with a convention that provides the basis for the numbering system for signal heads and detectors. Phasing diagrams typically use the NEMA phase numbering convention. In the absence of a phase numbering convention by the local agency, the following convention should be used:

4.2.7.1 Four way Intersections (8 - Phase Traffic Signal Controllers)

A. Major street runs North - South (see Figure 4.9)

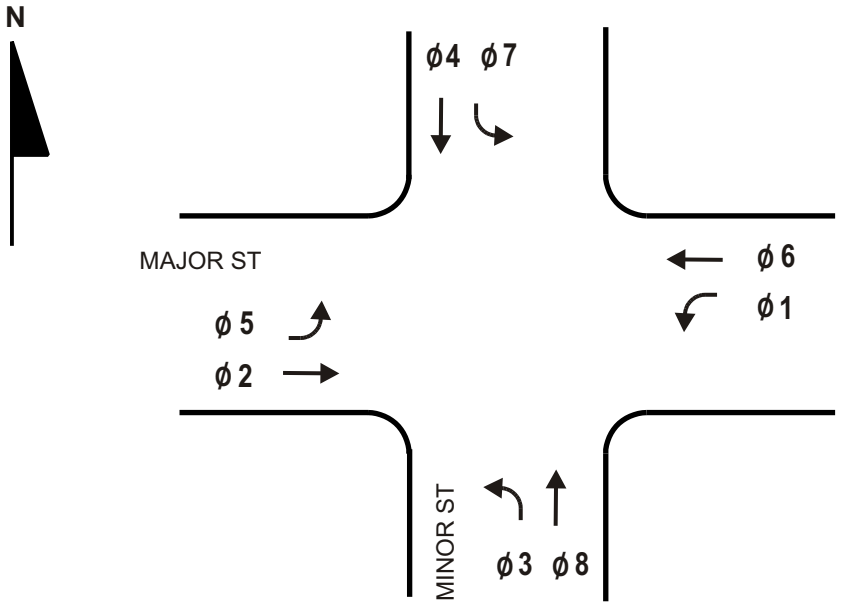
Phase 1	SB left turn traffic
Phase 2	NB thru traffic
Phase 3	WB left turn traffic
Phase 4	EB thru traffic
Phase 5	NB left turn traffic
Phase 6	SB thru traffic
Phase 7	EB left turn traffic
Phase 8	WB thru traffic

[11] MUTCD, FHWA, 2003. p. 4D-7.



NORTH-SOUTH AS MAJOR STREET

FOR 8-PHASE CONTROLLER



EAST-WEST AS MAJOR STREET

FOR 8-PHASE CONTROLLER

Tennessee Department of Transportation
Traffic Design Manual

Recommended Phase Assignments for Four-Leg Intersections

Figure 4.9

B. Major street runs East - West (see Figure 4.9)

Phase 1	WB left turn traffic
Phase 2	EB thru traffic
Phase 3	NB left turn traffic
Phase 4	SB thru traffic
Phase 5	EB left turn traffic
Phase 6	WB thru traffic
Phase 7	SB left turn traffic
Phase 8	NB thru traffic

4.2.7.2 Tee-Intersections – Overlaps A through D (phases operating concurrently with other phases) are used if a four phase cabinet is used.

A. Major street runs North - South; minor street intersects from the East (see Figure 4.10)

Phase 1	SB left turn traffic
Phase 2	NB thru traffic
Phase 4	WB traffic
Phase OL	SB thru traffic

B. Major street runs North - South, minor street intersects from the West (see Figure 4.10)

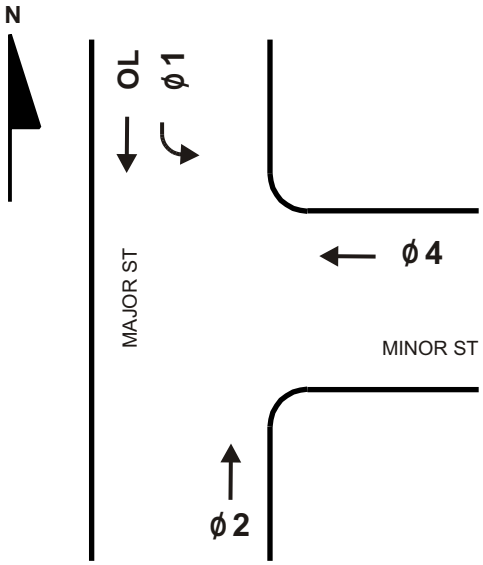
Phase 1	NB left turn traffic
Phase 2	SB thru traffic
Phase 4	EB traffic
Phase OL	NB thru traffic

C. Major street runs East - West, minor street intersects from the South (see Figure 4.10)

Phase 1	WB left turn traffic
Phase 2	EB thru traffic
Phase 4	NB traffic
Phase OL	WB thru traffic

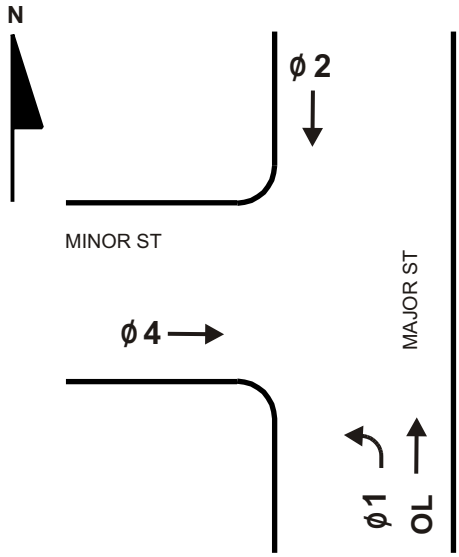
D. Major street runs East - West, minor street intersects from the North (see Figure 4.10)

Phase1	EB left turn traffic
Phase 2	WB thru traffic
Phase 4	SB traffic
Phase OL	EB thru traffic



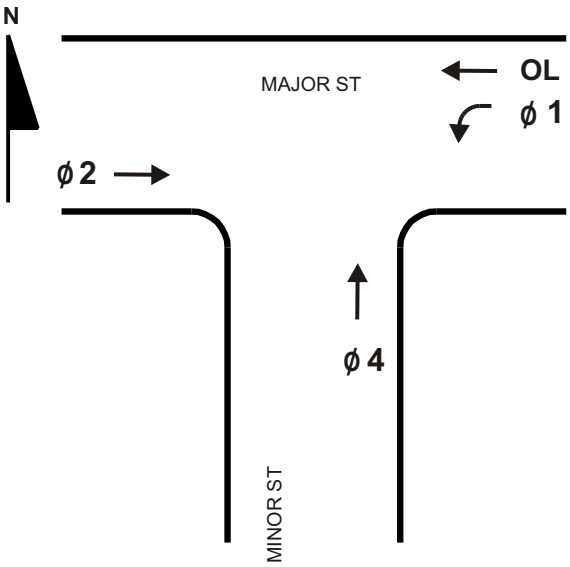
EAST APPROACH AS MINOR STREET

FOR 8-PHASE CONTROLLER IN A 4-PHASE CABINET



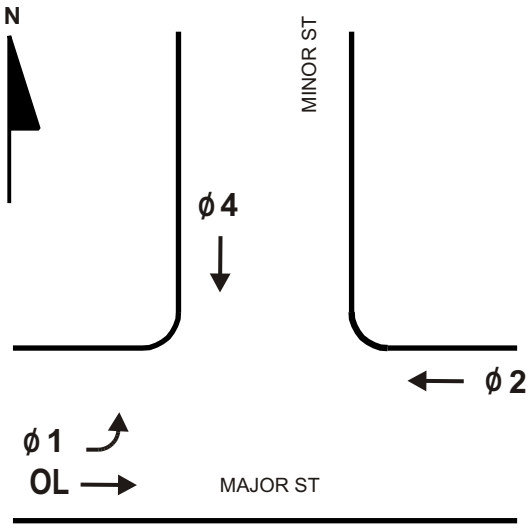
WEST APPROACH AS MINOR STREET

FOR 8-PHASE CONTROLLER IN A 4-PHASE CABINET



SOUTH APPROACH AS MINOR STREET

FOR 8-PHASE CONTROLLER IN A 4-PHASE CABINET



NORTH APPROACH AS MINOR STREET

FOR 8-PHASE CONTROLLER IN A 4-PHASE CABINET

Tennessee Department of Transportation
Traffic Design Manual

Recommended Phase Assignments for T-Intersections

Figure 4.10

4.3 Vehicle Detection – As described in Section 4.1.3, traffic signals are classified as pre-timed or actuated. Vehicle actuated traffic signals can be semi-actuated with detectors on some, but not all approaches, and in which right-of-way is relinquished only when a call is received for the actuated phase, or fully-actuated which requires detectors on all approaches and in which right-of-way does not automatically go to a designated phase unless it is recalled by a function on the traffic signal controller.

The type of vehicle detection system used for actuated traffic signal control depends on the operational requirements of the intersection in terms of type and use of data needed by the controller to operate efficiently and the construction and maintenance cost.

Vehicle detectors are used to detect the presence or passage of a vehicle on a portion of a roadway. They are an integral part of any traffic actuated traffic signal design as their input determines the variable timing and phasing of the traffic signal. Additionally, the proper placement of these detectors contributes significantly to the overall efficiency of the traffic operations at the intersection.

4.3.1 Locking vs. Non-Locking Memory – Traffic signal controllers have three modes for detection memory: lock, non-lock and recall.

A. Locking Memory – Locking memory means that a vehicle call is held by the controller (even after the vehicle has left the detection area) until the call has been satisfied. This is appropriate for left turn lanes which are controlled by a protected-only left turn phase, for some side streets and for high speed approaches that have advance loops only and no stop line loops.

B. Non-Locking Memory – Non-locking memory means that a waiting call is dropped (or forgotten) by the controller as soon as the vehicle leaves the detection area. This is particularly useful in lanes where a large number of vehicles turn right on red and also in left turn lanes with permissive or protected-permissive left turn phases. Most stop line loops are set as non-locking, except in unusual circumstances.

Where stop line detectors are used to detect the presence of a vehicle, they are typically located where the vehicle is anticipated to stop, and operate in the non-locking memory mode of detection. They may extend several feet beyond the stop line to ensure vehicle detection. Where advance detectors are used to detect the passage of a vehicle some distance back from the stop line, they are located in the path of the vehicle and typically operate in the locking memory mode of detection to retain the vehicle call. Table 4.1 shows the typical uses of locking and non-locking memory.

Table 4.1 Typical Uses of Locking and Non-Locking Memory

Location of Loop	Type	Memory Setting
Left Turn Lane Stop Line	Protected Only Phasing	Locking*
Left Turn Lane Stop Line	Protected/Permissive or Permissive Only Phasing	Non-Locking
Thru Lane Stop Line	Thru Phase (On Recall)	Non-Locking (typical) or Locking**
Thru Lane Advance	Thru Phase	Locking
Thru Lane Stop Line	Thru Phase (Not on Recall)	Locking**
Right Turn Lane Stop Line	Protected Only Phasing	Locking
Right Turn Lane Stop Line	Protected/Permissive or Permissive Only Phasing	Non-Locking

* Consider using delay features on loop detector units to prevent cross traffic from placing a vehicle call to the controller.

** Consider using delay features on loop detector units on side street combination thru/right turn lanes where vehicles may turn right on red.

4.3.2 Detection for Different Approach Speeds – Stop line presence detection is typically used on low speed approaches (30 mph or less). Approaches with only stop line detection and with speeds greater than 35 mph may cause problems for a driver in deciding whether or not to proceed through an intersection when faced with a Yellow Change Interval.[12] This is often referred to as a **"dilemma zone".**

A common method of addressing the dilemma zone issue is to install advance detectors. A combination of advance detectors and stop line loops can be used on moderate speed approaches (35 to 40 mph). Advance detectors alone are typically used on high speed approaches (40 mph and higher) and often on moderate speed approaches. A combination of advance detectors and stop line loops can be used on moderate speed approaches (35 to 40 mph).

4.3.3 Stop Line Detection – Stop line detectors are located at the stop line on an intersection approach. Stop line detection is used in thru lanes on minor approaches, thru lanes on low speed approaches, and in left turn lanes (see Figure 4.11). All left turn lanes at actuated traffic signals must have stop line detection. Stop line detection is obviously needed to actuate a dedicated left turn phase that is not on recall. Approaches with left turn lanes, but without separate left turn phases, must have stop line detection so that the traffic signal controller can hold the green phase while the left turn vehicle waits for possible gaps in opposing traffic.

4.3.4 Advance Detection – Advance detectors are used on the thru lanes of moderate/high speed approaches (35 mph or greater) in advance of the approach stop line (see Figure 4.11). These detectors typically operate in a locking memory mode and detect the passage of a vehicle. Advance detectors can provide the traffic signal controller with information on vehicles approaching the intersection and, in the case of a volume density operation, can count the number of vehicles on the approach that are waiting with a RED signal indication. The location of these detectors is based on the safe stopping distance of approaching vehicles for the approach speed (see Figure 4.12).[13]

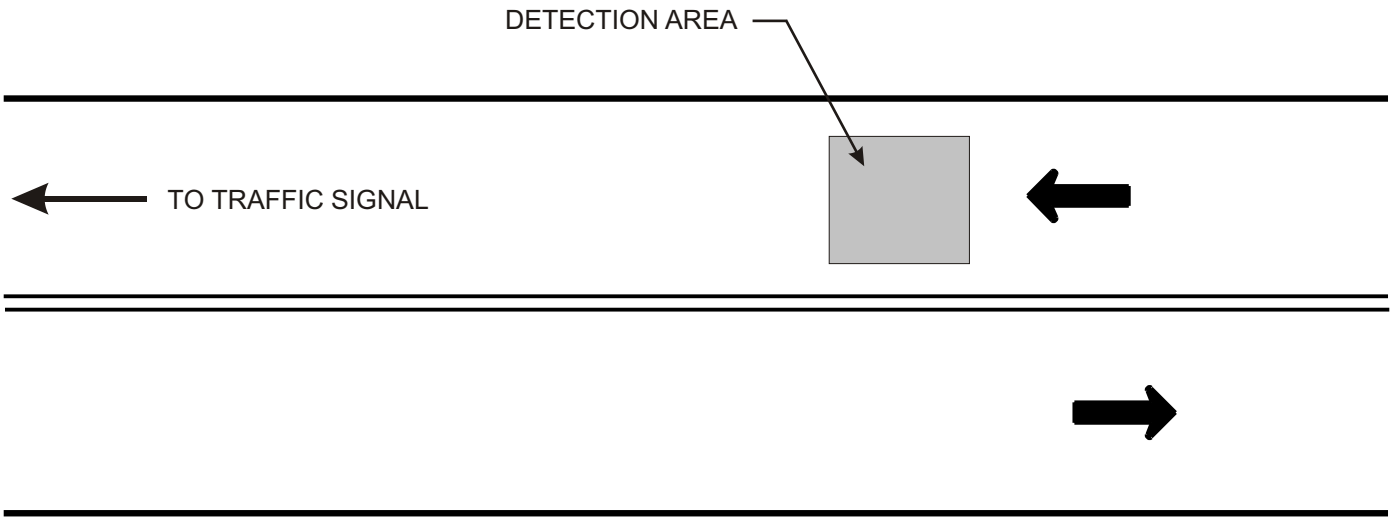
Advance detection should be used for approaches with speeds 35 mph or higher.

4.3.5 Methods of Detection – Many different technologies exist to enable detection of vehicles. The three types of detection typically used in Tennessee are:

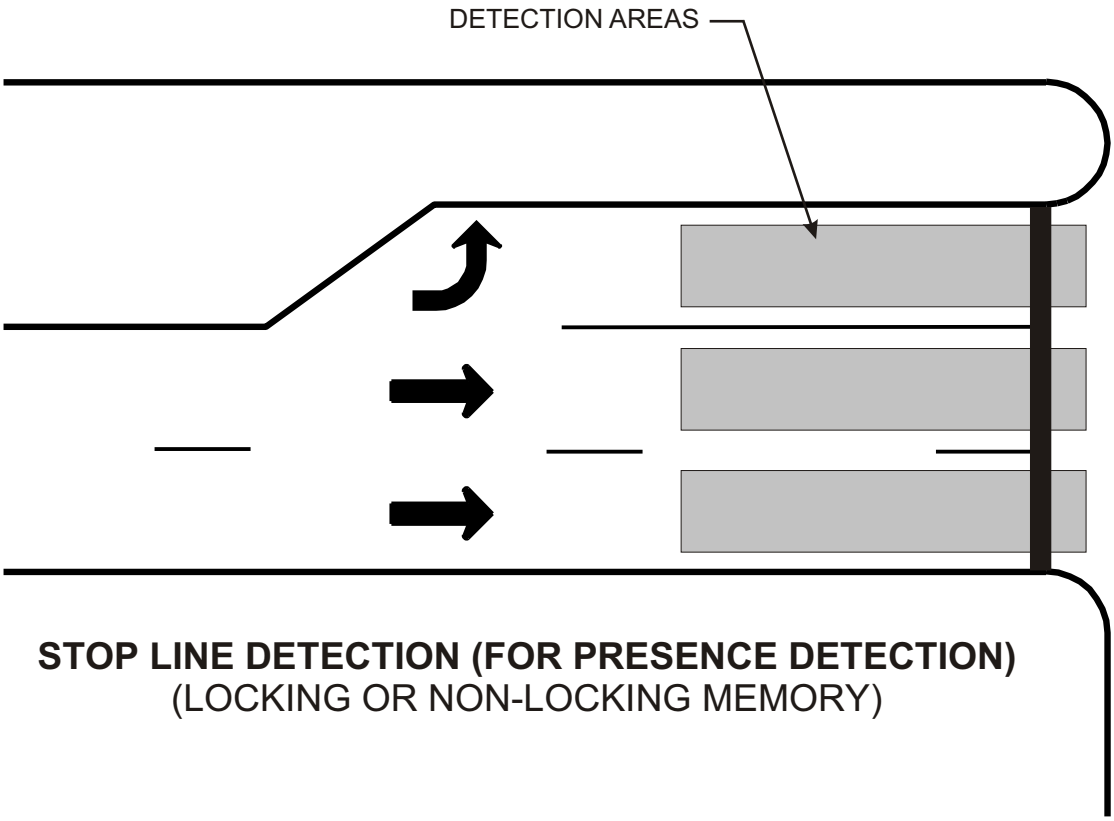
- Inductive Loop (standard saw cut loops or preformed loops)
- Microwave Detection
- Video Detection

All three of these methods of detection can be used for stop line detection. However, the inductive loop is normally used for advance detection. Table 4.2 lists the advantages and disadvantages of these and other types of detection technologies.

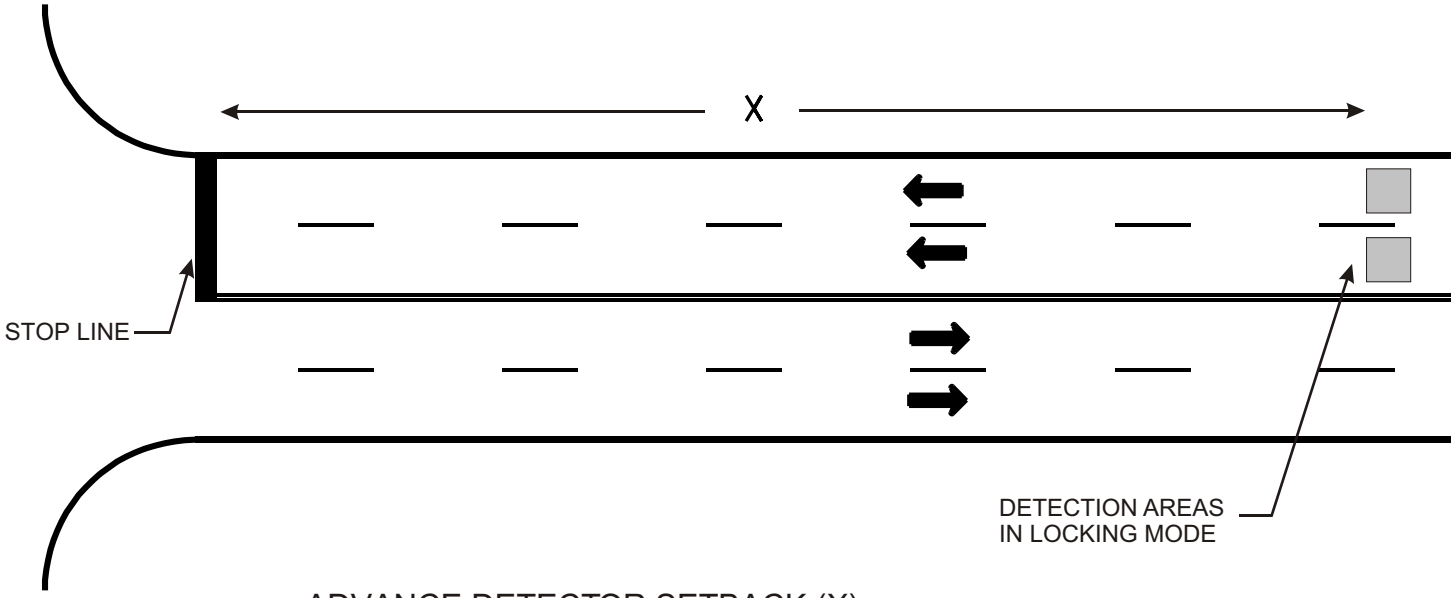
[12] Manual of Traffic Signal Design, ITE, 1998, p. 38
[13] Ibid, p. 89



ADVANCE DETECTION (LOCKING MEMORY)



STOP LINE DETECTION (FOR PRESENCE DETECTION)
(LOCKING OR NON-LOCKING MEMORY)



ADVANCE DETECTOR SETBACK (X)

SAFE STOPPING SIGHT DISTANCES:

$X = SSD = rV + 0.5V^2/d$

WHERE: SSD = STOPPING SIGHT DISTANCE (FT)
r = REACTION TIME = 1.0 SEC
V = APPROACH SPEED (FT/SEC)
d = DECELERATION RATE (10 FT/SEC^2)

APPROACH (MPH)	SPEED (FT/SEC)	DETECTOR SETBACK (X) (FEET)
35	51.3	185’ (USE VOLUME DENSITY CONTROLLER)
40	58.7	230’ (USE VOLUME DENSITY CONTROLLER)
45	66.0	285’ (USE VOLUME DENSITY CONTROLLER)
50	73.3	340’ (USE VOLUME DENSITY CONTROLLER)
55	80.7	405’ (USE VOLUME DENSITY CONTROLLER)
60	88.0	475’ (USE VOLUME DENSITY CONTROLLER)
65	95.3	550’ (USE VOLUME DENSITY CONTROLLER)

Source: *Manual of Traffic Signal Design,* ITE, 1998.

Table 4.2 Comparison of Vehicle Detection Technologies

Technology	Strengths	Weaknesses
Inductive Loop	■ Flexible design to satisfy large variety of applications. ■ Mature, well understood technology. ■ Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). ■ High frequency excitation models provide classification data.	■ Installation requires pavement cut. ■ Decreases pavement life. ■ Installation and maintenance require lane closure. ■ Wire loops subject to stresses of traffic and temperature. ■ Multiple detectors usually required to instrument a location.
Magnetometer	■ Less susceptible than loops to stresses of traffic. ■ Some models transmit data over wireless RF link.	■ Installation requires pavement cut. ■ Decreases pavement life. ■ Installation and maintenance require lane closure. ■ Small detection zones.
Magnetic	■ Can be used where loops are not feasible (e.g., bridge decks). ■ Some models installed under roadway without need for pavement cuts. ■ Less susceptible than loops to stresses of traffic.	■ Installation requires pavement cut or tunneling under roadway. ■ Cannot detect stopped vehicles.
Microwave Radar	■ Generally insensitive to inclement weather. ■ Direct measurement of speed. ■ Multiple lane operation available.	■ Antenna beamwidth and transmitted waveform must be suitable for the application.
Infrared	■ Active sensor transmits multiple beams for accurate measurement of vehicle position, speed, and class. ■ Multizone passive sensors measure speed. ■ Multiple lane operation available.	■ Operation of active sensor may be affected by fog or blowing snow. ■ Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog.
Ultrasonic	■ Multiple lane operation available.	■ Some conditions such as temperature change and extreme air turbulence can affect performance. ■ Large pulse repetition periods may degrade occupancy measurement
Acoustic	■ Passive detection. ■ Insensitive to precipitation. ■ Multiple lane operation available.	■ Cold temperatures have been reported as affecting data accuracy. ■ Specific models are not recommended with slow moving vehicles in stop and go traffic.
Video Image Processor	■ Monitors multiple lanes and multiple zones/lane. ■ Easy to add and modify detection zones. ■ Rich array of data available. ■ Provides wide-area detection when information gathered at one camera location can be linked to another.	■ Inclement weather, shadows, vehicle projection into adjacent lanes, occlusion, day-to-night transition, vehicle/road contrast, and water, salt grime, icicles, and cobwebs on camera lens can affect performance. ■ Requires 50- to 60-ft camera mounting height (in a side-mounting configura-tion) for optimum presence detection and speed measurement. ■ Some models susceptible to camera motion caused by strong winds. ■ Generally cost-effective only if many detection zones are required within the field of view of the camera.

Source: A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems, FHWA, 2000.

4.3.6 Inductive Loop Detection – The inductive loop detects vehicles by sensing a change of inductance in the loop caused by the passage or presence of a vehicle over the loop. Inductive loops have historically been placed in the pavement by saw cutting a slot, installing loop wire and encapsulating the loop wire by filling the saw cut with sealant. The induction detector is made up of three components; a loop of wire saw cut into the roadway surface, a lead-in (shielded) cable and a detector processing unit in the controller cabinet. It is capable of both passage and presence detection.[14]

The life of a regular inductive loop which is saw cut into the pavement is dependent on the condition of pavement and it must be replaced each time a road is milled and resurfaced.

When installing inductive loop detection, the saw cut, loop wire, lead-in cable and detector units are measured separately.

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.[15] A common inductive loop configuration that provides greater detection capabilities is the "quadrupole" loop. Quadrupole loops also provide more accuracy in vehicle detection and avoid false detections from adjacent thru lanes.

A. Placement/Pattern – A detector's function determines its pattern and placement. The basic inductive loop detector used by TDOT is either a square or rectangle that has a length of 6 to 50 feet. Figure 4.13 displays the typical layouts of inductive loop detectors.

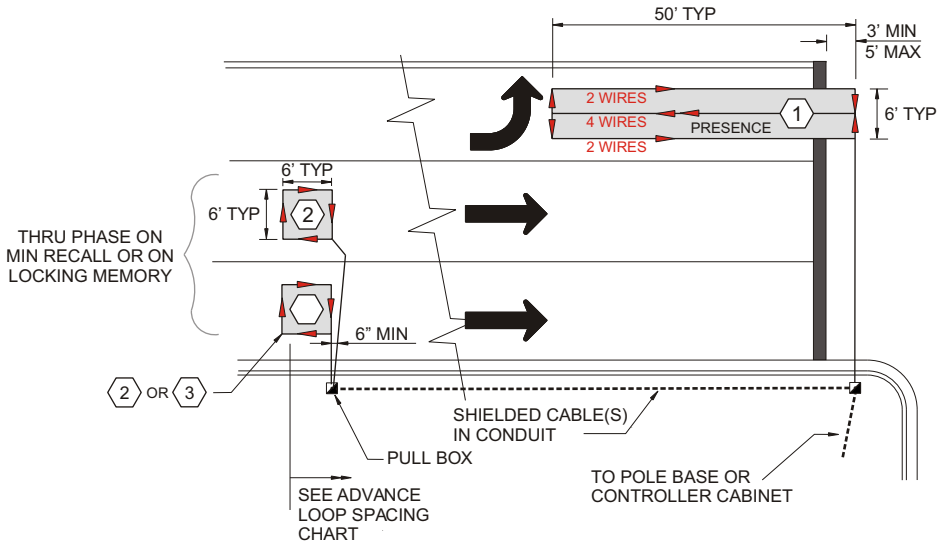
B. Preformed Inductive Loops – Preformed inductive loops function similarly to a regular saw cut loop; however, the conductor is encased in a heavy duty plastic housing. They are placed within concrete or in the lower lifts of asphalt prior to final paving (see Figure 4.14). Preformed loops can last 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, it is not recommended due to the size of the saw cut required.

When long term maintenance is a concern, an alternative to the traditional saw cut inductive loop for new construction projects is the preformed inductive loop.

C. Loop Detector Processing Units – Detector processing units are devices in the signal controller cabinet that receive and interpret the signal from inductive loops and transmit the data to the controller. The local maintaining agency should be consulted for the type of unit desired (single channel vs. multi-channel and shelf mount vs. card rack).

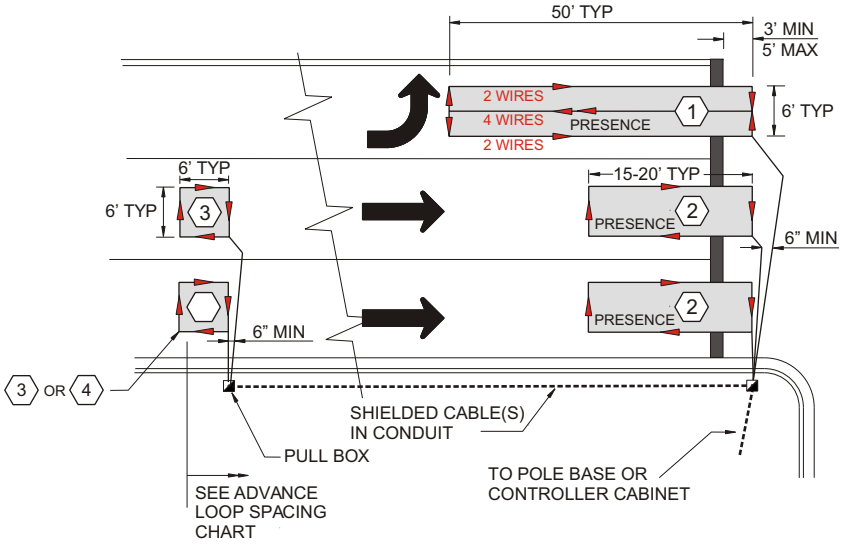
[14] Traffic Detector Handbook, ITE, 2nd Ed. p. 3
[15] Manual of Traffic Signal Design, ITE, 1998, p. 87

ADVANCE LOOP SPACING	
APPROACH SPEED (MPH)	DISTANCE TO STOP LINE (FT)
35	185'
40	230'
45	285'
50	340'
55	405'
60	475'



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

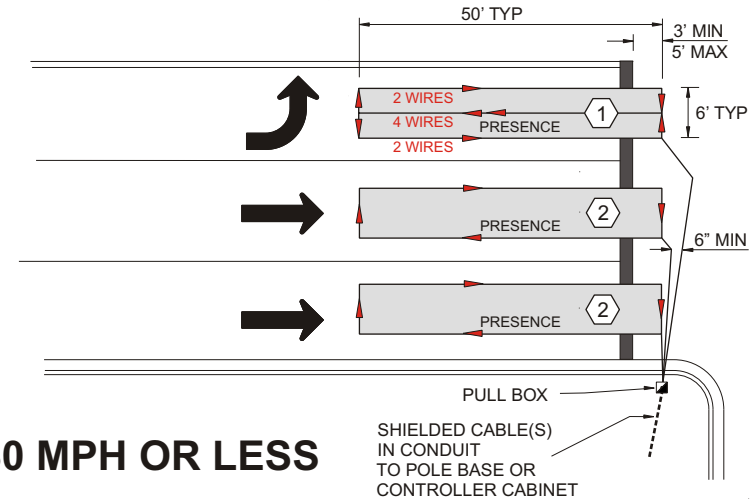


ALTERNATE HIGH SPEED APPROACH
(FOR USE WHEN PRESENCE DETECTION IS REQUIRED)

2 DETECTOR NUMBER (LOOPS WITH SAME NUMBER INDICATE WIRED IN SERIES

ALL LOOPS TO BE CENTERED IN TRAVEL LANE

ALL DISTANCES FROM STOP LINE



30 MPH OR LESS

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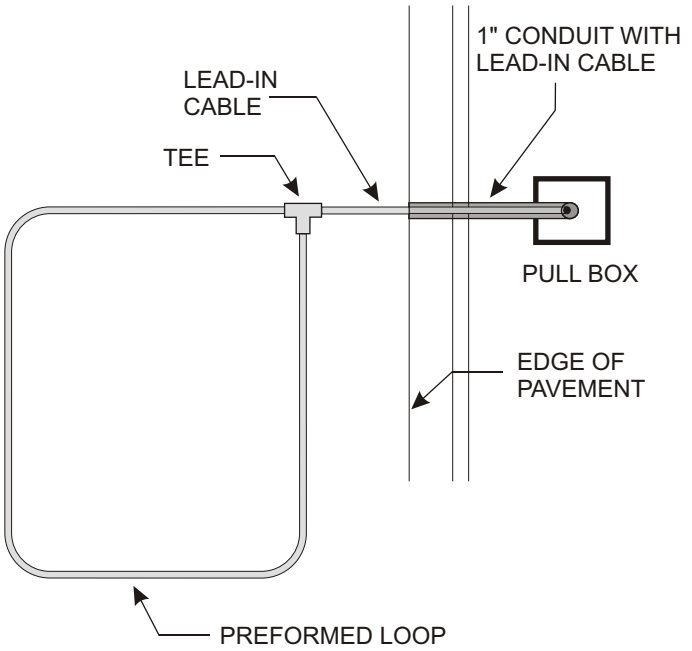
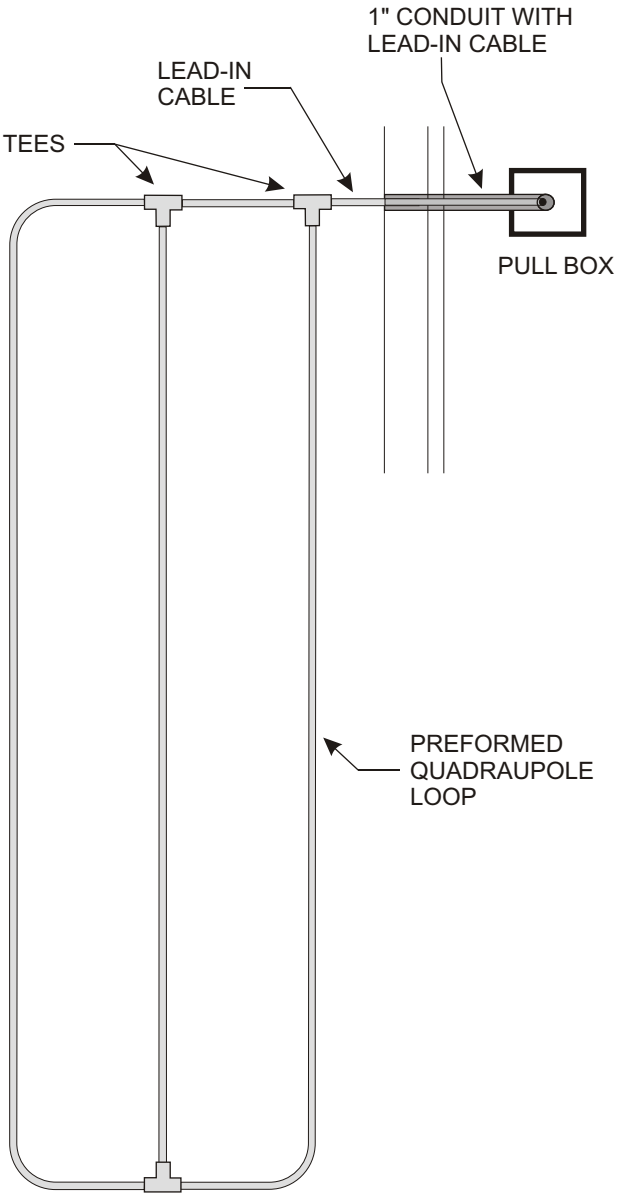
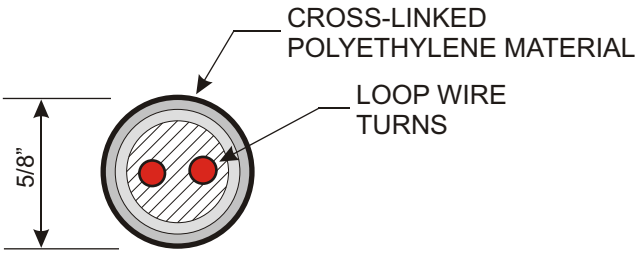
Typical Loop Detector Installation Layout

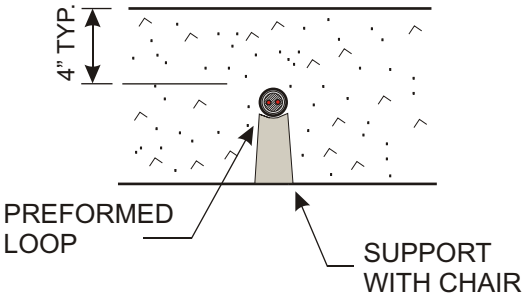
Figure 4.13





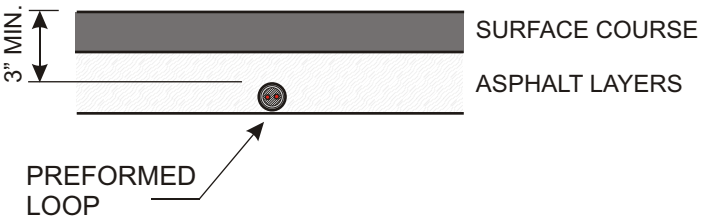


PREFORMED LOOP CROSS SECTION



PREFORMED LOOP INSTALLED IN NEW CONCRETE

(INSTALL UNDER NEW PAVEMENT)



PREFORMED LOOP INSTALLED IN NEW ASPHALT

(INSTALL UNDER NEW PAVEMENT)

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Traffic Design Manual

Preformed Inductive Loop

Figure 4.14

4.3.7 Microwave Detection – Sometimes referred to as radar detection, microwaves are beamed toward the roadway by a transmitter device. As a vehicle enters the influence area of this transmitter, the microwaves are reflected back to an antenna at a different frequency, allowing the presence of the vehicle to be detected (see Figure 4.15). This detection is not influenced by adjacent construction and can be implemented without lane closures associated with saw cutting loops. Microwave detectors are also immune to adverse weather such as fog and rain. One advantage that the microwave detector has over the video detector is that it can often see around tall vehicles and detect occluded (blocked) vehicles.

Older microwave detectors could not be used as presence detectors, requiring phases to be set on locking memory. Newer microwave detectors that use frequency modulated continuous wave (FMCW) can be used as a presence detector and can detect motionless vehicles. New microwave detectors can detect up to 200 feet for an area 15 feet wide and can detect eight separate detection zones within this detection area.

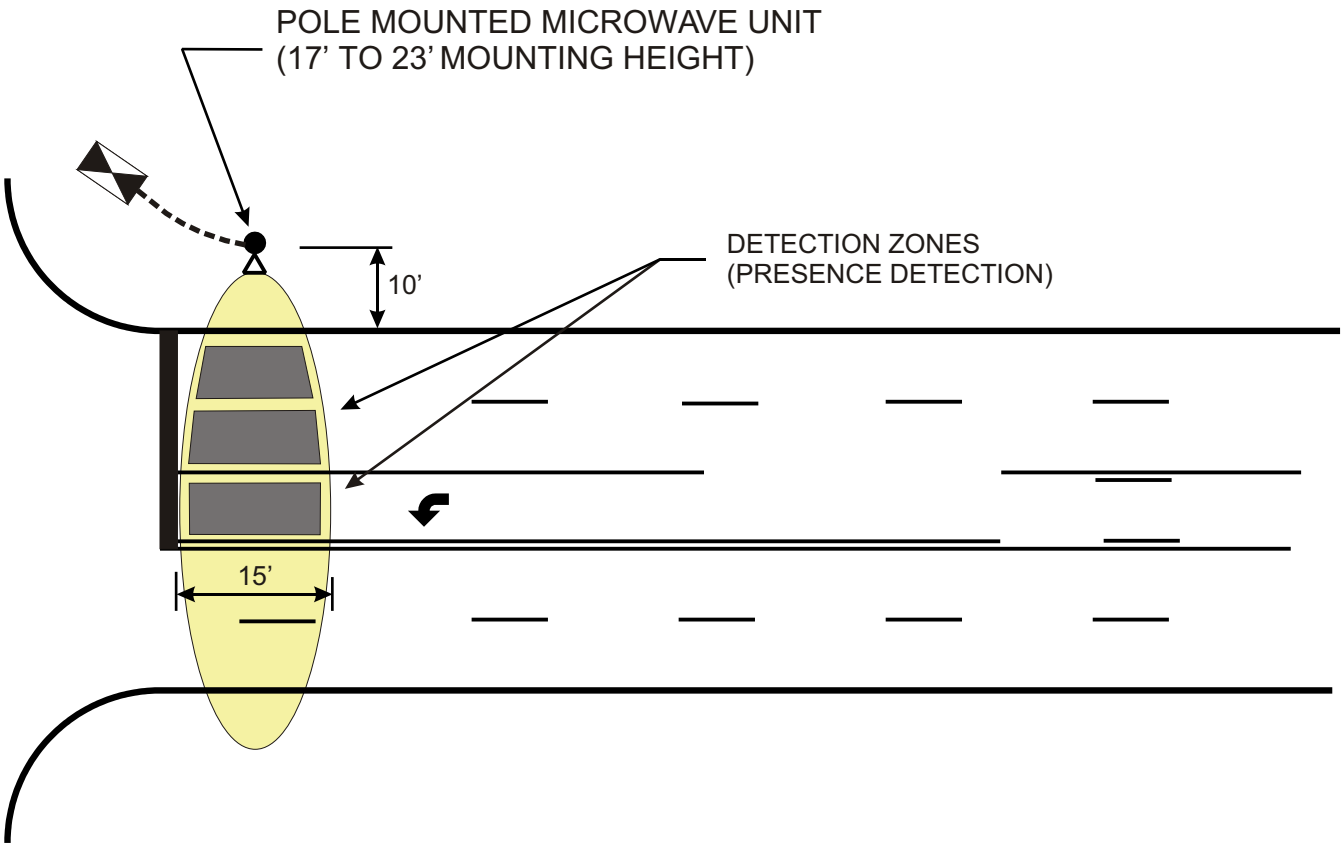
Microwave detection is typically accomplished by a side fire unit that can detect zones similar to those for stop line inductive loops. This type of detection can be considered in areas where loop installation is not possible, i.e., pavement is in poor condition, etc. The detection zones may be programmed using a laptop computer interfaced with the unit.

When installing microwave or video detection, a footnote should be added to the Plans noting the number of cameras, the number of processing units or other equipment and the estimated quantity of required cable. Each intersection is measured per each.

4.3.8 Video Detection – Video detection is an image processor consisting of a microprocessor-based CPU and software that analyzes video images. The detector areas are programmed through a laptop computer. Each detection zone emulates an inductive loop (see Figure 4.16). Video detection has the distinct advantage of working throughout a construction project, when inductive loops are often disturbed. This detection is not influenced by adjacent construction.

Camera systems provide many features loops cannot, such as incident monitoring and creating new detection zones anywhere in the field of view. They are non-destructive to the roadway surface. They also have shortcomings. Sun angle, shadows, rain, fog, dust, and power spikes can cause problems. Tall vehicles can obscure a lane causing missed signals.

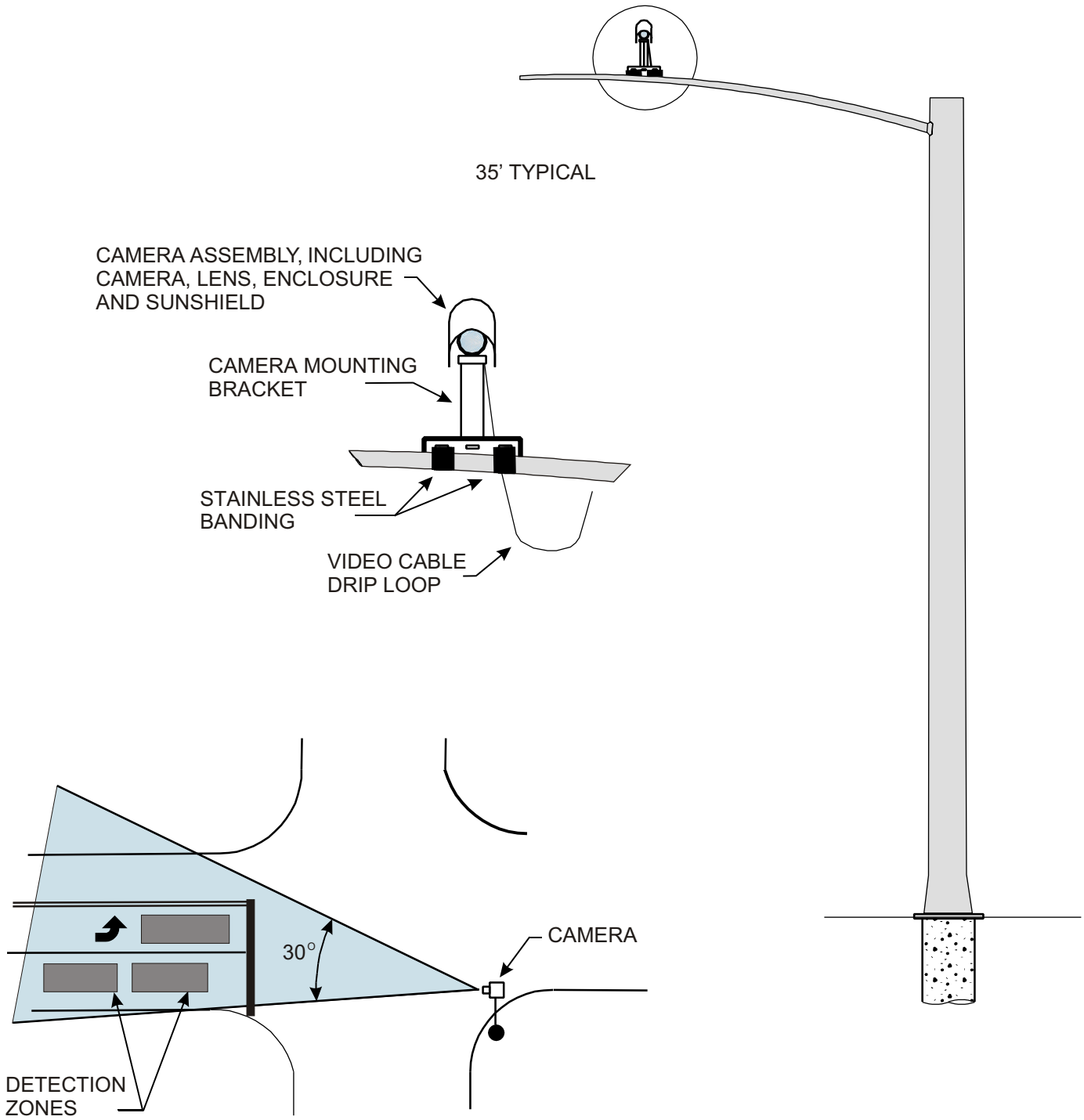
Camera position is the primary factor for successful operation. Cameras should be mounted on the most stable fixture possible. Typical mounting is on a luminaire arm. The use of video detection requires that consideration be given to sight lines to the detection zones, which can be obstructed by large trucks or other obstacles. Video detection is a more expensive detection alternative than other methods and is typically limited to stop line detection.



Tennessee Department of Transportation
Traffic Design Manual

Microwave Detection
(Side-Fired Radar)

Figure 4.15



VIDEO DETECTOR PLACEMENT

4.3.9 Phase Recalls – The recall feature of a traffic signal controller is a function that causes the automatic return of the right-of-way to a phase regardless of actuation on that approach. Minimum Recall returns to the selected phase for the minimum amount of green time (Minimum Green) for that phase. Maximum Recall returns to the selected phase for the maximum of green time (Maximum Green) for that phase. The Maximum Recall feature is used primarily for fixed time advances and the major street phase of traffic signals in a signal system. Minimum Recall is used primarily for the major street phase of a fully-actuated traffic signal not in a system and for the phase in which the signal is expected to rest.

- **Minimum Recall** is used for the arterial phase of full-actuated traffic signals.
- **Maximum Recall** is used primarily for fixed time (pre-timed) intersections and the coordinated phase of traffic signals in a system.
- **Minimum Recall** may be used for left turn or side street phases of traffic signals in systems when that feature is needed for the desired operation (to ensure a minimum side street call, etc).

4.4 Pedestrian Signal Interval – Pedestrian intervals are signal timing features activated by pedestrian pushbuttons or internally generated recalls which allow pedestrians to receive pedestrian signal displays and/or adequate signal time to aid in crossing the street. Pedestrian phase timing parameters are detailed in Section 4.5.7 and the pedestrian signal head requirements are discussed in Section 4.9.11. Pedestrians are better controlled by pedestrian signal faces rather than vehicular signal faces, therefore pedestrian signal heads should be installed at any new intersections where pedestrian phasing is provided.

A pedestrian signal interval is made up of two parts:

- **Walk Interval –** an interval during which the WALKING PERSON (symbolizing WALK) signal indication is displayed.
- **Pedestrian Change Interval –** an interval during which the flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication is displayed.

4.4.1 Pedestrian Signal Warrants – A pedestrian signal phase with pedestrian signal heads shall be installed when any of the following occur:[16]

Pedestrian phasing needs should be considered for all new signalized intersections unless pedestrians are prohibited from using the intersection.

1. When Signal Warrant 4, "Pedestrian Volume" is fulfilled.
2. When Signal Warrant 5, "School Crossing" is fulfilled.
3. Obscured signal heads or confusing phasing (such as split-phasing operation) might present problems for pedestrians.
4. Where there is an established school crossing at the proposed signal location.

[16] MUTCD, FHWA, 2003, p. 4E-1.

5. Where sidewalks and pedestrians are present or could be expected to be present.

4.4.2 Pedestrian Interval Sequence

A. **Concurrent Movement –** The most common sequence is to move pedestrians concurrent with parallel vehicular traffic. Care must be taken, however, not to move pedestrians during the display of a conflicting left turn or right turn arrow for the parallel vehicular traffic.

B. **Exclusive Movement –** This sequence moves pedestrians on a phase totally separate from any vehicular phase. When used, pedestrians cross all approaches simultaneously. This sequence shall only be used where both pedestrian volumes and conflicting vehicular turning movement volumes are high.

4.4.3 Countdown Pedestrian Signals – Technology has been developed to provide additional information to the pedestrian regarding the necessary clearance time to successfully complete the crossing of a roadway at crosswalks. A pedestrian interval countdown display may be added to a pedestrian signal head in order to inform pedestrians of the number of seconds remaining in the Pedestrian Change Interval (see Figure 4.17). The countdown indication is located adjacent to the standard pedestrian signal indication and provides a sequential countdown in seconds from the start of the flashing Pedestrian Clearance Interval ("DON'T WALK" indication) until the steady "DON'T WALK" indication is displayed.

The pedestrian countdown indication provides additional information on the time left before the pedestrian phase terminates.

The flashing "DON'T WALK" indication is intended to provide the pedestrian, who has already begun crossing, with adequate time to finish the crossing; a clearance interval. The solid "DON'T WALK" indication is intended to keep all pedestrians from being in the intersection at that time. A countdown pedestrian indication provides pedestrians with additional information, specifically a descending numerical countdown of the flashing hand clearance interval, which indicates to the pedestrian the time available for their crossing and is intended to be intuitively understood. Providing additional pedestrian clearance time information may help the pedestrian decide whether to start the crossing or wait for the next "WALK" indication.

Countdown features on pedestrian signal heads are supplemental and are not required, but may be used by a local agency.

If countdown pedestrian signals are used, a steady UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed during the Yellow Change Interval and any All Red Clearance Interval (prior to a conflicting green being displayed).

TYPICAL PEDESTRIAN SIGNAL HEADS

DON'T WALK INDICATION

WALK INDICATION

COUNTDOWN PEDESTRIAN SIGNAL HEAD

R10-1

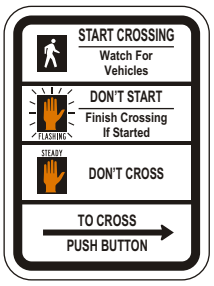
SIGN FOR INTERSECTION WITHOUT PED SIGNALS OR PUSHBUTTONS

R10-3a

SIGN FOR INTERSECTION WITH PUSHBUTTONS BUT NO PEDESTRIAN SIGNALS

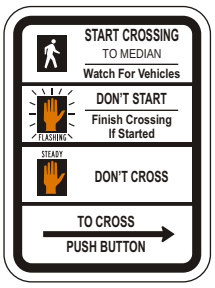
R10-2a

SIGN FOR INTERSECTION WITH PED SIGNALS BUT NO PUSHBUTTONS (OPTIONAL)



R10-3b

SIGN FOR INTERSECTION WITH PEDESTRIAN SIGNALS AND PUSHBUTTONS



R10-3d

INSTALL AT CORNER

R10-4b

INSTALL IN MEDIAN

PEDESTRIAN SIGNAL SIGNS FOR STREETS WITH MEDIANS

4.4.4 Pedestrian Actuation – Pedestrian detection is typically accomplished by active devices, primarily a pushbutton. While passive pedestrian detection is possible, it is rarely used. Pushbuttons shall be provided where the local governing agency requests or requires, sidewalks are present, or where appropriate.

If pedestrian phasing is utilized, but no pushbuttons are provided, any concurrent thru phases must be on recall to serve the pedestrian phase.

A. Undivided Roadways – When pedestrian actuated phases are provided, pedestrian pushbuttons are to be provided on the appropriate corners with a pushbutton for each crossing direction. Each pushbutton is to be supplemented by an R10-3a or R10-3b sign as appropriate with an arrow pointing in the direction of the crossing.

B. Divided Roadways – On divided roadways, both pedestrian pushbuttons and pedestrian signals are also to be installed in the median area if the median is of sufficient width to safely store pedestrians, and if the amount of pedestrian clearance time provided is only sufficient to reach the median area.[17] The pushbuttons are to be supplemented with an R10-3d sign.

C. Semi-Actuated Locations – At locations that have vehicle detectors only on the minor street and pedestrians crossing the major street are a concern, pedestrian pushbuttons will be needed for the semi-actuated approaches along with an adequate Minimum Green to assure a safe crossing of the major street.

D. Fully-Actuated Locations – At locations that have vehicle detectors on all approaches and pedestrian crossing is allowed, pushbuttons will be needed on all non-recalled approaches.

A pedestrian pushbutton is required for any actuated phase with a concurrent pedestrian movement.

Requirements for locations with and without pedestrian signal heads and pushbuttons are listed in Table 4.3. The various signs required for the different pedestrian actuation and indication scenarios are shown in Figure 4.17.

[17] MUTCD, FHWA, 2003, p. 4E-6.

Table 4.3 Pedestrian Signal Head and Pushbutton Needs

Pedestrian Signal Heads	Pedestrian Pushbuttons	Requirements	
NO	NO	Pedestrians use Vehicle Signals to cross street Recall for Vehicle Phases with concurrent Pedestrian Movements Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance CROSS ON GREEN LIGHT ONLY (R10-1) sign required	NOT RECOMMEDED
NO	YES	Pedestrians use Vehicle Signals to cross street Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance TO CROSS STREET PUSH BUTTON WAIT FOR GREEN LIGHT (R10-3a) sign required	NOT RECOMMEDED
YES	**NO**	**Good for Fixed Time Signals** **Recall for Vehicle Phases with concurrent Pedestrian Movements** **Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance** **No Sign Required (R10-2a Optional)**	**RECOMMENDED FOR FIXED TIME CONTROL**
YES	**YES**	**Good for Actuated Signals** **Minimum Green time for Vehicle Phases must be greater than required Walk and Pedestrian Clearance** **Pushbutton/Pedestrian Signal (R10-3b or (R10-3d and R10-4b)) sign required**	**RECOMMENDED FOR ACTUATED CONTROL**

4.4.5 Accessible Pedestrian Signals – The Americans with Disabilities Act (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.[18]

The technique used by pedestrians with visual disabilities to cross streets at traffic signals is to start crossing when they hear the traffic in front of them stop and the traffic alongside them begin to move, corresponding to the onset of the Green Interval. This is effective at many locations. The existing environment is often sufficient to provide the information that pedestrians who have visual disabilities need to operate reasonably safely at a signalized location. Therefore, many signalized locations will not require any accessible pedestrian signals.[19]

"Most intersections will not require accessible pedestrian signals. If a particular signalized location presents difficulties for pedestrians who have visual disabilities to cross reasonably safely and effectively, an engineering study should be conducted that considers the safety and effectiveness for pedestrians in general, as well as the information needs of pedestrians with visual disabilities" - *MUTCD* 2003.

An accessible pedestrian signal detector may provide assistance in locating the pushbutton as well as physical confirmation of the Walk Interval (see Section 4.5.7 for more information on a Walk Interval). The installation of accessible pedestrian signals at signalized locations should be based on an engineering study, which should consider the following factors:[20]

1. Potential demand for accessible pedestrian signals
2. A request for accessible pedestrian signals
3. Traffic volumes during times when pedestrians might be present, including periods of low traffic volumes or high turn-on-red volumes
4. The complexity of traffic signal phasing
5. The complexity of intersection geometry

For accessible pedestrian signal locations, each crosswalk can have a signal device that includes either audible indications or vibrotactile indications of the WALK indication. In addition, these locations may contain accessible pedestrian detectors.

[18] "Accessible Pedestrian Signals", U.S. Access Board, 1998.
[19] MUTCD, FHWA, 2003, p. 4E-3.
[20] Ibid, p. 4E-4.

4.4.5.1 Accessible WALK Indications – An accessible pedestrian signal typically includes a signal device that provides either audible indications or vibrotactile indications of the Walk Interval.

A. Audible Conformation – Audible pedestrian signal devices supplement visual WALK indications and are designed to aid visually impaired pedestrians. When verbal messages are used to communicate the pedestrian interval, they provide a message that the Walk Interval is in effect, as well as to which crossing it applies. The verbal message is provided at regular intervals throughout the timing of the Walk Interval.

B. Vibrotactile Confirmation – A vibrotactile pedestrian device communicates information about pedestrian timing through a vibrating surface by touch. Vibrotactile pedestrian devices indicate that the Walk Interval is in effect, and for which direction it applies, through the use of a vibrating directional arrow or some other means. They are located adjacent to the pushbutton.

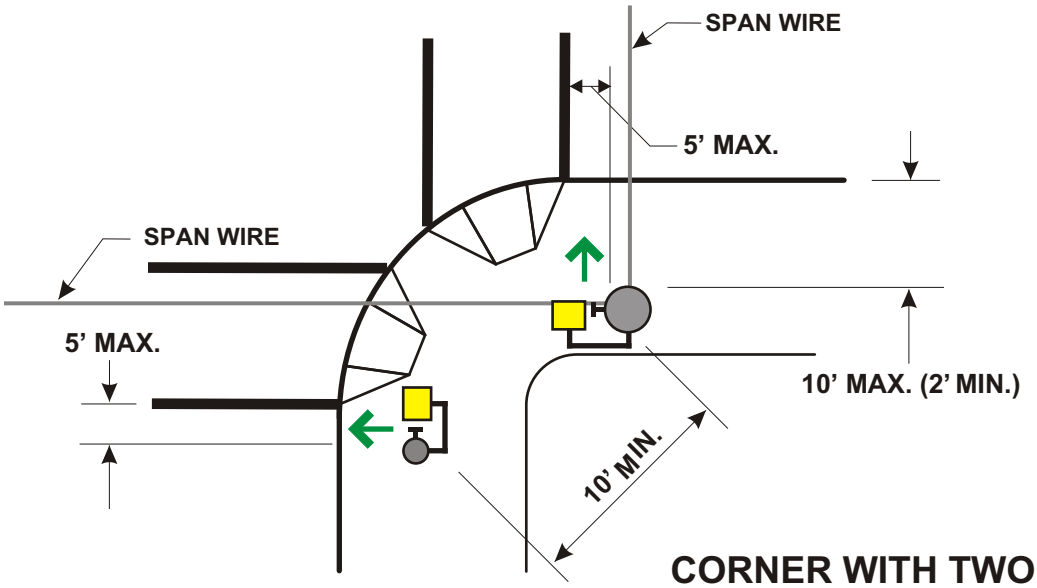
4.4.5.2 Accessible Pedestrian Signal Detector – An accessible pedestrian signal detector is a device that can assist a pedestrian with visual or physical disabilities in activating the pedestrian phase. Accessible pedestrian signal detectors may be either pushbuttons or passive detection devices. Pushbutton locator tones, which help the pedestrian find the pushbutton, may also be used with accessible pedestrian signals. A pushbutton locator tone is a repeating sound that informs approaching pedestrians that they are required to push a button to actuate pedestrian timing, and that enables visually impaired pedestrians to locate the pushbutton.

When used, accessible pedestrian pushbuttons on corners should be separated by at least 10'.

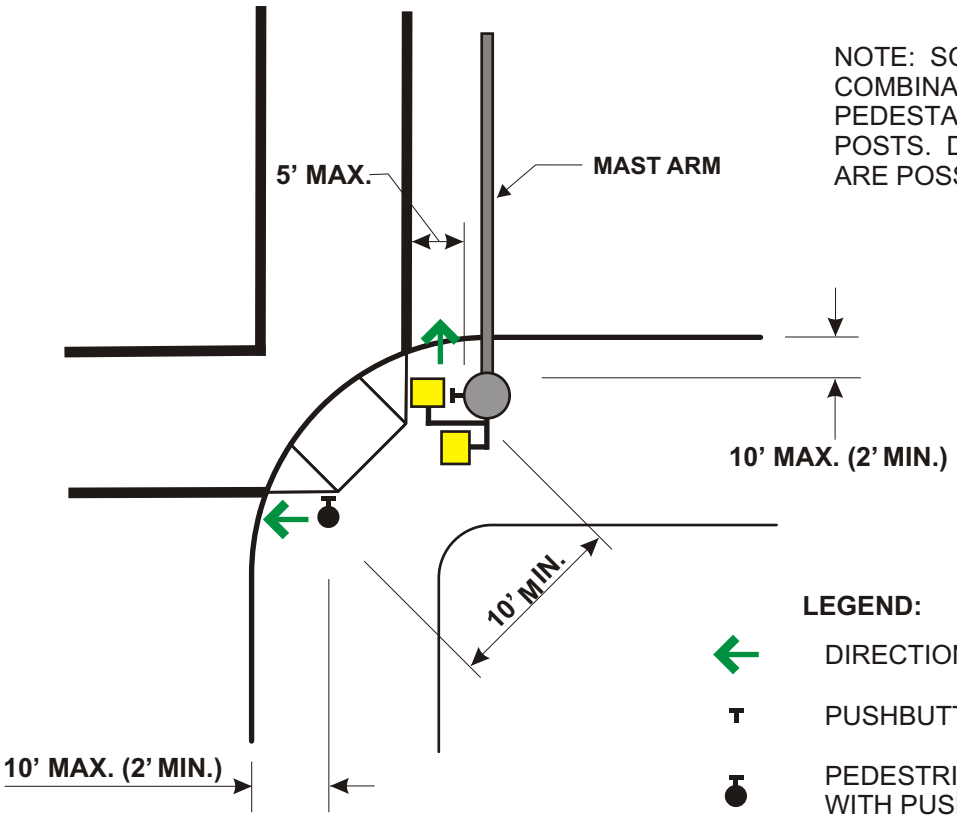
At accessible pedestrian signal locations, pushbuttons should clearly indicate which crosswalk signal is actuated by each pushbutton. At corners of signalized locations with accessible pedestrian signals where two pedestrian pushbuttons are provided, a distance of at least 10 feet should separate the pushbuttons to enable pedestrians who have visual disabilities to distinguish and locate the appropriate pushbutton.

Pushbuttons for accessible pedestrian signals should be located as follows (see Figure 4.18):

- Adjacent to a level all-weather surface to provide access from a wheelchair and where there is an all-weather surface, wheelchair accessible route to the ramp
- Within 5 feet of the crosswalk extended
- Within 10 feet of the edge of the curb, shoulder or pavement
- Parallel to the crosswalk to be used



CORNER WITH TWO RAMPS



NOTE: SCHEMATICS SHOW VARIOUS COMBINATIONS OF SIGNAL POLES, PEDESTAL POLES AND PUSHBUTTON POSTS. DIFFERENT COMBINATIONS ARE POSSIBLE.

CORNER WITH SINGLE RAMP

LEGEND:

- DIRECTION FOR PUSHBUTTON
- PUSHBUTTON
- PEDESTRIAN PUSHBUTTON POST WITH PUSHBUTTON
- PEDESTAL POLE WITH PEDESTRIAN SIGNAL AND PUSHBUTTON
- SIGNAL SUPPORT POLE WITH PEDESTRIAN SIGNAL AND PUSHBUTTON

Tennessee Department of Transportation
Traffic Design Manual

Accessible Pedestrian Signal Pushbutton Locations

Figure 4.18

4.5 Traffic Signal Timing – Proper signal timing is essential to the efficient operation of a signalized intersection. The objective of signal timing is to determine the appropriate timing for each required signal phase so as to minimize the average delay to any single group of vehicles or pedestrians and to reduce the probability of conflicts that could cause accidents.[21]

Regardless of how precise a theoretical method of signal timing might be, its effectiveness in actual traffic conditions must be observed in the field and appropriate timing adjustments made after implementation.

TDOT typically provides basic signal timings on the timing detail sheet to allow a safe startup of the system while the road project is still in the construction phase. If the local agency agrees, plans can note that the local agency is to provide initial signal timings. Startup timing should emphasize safety over efficiency. These timings should be based on operational traffic volumes expected for approximately three years after completion of construction.

4.5.1 Types of Signal Timing Data – In general, an intersection will require one or more of the following types of signal timing data:

- **Preset Timing Intervals –** phase timing intervals that are fixed and do not change.
- **Actuated Timing Intervals –** a number of timing variables that can change including individual phase splits that can vary.
- **Fixed Time Plan –** based on a fixed cycle length (see Figure 4.1 for basic fixed time cycle schematic). Multiple timing plans may be needed for different time periods.
- **Coordinated Signal Timing Plan –** time-of-day and traffic responsive plans (splits, cycle lengths and offsets) with the intersection is part of a larger system.

4.5.2 Preset Timing Intervals – All traffic signal controllers have some preset timing intervals. In non-actuated (pre-timed) control, all intervals are preset. In semi-actuated or fully-actuated control, some intervals are also preset and some are variable. Preset intervals found in both pre-timed and actuated control include the following:

- **"Yellow Change (Clearance)" Interval** (see Section 4.5.6)
- **"Red Clearance (All Red)" Interval** (see Section 4.5.6)
- **"Walk" Interval** (see Section 4.5.7)
- **"Pedestrian Change" Interval** (see Section 4.5.7)

4.5.3 Pre-Timed Timing Intervals – As previously defined, a pre-timed traffic signal controller is one in which the timing and phasing do not vary from

[21] Traffic Control Devices Handbook, ITE, 2001, p. 352

cycle to cycle. In addition to the intervals listed in Section 4.5.2, the basic timing parameters for a pre-timed controller are:

- **Cycle Length**
- **Green Intervals (Splits) – Maximum Green on Recall**
- **Number of Timing Plans**

If pedestrians regularly use the intersection, pedestrian timing will also have to be considered both with and without pedestrian signal indications and/or pushbuttons. The movement green required for vehicles shall be compared with the required pedestrian crossing times (see Section 4.5.7). If the pedestrian timing requirement exceeds the movement green, the pedestrian timing shall govern and the movement green lengthened.

Green movement timing for pre-timed signals shall be equal to or greater than the required pedestrian crossing time if pedestrians use the intersection.

Once the signal phasing has been decided upon using the guidelines in Section 4.2, the cycle length of the signal must then be determined. A signal's cycle length is defined as the total time in seconds required to complete a prescribed sequence of signal phases. In general, signal cycles should be as short as possible to adequately handle the traffic demand.

4.5.3.1 Cycle Length Determination – Cycle lengths should be calculated for the different time periods (AM Peak hour, the PM Peak hour and the off peak periods as a minimum). Additional cycle lengths for additional time periods may also be needed. There are several methods that can be used to calculate cycle lengths, two of which are provided below.

A. Critical Lane Volume Method – The sum of the critical lane volumes for each signal phase can be used to determine a minimum cycle length. The first step is assigning peak hour approach volumes to individual lanes as follows:

- **Exclusive Turn Lanes –** Where exclusive turn lanes are available, all turns are assigned to the appropriate turn lane. The remaining approach thru volumes are equally distributed to the approach thru lanes.

- **Shared Lanes Without Permissive Left Turns –** For shared and/or thru lanes where permissive left turns are not present, the approach volume is equally distributed amongst the approach lanes.

- **Shared Lanes With Permissive Left Turns –** Where permissive left turns are present in shared lanes, the left turn volumes must be converted to thru vehicle equivalents (TVE) (refer to Chapter 16 of the 2000

Highway Capacity Manual). They are then added to the thru and right turn volumes on the approach and equally distributed to the approach lanes.

The total TVE left turn volume is then subtracted from the inside (left) shared lane volume to determine the actual number of thru vehicles in that lane. This actual number of thru vehicles is added to the actual left turn volume and assigned to the shared inside (left) lane. The actual remaining traffic is then distributed equally to the remaining approach lanes. The highest lane volume for this approach is the critical lane volume for the approach.

- Using the assumed signal phasing, the highest lane volume moving in each phase is identified as the critical lane volume for that phase.
- The critical lane volume for all phases is totaled, determining the minimum cycle length.

Various methods of establishing cycle length exist; Webster's equation is given as Equation 4.1.

Equation 4.1 [22]

Optimal Cycle Length (C) = $\dfrac{1.5L + 5}{1.0 - \sum Y_i}$

Where: L = usable time per cycle (seconds)

Y_i = critical lane volume (i^{th} phase, vph)/saturation flow (vph)

B. Signal Timing Software – WIN TEAPAC 2000 and SIGNAL 2000 software applications provide a relatively quick and easy method of determining how well a range of cycle lengths will work for a given set of conditions at an intersection.

4.5.3.2 Cycle Lengths in Signal Systems

A. Existing System – Where a traffic signal is to be added to an existing signal system, it must operate on the same cycle length as the system or a multiple of it.

B. New System – If individual traffic signals are being timed for a new signal system, the intersection requiring the longest cycle lengths is the "critical intersection" and its cycle length will determine the cycle length for the system.

[22] Northwestern University Traffic Institute, Traffic Actuated Control Workshop, November 2001.

4.5.3.3 Movement Timing – With solid state equipment the green time for each phase is set on Maximum Recall because of the lack of signal detection. This setting for each phase is based on the average needs for that particular movement as determined by traffic counts. Ideally, it should be long enough to service all the vehicles and pedestrians accumulated during the Change Interval.[23] Two methods of calculating the Maximum Green time are as follow:

A. Manual Calculation – The Green Interval timing can be calculated for each phase by Equation 4.2.

Equation 4.2 [24]

$$G = \left[\frac{V_A}{V_T} xC \right] - CLR$$

Where: G = Green Interval for phase (sec.)

V_A = Critical lane volume for phase (veh/hr.)

V_T = Sum of critical lane volumes for all phases (veh/hr.)

C = Cycle Length

CLR = Clearance Interval for phase (sec.)

B. Signal Timing Software – WIN TEAPAC 2000 and SIGNAL 2000 are examples of software applications that provide a relatively quick and easy method to determine optimum green phase settings while minimizing the approach and overall intersection delay.

4.5.4 Basic Actuated Timing Intervals – In addition to the intervals listed in Section 4.5.2, the following timing parameters are used in a basic actuated traffic signal controller:

- **Minimum Green**
- **Passage Time**
- **Maximum Green**

4.5.4.1 Minimum Green – The Minimum Green setting is the shortest time allowed by a phase.

- **Approach with Stop Line Detection –** When detectors are located at the approach stop line, a Minimum Green of 6.0 seconds shall be used for thru movements on side streets and longer for major streets.

[23] Traffic Engineering Handbook, ITE, 1999, p. 480
[24] Northwestern University Traffic Institute, Traffic Actuated Control Workshop, November 2001.

- **Approach with Advance Detection Only –** When an approach has only advance detection, the Minimum Green shall be the amount of time required to clear the stored vehicles between the stop line and the detectors (see Section 4.5.3.3 for equation to determine Minimum Green for advance detection).

- **Turn Lanes –** A Minimum Green of 6.0 seconds shall be used for any turn lane.

- **Approaches with Pedestrian Phases –** The Minimum Green required for vehicles shall be compared with the required pedestrian crossing times (see Section 4.5.7). If the pedestrian timing requirement exceeds the Minimum Green, the pedestrian timing shall govern and the Minimum Green lengthened.

For approaches with pedestrian phases, the Minimum Green shall be equal to or greater than the required pedestrian crossing time.

4.5.4.2 Passage Time (Vehicle Extension or Interval) – This function extends the green for a phase beyond Minimum Green up to a preset maximum timing to accommodate additional vehicles stopped behind the stop line or vehicles approaching the stop line after the phase indication turns green. It is also the allowable gap in approaching traffic for the signal phase to lose the green.[25] The basic relationship between these timing parameters is shown in Figure 4.19.

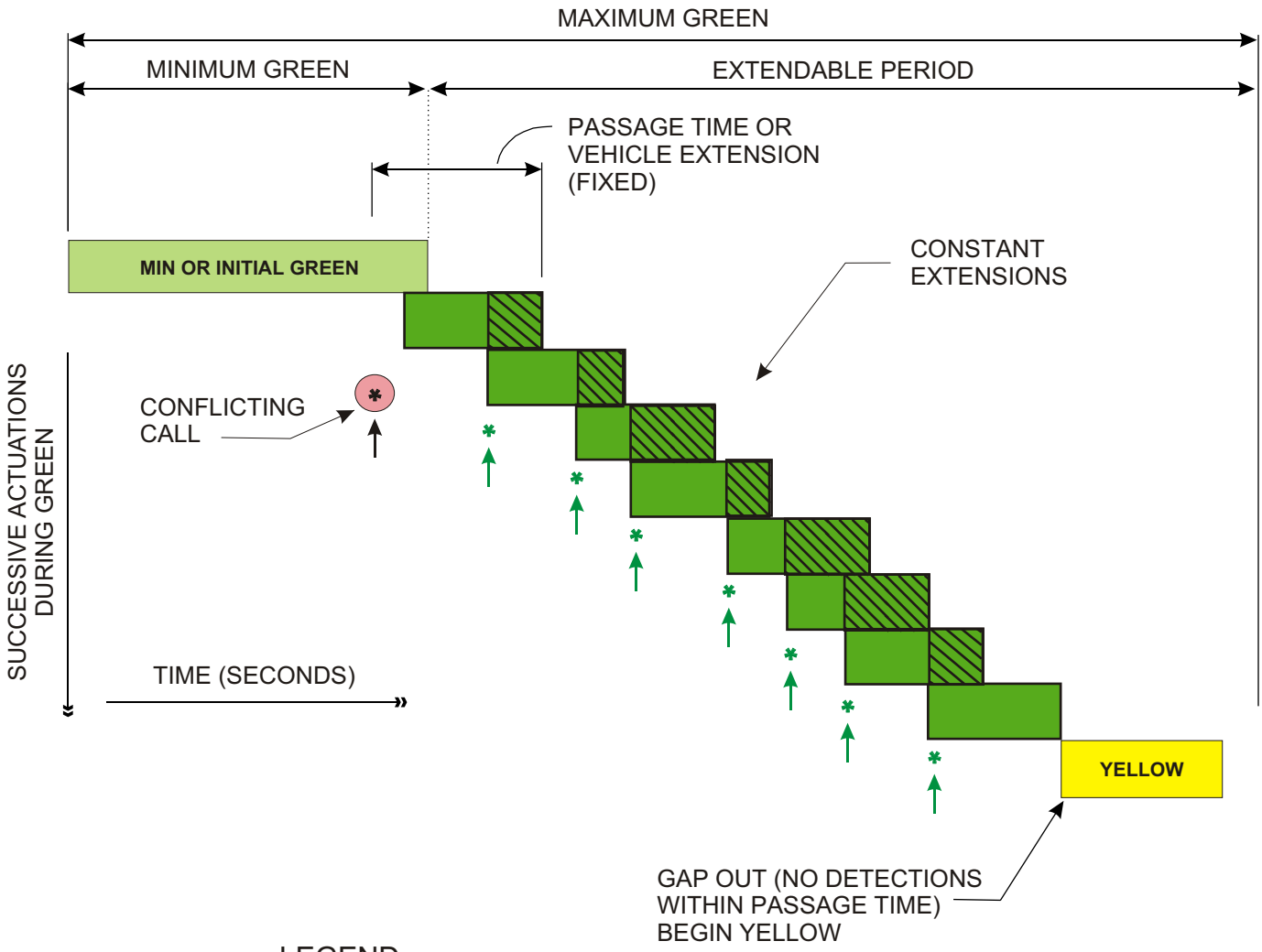
For maximum efficiency the Passage Time should be set as short as practical to retain the green as long as a consistent demand is present, but not so long that it retains vehicles straying behind. However, where detectors are located at some distance from the stop line, the Passage Time must be long enough to permit the vehicle to travel from the detector to the stop line without gapping out.

Typical Passage Times are 2.0 to 3.0 seconds for stop bar loops, with longer times for advance loops (3.5 to 6.0 seconds).

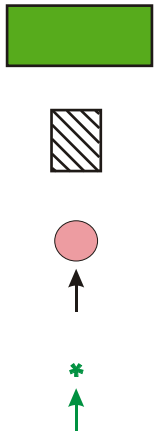
4.5.4.3 Maximum Green – The Maximum Green defines the longest green time allowed for the signal phase in the presence of a serviceable conflicting call or another phase on recall. It can be determined using the methods described for Green Interval timing for pre-timed controllers (see Section 4.5.3.3). At all but oversaturated intersections, the Maximum Green should be long enough to clear the largest platoons of traffic expected.

Major thru movements should have a Maximum Green time of between 60 and 120 seconds.

[25] Manual of Traffic Signal Design, ITE,1998, p. 152



LEGEND



PASSAGE TIME (OR VEHICLE EXT)

UNEXPIRED PORTIONS OF PASSAGE TIME
OR VEHICLE EXTENSION INTERVALS

DETECTOR ACTUATION ON
CONFLICTING PHASE

DETECTOR ACTUATION ON A PHASE
WITH RIGHT OF WAY

NOTE - IN THIS SCHEMATIC, THERE IS A DEMAND FOR ANOTHER PHASE AND THE PHASE GAPS OUT PRIOR TO REACHING MAX GREEN.
IF ACTUATIONS CONTINUE TO MAX GREEN, THE GREEN WILL END AT MAX GREEN TIME AND YELLOW WILL BEGIN AT THAT POINT.
IF THERE IS NO DEMAND FROM ANOTHER PHASE, THIS PHASE WILL REST IN GREEN AFTER REACHING MAX.

Actuated Phase Intervals

Figure 4.19

4.5.5 Volume Density Timing Intervals – Even more sophisticated operation is possible with the volume density traffic actuated traffic signal controller unit. In addition to the features discussed above, volume density provides two means of modifying the basic timing intervals. These are:

Volume-density operation is a more advanced form of fully-actuated control. It has the ability to calculate the duration of Minimum Green based on actual demand (calls on red) and the ability to reduce the maximum allowable time between calls from Passage Time down to a Minimum Gap. Reducing the allowable time between calls below the passage time will improve efficiency by being better able to detect the end of queued flow.

- **Variable Initial** is a means of extending the initial portion of the Green Interval. This is done on the basis of the number of actuations above a preset number while the phase is displaying a YELLOW or RED indication. This extended initial provides additional green time for a queue of vehicles waiting, when the GREEN signal indication appears, to clear the intersection if the detectors are set back a distance from the stop bar and there are no vehicles following.

- **Gap Reduction** is a means of reducing the Passage Time or gap on the basis of the time that opposing vehicles have waited. In effect, it benefits the waiting vehicles by reducing the time allowed between vehicles arriving on the green phase before that phase is terminated.

In addition to the intervals listed in Section 4.5.2, the following timing parameters are used in volume density signal operation:

- **Minimum Initial (Minimum Green)**
- **Maximum Initial**
- **Added Initial**
- **Variable Initial**
- **Initial Gap (Passage Time),**
- **Time Before Reduction (TBR)**
- **Time to Reduce (TTR)**
- **Minimum Gap**
- **Maximum Green**

These features are typically used for approach speeds of greater than 30 mph and provide a Variable Initial green time as well as a variable “gap” reduction feature.

Variable Initial – This feature increases the minimum assured green time (Minimum Initial) so it will be long enough to serve the actual number of vehicles waiting for the green between the stop line and the detector. This

interval is generally used on phases for higher speed approaches where the detectors are placed quite a distance from the stop line (resulting in unacceptably long Minimum Initial requirements). This feature allows the Minimum Initial to be set low for light volumes. Vehicles crossing the detector when the phase is red will add time to the minimum assured green, so that when the phase is served, the minimum assured green will be long enough to serve the actual number of vehicles waiting for the green (see Figure 4.20).

4.5.5.1 Minimum Initial (Minimum Green) – This setting provides the guaranteed shortest green time for the signal phase. It cannot vary. Because of the Added Initial feature, the Minimum Initial does not have to be long enough to start up and clear the intersection of all the vehicles waiting between the stop line and the detector. Instead, it is intended to allow time for the first motorist to respond to the onset of the GREEN signal indication.[26] If pedestrians regularly use the intersection, the Minimum Green shall also be calculated for the pedestrian crossing (see Section 4.5.7). If the pedestrian timing requirement exceeds the Minimum Green plus its Yellow Change Interval, the pedestrian timing shall govern.

For approaches with pedestrian phases, the Minimum Green shall be equal to or greater than the required pedestrian crossing time.

This value can usually be expected to range between 10-15 seconds on a moderate speed approach and 15-20 seconds for high-speed approaches.

4.5.5.2 Maximum Initial – The maximum initial setting is the longest timing to which the Variable Initial interval can be extended. It is the timing necessary to ensure that a queue of vehicles released at the beginning of green will be moving across the stop line detector before the termination of green. Assuming a start up delay of 3 seconds and a discharge rate of 2 seconds per vehicle, the maximum initial can be calculated by the following equation.

Equation 4.3

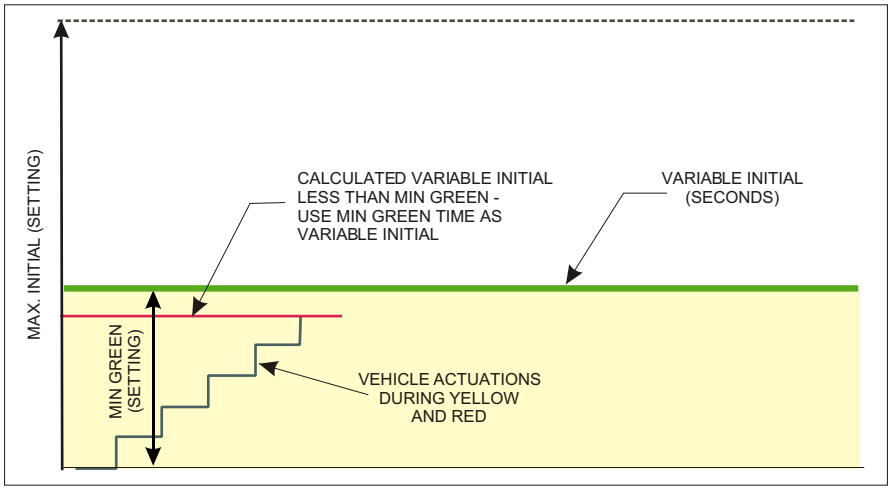
MI (sec.) = 3 + 2n

Where: MI = Maximum Initial

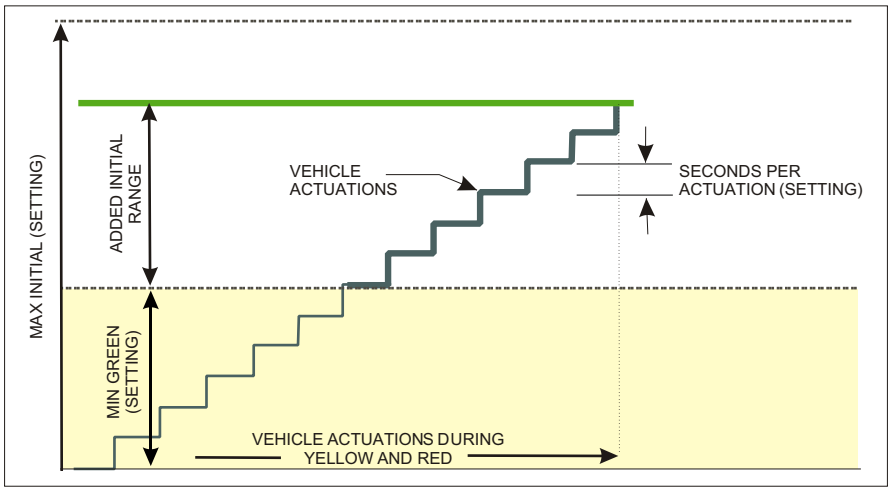
n = max number of queued vehicles per lane (from stop line to detector), calculated as the distance from stop line to detector divided by 25 ft/vehicle

The maximum initial can not exceed the Maximum Green time for the phase.

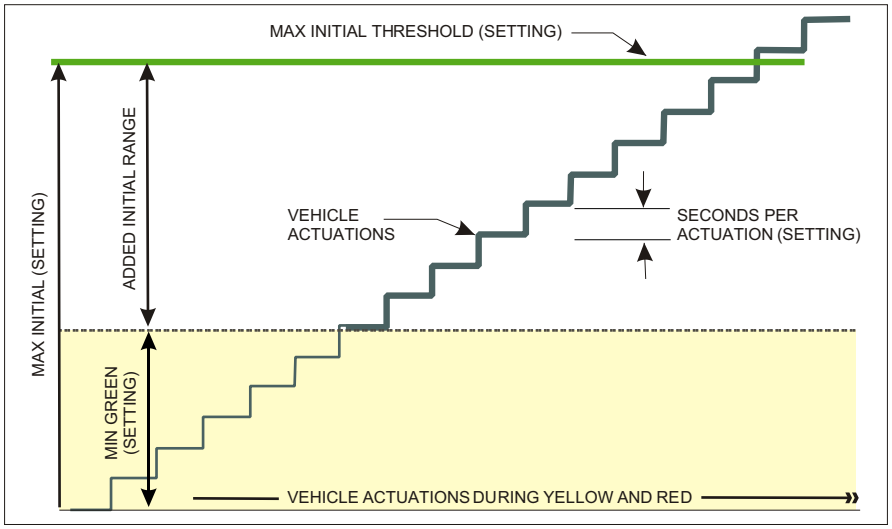
[26] Traffic Control Devices Handbook, ITE, 2001, p. 329



VARIABLE INITIAL INTERVAL TIMING DETERMINATION
CALCULATED VARIABLE INITIAL LESS THAN MIN. GREEN



VARIABLE INITIAL INTERVAL TIMING DETERMINATION
VARIABLE INITIAL BETWEEN MIN. GREEN AND MAX. INITIAL



VARIABLE INITIAL INTERVAL TIMING DETERMINATION
CALCULATED VARIABLE INITIAL GREATER THAN MAX. INITIAL

Tennessee Department of Transportation
Traffic Design Manual

Volume Density Timing
Variable Initial Interval

Figure 4.20

4.5.5.3 Added Initial – Because the initial (or minimum) green is set low for volume density timing (unless pedestrian timing governs); additional time is needed to clear the queue of vehicles which have arrived during the clearance and change intervals. The Added Initial function provides the additional initial green timing to clear into the intersection all the vehicles waiting between the stop line and the detector who were not accommodated by the Minimum Initial green timing.

The Added Initial is the added interval of timing for each vehicle actuation that is received on the approach during the clearance and change intervals, but only becomes active once it exceeds the Minimum Initial setting.[27] The Added Initial can be calculated by Equation 4.4. The adequacy of this timing must be checked in the field.

Equation 4.4

$$\text{Added Initial (sec./act.)} = \frac{\text{MI}}{n}$$

Where: MI = Maximum Initial

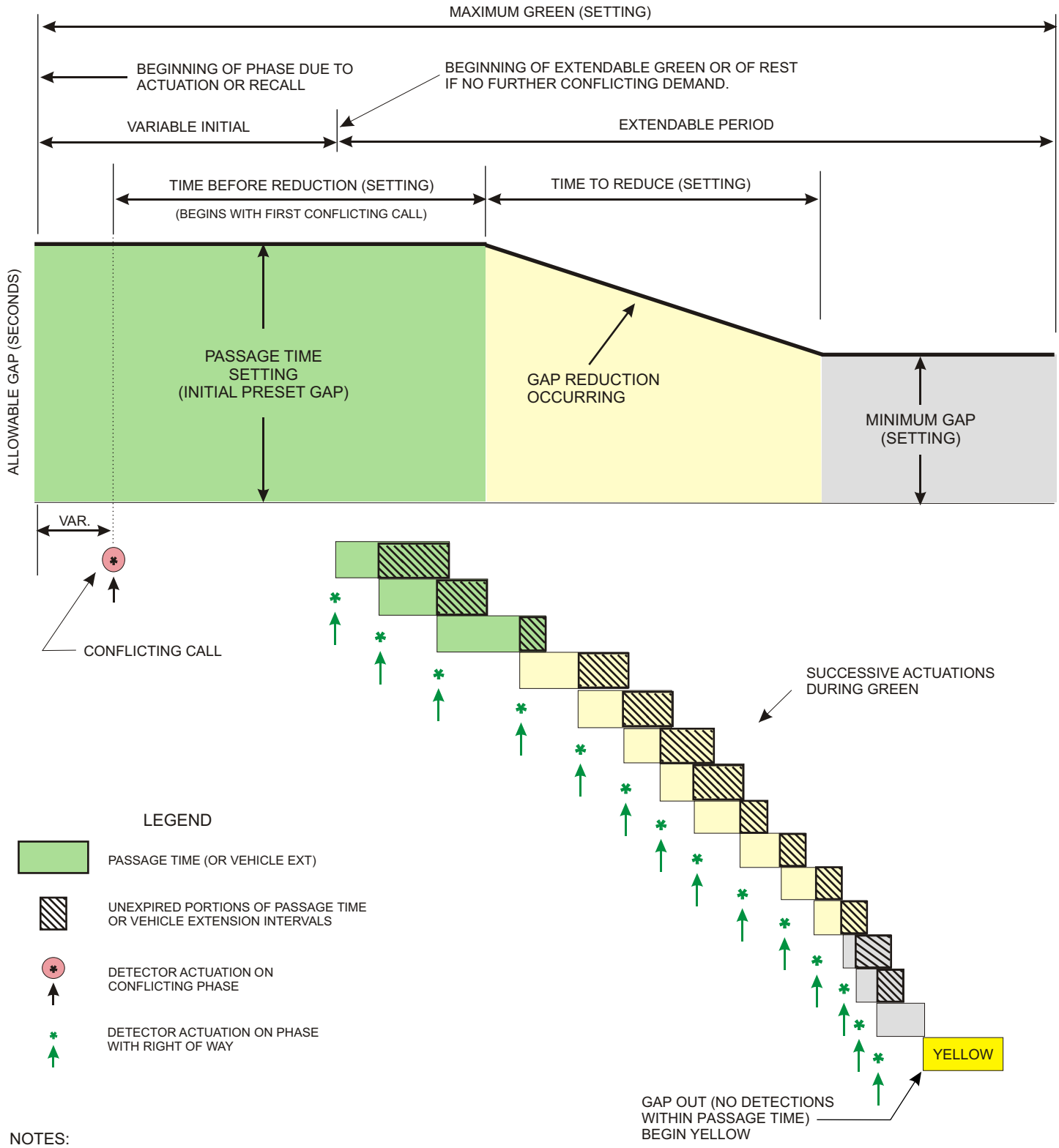
n = max number of queued vehicles per lane (from stop line to detector), calculated as the distance from stop line to detector divided by 25 ft/vehicle

Often a value of 2 or 3 seconds per vehicle seconds is used for the Added Initial.

4.5.5.4 Variable Initial – Variable Initial timing describes the initial green used in a volume density phase before the extendable portion of the phase starts. If the number of actuations during the clearance and change intervals is small and the Added Initial time calculated for these vehicles is less than the Minimum Green, the Variable Initial is the Minimum Green. With heavy traffic, the Added Initial increases the initial green beyond the Minimum Green to ensure that vehicles between the stop line and the detector can clear the intersection.

Gap Reduction – This feature reduces the Passage Time and as a result reduces the allowable time gap between actuations that will cause the green to remain on that approach (see Figure 4.21). When a phase is green, the time between vehicles to terminate that phase starts out at the amount of time set for the Passage Time. After the phase has been green for some time, it becomes desirable to terminate the phase on smaller distances between vehicles. (i.e., successive actuations must be closer together than the Passage Time to extend the green).

[27] Manual of Traffic Signal Design, ITE, 1998, p. 154



NOTES:

1. IN THIS SCHEMATIC, THERE IS A DEMAND FOR ANOTHER PHASE AND THE PHASE GAPS OUT PRIOR TO REACHING MAX GREEN. IF ACTUATIONS CONTINUE TO MAX GREEN, THE GREEN WILL END AT MAX GREEN TIME AND YELLOW WILL BEGIN AT THAT POINT. IF THERE IS NO DEMAND FROM ANOTHER PHASE, THIS PHASE WILL REST IN GREEN AFTER REACHING MAX.
2. SEE FIGURE 4.17 FOR VARIABLE INITIAL DETERMINATION.

Tennessee Department of Transportation
Traffic Design Manual

Volume Density Timing Gap Reduction Feature

Figure 4.21

4.5.5.5 Initial Gap (Passage Time) – The Initial Gap setting in a volume density controller is the beginning value of the green extension timing after the Variable Initial green timing expires. It is the same as Passage Time and is calculated as the time it takes a vehicle to travel from the detector to the stop line. This can be calculated using Equation 4.5 shown below.

Equation 4.5

Initial Gap (Passage Time) = $\frac{D}{V}$

Where: D = Distance from the detector to the stop line (feet)

V = 85th percentile approach speed (ft/sec.)

4.5.5.6 Time Before Reduction (TBR) – The Time Before Reduction setting sets the time before the Initial Gap setting is allowed to begin reducing towards the Minimum Gap setting. It starts as soon as a call is received on a conflicting phase. It can start at the beginning of the Minimum Green if vehicles are waiting on other approaches before the Minimum Green.

The Time Before Reduction should be set at approximately 1/3 of the Maximum Green. However, it should be observed in the field to assure that it does not cause the green to prematurely gap out.

4.5.5.7 Time to Reduce (TTR) – The Time to Reduce setting is the time over which the Initial Gap is reduced to the Minimum Gap and assures that the phase will not be held by large gaps in traffic. It begins after the Time Before Reduction is timed out. During the Time to Reduce, there is a linear reduction in the allowable gap from the Initial Gap (Passage Time) setting to the Minimum Gap setting.

The Time to Reduce should be set at approximately 1/3 of the Maximum Green.

4.5.5.8 Minimum Gap – The Minimum Gap setting establishes the minimum value for which the allowable gap between actuations can be reduced after expiration of the Time to Reduce. This is the average headway between vehicles and is approximately the time it takes a vehicle to travel from the detector through the dilemma zone. The amount of time into the green to reduce to the Minimum Gap should be set at about 2/3 of the maximum time. The allowable gap will gradually reduce in that time frame. Therefore, the last 1/3 of the Maximum Green would be extended only by tightly spaced vehicles.

A setting of 2.5 seconds is adequate for a single lane approach. Generally the Minimum Gap should not be set lower than 2 seconds.

4.5.5.9 Last Car Passage – Last Car Passage is a feature to provide full Passage Time to the last vehicle upon a gap out when the gap time has been reduced. This helps ensure that the last vehicle receives sufficient Passage Time to clear the intersection without encountering dilemma zone issues. When using volume density timing, this feature should normally be set to "on" when gap reduction features are utilized.

4.5.5.10 Listed below are some basic rules for volume density timing:

- Min Green ≥ Ped Walk + Ped Clearance
- Min Green ≤ Variable Initial ≤ Max Initial
- Max Initial ≤ Max Green
- TBR + TTR ≤ Max Green
- Passage Time ≥ Min Gap

Table 4.4 lists some recommended volume density timing values for different approach speeds.

Table 4.4 Recommended Volume Density Timing Values

Approach Speed (MPH)	Distance from Stop Line to Advance Detector (feet)	Minimum Green* (secs)	Maximum Initial (secs)	Added Initial (secs)	Initial Gap (Passage Time) (secs)	Time Before Reduction (secs)	Time to Reduce (secs)	Time to Reduce (secs)	Maximum Green (secs)
35	185	10	18	2.4	3.6	1/3 Max Green	1/3 Max Green	2.0	35-70
40	230	15	21	2.3	3.9	1/3 Max Green	1/3 Max Green	2.0	40-80
45	285	15	26	2.3	4.3	1/3 Max Green	1/3 Max Green	2.0	45-90
50	340	20	30	2.2	4.6	1/3 Max Green	1/3 Max Green	2.0	50-100
55	405	20	35	2.2	5.0	1/3 Max Green	1/3 Max Green	2.0	55-110
60	475	25	41	2.2	5.4	1/3 Max Green	1/3 Max Green	2.0	60-120
65	550	25	47	2.1	5.8	1/3 Max Green	1/3 Max Green	2.0	60-120

* If pedestrians are an issue for the approach, Minimum Green must be compared against pedestrian timing requirements.

4.5.6 Vehicle Clearance Intervals – Vehicle clearance intervals consist of a Yellow Change Interval and an optional All Red Clearance Interval and should provide enough time so that the motorist can either stop or proceed safely through the intersection prior to the release of opposing traffic.

A vehicle clearance interval is composed of a Yellow Change Interval and an All Red Clearance Interval.

4.5.6.1 Yellow Change Interval (Yellow Clearance Interval) Timing – The Yellow Change Interval of a traffic signal is used to notify the motorist that the Green Interval is ending. The Yellow Change Interval normally has a range of 3.0 to 6.0 seconds. *Tennessee Code Annotated* requires a minimum three seconds yellow time, with 4.0 seconds preferred. Yellow Change Intervals in excess of 5.0 seconds may encourage motorists to "run the yellow" instead of stopping.[28] If a clearance interval time in excess of 5.0 seconds is required on all but very high speed approaches (greater than 55 mph), the additional time should be provided by an All Red Clearance Interval.

A. Thru Vehicle Clearances – The clearance interval time for thru vehicles is calculated by the Equation 4.6 which includes a reaction time, a deceleration time and an intersection clearance time. This equation assures that the clearance interval time is of sufficient length to eliminate the "dilemma zone" in which a motorist has difficulty in deciding whether to stop or proceed through the intersection.

Equation 4.6 [29]

$$CP = t + \frac{V}{2a} + \frac{(w+L)}{V}$$

Where: CP =non-dilemma clearance interval (yellow + All Red), (sec.)

t =Perception – Reaction Time (normally 1 sec.)

V=Approach speed (ft./sec.)

a =Deceleration rate (typically 10 ft./sec.^{2})

w =Intersection width, stop line to far cross street curb line (ft.)

L =Length of vehicle (typically 20 ft.)

The Yellow Change Interval is often set as the sum of the first two terms of Equation 4.6 (t + V/2a) rounded up to the next ½ second, and the All Red is set at the value of the third

[28] Traffic Engineering Handbook, ITE, 1999, p. 481
[29] Manual of Traffic Signal Design, ITE, 1998 p. 143

term. Table 4.5 lists calculated and recommended rounded vehicle clearance timing values for thru phases.

B. Left Turn Vehicle Clearance Interval – In determining the clearance interval for left turn phases, Equation 4.6 is also used but the turning path of the vehicle is used for "w" and the speed of the turning vehicle "V" should be 15 mph. The turning path of the vehicle is measured on an arc from the stop line in the left turn lane to the far left curb line of the street from which the turn is made.

4.5.6.2 All Red Clearance Interval – The All Red timing is an optional part of the clearance interval and immediately follows a Yellow Change Interval. It is used to provide additional timing (beyond that needed to stop) for a vehicle to clear the intersection before the display of a conflicting GREEN signal indication. It is calculated using the third term in Equation 4.6 shown above (2.5 seconds max).

Table 4.5 Recommended Yellow Change and All Red Clearance Interval Values

Approach Speed (MPH)	Calculated Yellow Interval (secs)	Calculated Minimum TOTAL Clearance Interval (seconds)*								
		Crossing Street Width (feet)								
		30	40	50	60	70	80	90	100	110
25	2.8	4.2	4.5	4.7	5.0	5.3	5.6	5.8	6.1	6.4
30	3.2	4.3	4.6	4.8	5.0	5.2	5.5	5.7	5.9	6.2
35	3.6	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.1
40	3.9	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.1
45	4.3	5.1	5.2	5.4	5.5	5.7	5.8	6.0	6.1	6.3
50	4.7	5.3	5.5	5.6	5.8	5.9	6.0	6.2	6.3	6.4
55	5.0	5.7	5.8	5.9	6.0	6.1	6.3	6.4	6.5	6.6
60	5.4	6.0	6.1	6.2	6.3	6.4	6.5	6.7	6.8	6.9
65	5.8	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1

** Based on Equation 4.6*

Approach Speed (MPH)	**Recommended Yellow Interval (secs)**	**Recommended All Red Clearance Interval (seconds)**								
		Crossing Street Width (feet)								
		30	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**
25	**4.0**	**0.5**	**0.5**	**1.0**	**1.5**	**1.5**	**2.0**	**2.0**	**2.5**	**2.5**
30	**4.0**	**0.5**	**1.0**	**1.0**	**1.5**	**1.5**	**1.5**	**2.0**	**2.0**	**2.5**
35	**4.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**1.5**	**1.5**	**2.0**	**2.0**
40	**4.5**	**1.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**1.5**	**2.0**	**2.0**
45	**4.5**	**1.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**1.5**	**2.0**	**2.0**
50	**5.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**1.5**	**2.0**	**2.0**
55	**5.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**1.5**	**2.0**	**2.0**
60	**5.5**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**2.0**	**2.0**
65	**6.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.5**	**1.5**	**2.0**	**2.0**

4.5.7 Pedestrian Phase Timing

4.5.7.1 Walk Interval – Where pedestrian phases are provided, Walk Interval timing provides the time necessary for a pedestrian to leave the curb to cross the street. The typical **minimum** Walk Interval time value is 7 seconds.[30] Where large groups of pedestrians cross, field observation and timing should be used to see how long it takes the group to leave the curb.

To safely cross the street, pedestrians need at least 7 seconds to leave the curb (a Walk Interval) and time to cross the street (a Pedestrian Change Interval) – MUTCD 2003

4.5.7.2 Pedestrian Change ("Flashing" Don't Walk) Interval – The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the Walk Interval signal indication to travel at a maximum walking speed of 4 feet per second, to at least the far side of the traveled way (or to a median of sufficient width for pedestrians to wait). Where pedestrians who walk slower than normal, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 4 feet per second per second should be used in determining the pedestrian clearance time (typically 3.0 feet per second).

For typical intersections, a walking speed between 3.0 and 4.0 feet per second shall be used. Where the crossing is routinely used by young children, the elderly, the physically challenged or large groups of pedestrians, a walking speed of 3.0 feet/second is recommended. The pedestrian clearance time for the Pedestrian Change Interval is calculated by Equation 4.7 shown below.

When pedestrian signals are used, the concurrent and parallel vehicular Green Interval plus its Yellow Change Interval must be checked to assure it is of adequate length to provide enough time for the pedestrians to cross the street. This must be done whether or not pedestrian signal indications are provided.

Equation 4.7

$$\text{PED CLR} = \frac{W}{V_P}$$

Where: PED CLR = Pedestrian clearance time (sec.)

W = width of the street (curb line to the far side of the traveled roadway) (ft.)

V_P = pedestrian walking speed (3.0 to 4.0 ft./sec.)

[30] MUTCD, FHWA, 2003, p. 4E-8

The Pedestrian Change Interval (pedestrian clearance time) may be entirely contained within the vehicular Green Interval (Equation 4.8), or may utilize the time of both the vehicular Green and Yellow Change Intervals (Equation 4.9) [31] Figure 4.22 displays the two Pedestrian Change Interval timing alternatives.

On high speed approaches, or when the intersection operates well below capacity, the preferred method for displaying the Pedestrian Change Interval is to have the pedestrian clearance time entirely within the vehicular Green Interval.

Equation 4.8

Minimum Green (sec.) $\geq$ Ped. Walk (sec.) + Ped. Clr. (sec.)

Where: Ped. Walk = Pedestrian Walk Interval

Ped. Clr. = Pedestrian clearance time (sec.)

Equation 4.9

Minimum Green (sec.) + Yellow Change (sec.) + All Red (sec.) $\geq$ Ped. Walk (sec.) + Ped. Clr. (sec.)

Where: Ped. Walk = Pedestrian Walk Interval

Ped. Clr. = Pedestrian clearance time (sec.)

Table 4.6 Recommended Pedestrian Interval Timing Values

Walking Speed (feet/sec)	Recommended Walk Interval (secs)	Recommended Pedestrian Clearance Interval (seconds)					
		Crossing Street Width (feet)					
		30	40	50	60	70	80
3.0	7.0	10.0	13.3	16.7	20.0	23.3	26.7
3.5	7.0	8.6	11.4	14.3	17.1	20.0	22.9
4.0	7.0	7.5	10.0	12.5	15.0	17.5	20.0

4.5.8 Traffic Signal Timing Plans – A signal timing plan is a unique combination of cycle length, phasing, splits (green interval + clearance interval for each phase) and offsets (for system operation).[32] Where overall intersection volumes vary significantly during the day, more than one cycle length will be needed. A change in either cycle length or phase splits will require multiple timing plans. See Section 4.6 for more detail.

[31] MUTCD, FHWA, 2003, p. 4E-9.
[32] Traffic Control Devices Handbook, ITE, 2001. p. 337

PREFERRED PEDESTRIAN TIMING SEQUENCE

ALTERNATE PEDESTRIAN TIMING SEQUENCE

Tennessee Department of Transportation
Traffic Design Manual

Vehicle/Pedestrian Interval Timing Relationship

Figure 4.22

4.6 Traffic Signal Coordination – Signal coordination occurs when a fixed timing relationship is established between two or more traffic signals in order to reduce overall vehicular delay. Signal systems should be designed to move platoons of the volume of traffic prevailing on any section of roadway. The development of a wide "green band" to move low volumes of traffic should not restrict the flow of other traffic. Normally systems are developed to favor the flow of the arterial street traffic. Sometimes the volume of traffic entering or leaving the system from side streets may exceed the thru volume on the arterial. Every effort should be made to define the origin and destination of traffic in the system and to be sure that the major flows are incorporated into the progression.

The goal of coordination is delay reduction. Which approaches experience this reduction depends on the objectives of the system.

On a heavily traveled corridor, the goal of signal coordination would be to reduce delay on the major street by allowing uninterrupted flow without significantly impacting side street delay. In a city grid system, the goal of coordination is to reduce overall delay within the system through the elimination of bottlenecks and long queues.

To be cost effective and beneficial, signal coordination requires the following:

1. **A plan.** Federal requirements now call for any agency that implements any kind of signal coordination or intelligent transportation system to eventually develop a citywide or regional architecture. The city will have to determine not only the equipment requirements, but all stakeholders involved in the plan.

2. **A commitment.** To function effectively, the local agency must commit to providing proper maintenance and operation. Timing plans must be monitored and updated regularly. Whether maintenance and operations are monitored by in-house staff or by consultant, the agency must have the staff capability to understand the basic functions of the system and determine where and when changes and modifications are needed.

3. **A need.** Signal interconnection systems have varying degrees of benefit. While any coordination may reduce delay somewhat, it has to be weighed against the costs of installation, operation, and maintenance. If the corridor functions well without excessive queuing or delay, interconnection may not be cost effective.

Traffic signals that are within 1/2 mile of one another should be strongly considered for coordination.[33] The type of coordination utilized may be dependent upon the maintenance capabilities of the maintaining agency.

4.6.1 Time Base Coordination – This type of traffic coordination is based on an internal or external electronic clock rather than a physical interconnect. Timing plans are developed and entered individually into each controller and a common time reference is used by the individual controller clocks to

[33] MUTCD, FHWA, 2003, p. 4D-12.

initiate timing patterns. Because this system has no master controller to keep individual controllers in-synch, it is totally dependent on the time clocks not drifting. This type of coordination requires frequent visits to controllers to reset time clocks.

4.6.2 Closed Loop Signal System – The most common signal system used for coordination today is the "closed loop" system. This is a distributive processing, traffic responsive, control and monitoring system. Access to the system from the office is usually made through a dial-up modem.

A closed loop system utilizes on-street master controllers to monitor and manage local intersection controllers.

A "closed loop" system consists of the following elements:

- System Detectors
- Local Controller Units
- Controller-Master Communications
- On-Street Master Controller
- Master-Central Communications
- Central Computer and Windows based Software

The system's principal operational task is to select and implement traffic signal timing plans in response to real-time traffic conditions, preset time based events and/or operator commands. The system can also provide extensive control monitoring, data collection, reporting, and analysis functions.

Typical capabilities include the ability to upload all timing settings, operation parameters and status information, as well as the ability to download all timing settings and operation parameters. Many of today's closed loop systems utilize a building block design which enables future system expansion to occur without major modifications to the existing system.

4.6.3 Methods of Communication

A. Hard Wire (see Section 4.12) **–** A 6 pair 19 gauge copper cable may be run between controllers at adjacent intersections and on-street masters for coordination purposes. A fiber optic cable may also be used for coordination and communication purposes. While fiber optic cable has a high capacity for transmitting information and is extremely versatile, it has higher installation and maintenance costs. Fiber optic cables generally require larger termini and pull boxes.

B. Time-Based (Wireless) – Coordination may be accomplished internally in each coordinated controller with timing referenced to a system time base. The internal clock in each controller must be set precisely (to the second) with the clocks in the adjacent coordinated

controllers. However, these internal clocks often drift and can cause coordination problems over time.

C. **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.

4.6.4 Hard Wire Interconnect Installation – Generally, underground rather than overhead installation is preferred. The choice, however, may be determined by local preference, utility conflicts or cost.

A. **Conduit –** Interconnect cable shall be run in its own conduit, separate from signal and detector cables. The cable shall be run in a 2" diameter RGS or PVC conduit at a minimum depth of 30".

B. **Pull boxes –** To provide access and facilitate the pulling of long runs of underground interconnect cables. See Section 4.14 for details on pull box types.

- **Types –** Pull boxes for standard interconnect cable shall be Type B Pull Boxes. Pull boxes for pulling fiber optic cable shall be larger.
- **Spacing –** Pull boxes for interconnect cable shall be placed at distances no greater than 300 feet or at locations where access for splicing is required. Pull boxes for fiber optic cable runs shall be placed at 1000 foot intervals.

C. **Risers –** When transitioning from overhead to underground or vice versa on a utility pole, 2" RGS diameter riser must be specified for the interconnect cable.

4.6.5 Coordinated Timing Plans – Arterial control is concerned with controlling traffic signals along an arterial highway so as to give major consideration to progressive flow of traffic along that arterial. The green should be displayed at an intersection sufficiently in advance of the arrival of a major platoon, to clear vehicles that may be stopped and to allow the platoon to continue without stopping.

It is better to arrive too early than too late. Vehicles arriving a little bit early wait a lot less time than vehicles arriving late. Early arrivals can avoid stopping by adjusting their speed. Vehicles that are a bit late are tempted to run the yellow light or increase their speed.

The timing plan of a system consists of three elements; cycle length, splits and offsets. The splits must be determined for each individual intersection in the system and may vary from intersection to intersection. The split is the segment of the cycle length allocated to each phase or interval that may occur (expressed in percent or seconds). In an actuated controller unit, split is the time in the cycle allocated to a phase. However, the cycle length for each traffic signal in a system must be the same or a multiple of

one another. Determination of an optimum cycle length is the key to any efficient signal system.

Another factor in the design of the individual intersection that may become evident during the arterial analysis is that some intersectional cycle lengths may not be compatible with the cycle length for the system during some timing plans. These intersections should be designed to have flexibility to operate fully-actuated during these time periods. The same approach should be used for traffic signals that do not have programmed flash where most of the other traffic signals in the system flash during nighttime hours to reduce delay and improve traffic flow along the corridor.

Signal Timing Plan Development Methods – The following methods of calculating signal offsets and splits are commonly used:

- Synchro Software
- PASSER II Software
- TEAPAC Software
- Transyt 7f Software

Signal timing plans should always be monitored after installation and field fine tuned to ensure safe and efficient operation.

4.6.6 Offsets – Where adjacent traffic signals are coordinated (interconnected), signal offset settings are needed. An offset is the time difference (in either seconds or percent of cycle) between the start or end of the Green Interval at one intersection and the start or end of Green Interval at another intersection, both measured from a system time base.[34]

4.7 Preemption and Priority Control of Traffic Signals – Traffic signals may be designed and operated to respond to certain classes of approaching vehicles by altering the normal signal timing and phasing plan(s) during the approach and passage of those vehicles. The alternative plan(s) may be as simple as extending a currently displayed GREEN indication or as complex as replacing the entire set of signal phases and timing.[35]

Preemption describes the transfer of normal operation of a traffic signal to a special control mode of operation. Preemption control is typically given to emergency vehicles and trains.

Typical preemption examples are:

- The prompt displaying of GREEN signal indications at signalized locations ahead of fire vehicles, law enforcement vehicles, ambulances, and other official emergency vehicles.
- A special sequence of signal phases and timing to provide additional clearance time for vehicles to clear the tracks prior to the arrival of a train.
- A special sequence of signal phases to display a RED signal indication to prohibit turning movements towards the tracks during the approach or passage of a train or transit vehicle.

[34] Traffic Control Devices Handbook, ITE, 2001, p. 335
[35] MUTCD, FHWA, 2003, p. 4D-10.

Priority control is typically given to certain non-emergency vehicles such as buses and light-rail vehicles. Priority Control describes a means by which the assignment of right-of-way is obtained or modified.

Priority control describes a means by which the assignment of right-of-way is obtained or modified usually for transit vehicles.

Typical priority control examples are:

- The displaying of early or extended GREEN signal indications at an intersection to assist public transit vehicles in remaining on schedule.
- Special phasing to assist public transit vehicles in entering the travel stream ahead of the platoon of traffic.

Railroad preemption is by far the most important and most complex type of preemption. It is discussed in detail in Section 4.8.

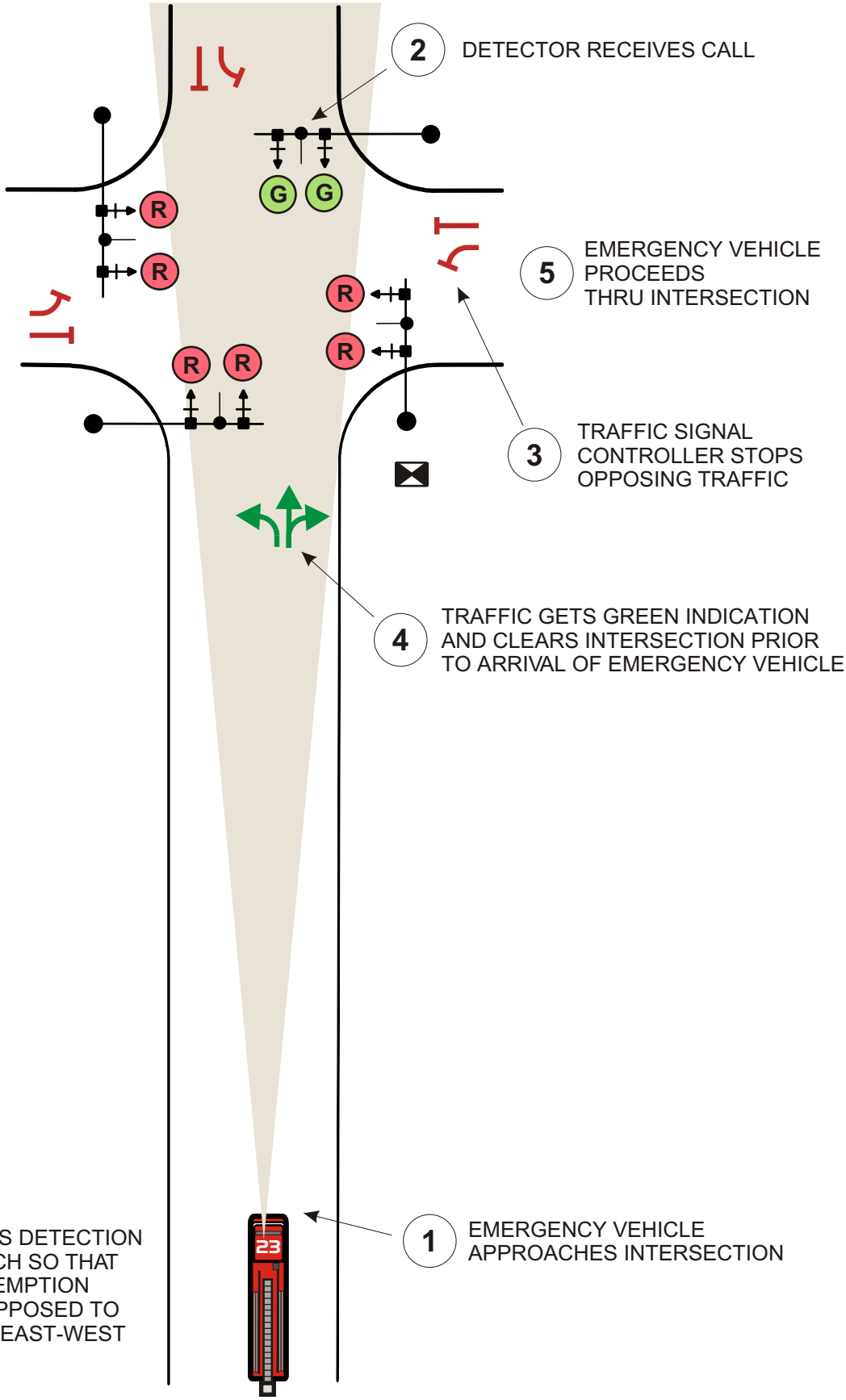
4.7.1 Emergency Vehicle Preemption – Various mechanisms can be used to preempt traffic signals so that emergency vehicles are provided with safe right of way as soon as practical. The purpose of such preemption is to provide the right of way to the emergency vehicle as soon as practical. Emergency preemption systems allow emergency vehicles to interrupt the normal sequence of traffic signal phasing and provide priority to the approach with the emergency vehicle. Traditionally, this was accomplished by communications cables between an emergency center and traffic signal controllers along predetermined emergency routes.

Preemption for emergency vehicles is a method of ending conflicting phases and providing a green indication for emergency vehicles in advance of their arrival.

Newer technologies allow a flexible response system 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. Figure 4.23 shows a sample emergency vehicle preemption design.

4.7.2 Preemption Justification – Emergency vehicle preemption should be considered at intersections that have frequent conflicts with emergency vehicles and any intersection that is along a route already using emergency vehicle preemption equipment.

Because priority control primarily benefits transit operations and is not a safety device, justification for installation of priority control should be a joint decision between the traffic engineering agency and the transit agency. Benefits to transit operations must be weighed against the possible increased delay for passenger vehicles.



NOTE: THIS EXAMPLE USES DETECTION ON EACH APPROACH SO THAT DIRECTIONAL PREEMPTION IS POSSIBLE (AS OPPOSED TO NORTH-SOUTH OR EAST-WEST PREEMPTION)

Tennessee Department of Transportation
Traffic Design Manual

Emergency Vehicle Preemption Sequence

Figure 4.23

4.7.3 Preemption Sequence – Preemption of the traffic signal should provide the following sequence of operation:

1. A Yellow Change Interval and any required All Red Clearance Interval for any signal phase that is green when preemption is initiated and which will be red during the preemption interval. The length of the Yellow Change and All Red Clearance Intervals shall not be altered by preemption. Phases which will be green during the preemption period and which are already green when preemption is initiated shall remain green. Any Pedestrian Walk Interval in effect when preemption is initiated shall be immediately terminated. The normal Pedestrian Change Interval may be abbreviated.
2. An all-red intersection preemption display shall not be used.
3. The traffic signal shall return to normal operation upon termination of the demand for preemption or the termination of the assured Green Interval.

4.7.4 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 or priority occurs first when more than one is received by the traffic signal controller. "Preemption" always is serviced before "priority". However, railroad preemption must always override emergency preemption. This hierarchy shall be as follows:

Railroad preemption must always take priority over emergency vehicle preemption.

A. **Preemption –** Railroad Train over Emergency Vehicle (Fire, Rescue or Ambulance) over Law Enforcement Vehicle

B. **Priority –** Light Rail over Bus

4.7.5 Methods of Emergency Vehicle Preemption – Several methods of traffic signal preemption are typically utilized for emergency vehicles.

A. **Hardwired from Source –** A connection between the traffic signal controller and the source of an emergency call (e.g. fire station) allows preemption.

B. **Optically Activated –** Optical priority control 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.

C. **Siren Activated –** Siren priority control 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.

4.7.6 System Components for Optical and Siren Activated Emergency Vehicle Preemption – A particular brand can be specified provided the city has installed the same at other locations and it is the predominate brand. TDOT will normally install emergency vehicle preemption 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 citywide 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 4.24.

When installing preemption, a footnote should be added to the Plans noting the number of sensors, the number of phase selectors or other equipment and the estimated quantity of required cable. Each intersection is measured per each.

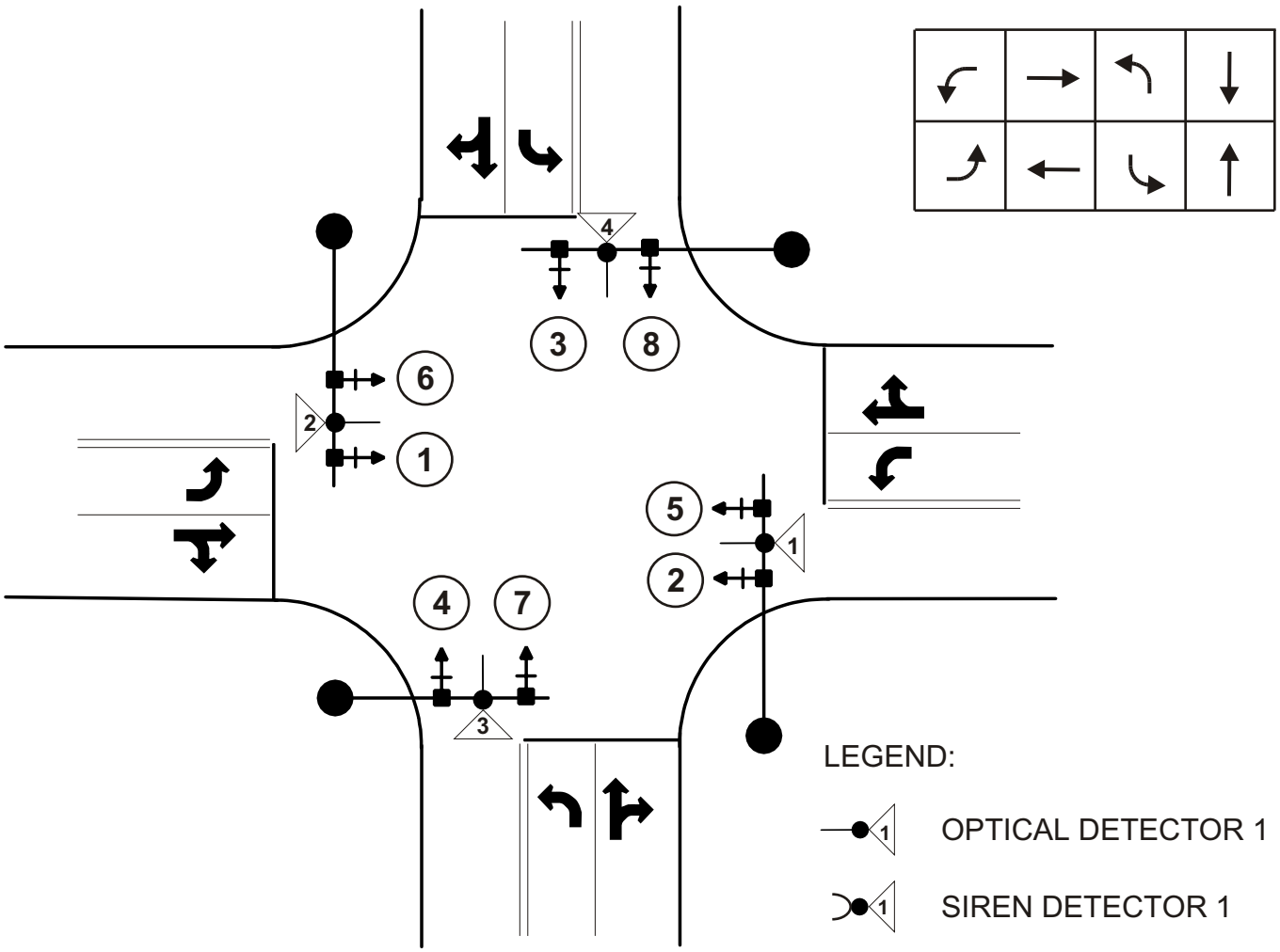
4.7.7 Priority Control – Priority control systems are less common than emergency vehicle preemption systems. While a priority control system might benefit a transit system by keeping its vehicles on a tighter schedule, it can lead to overall increased congestion at an intersection. Benefits to transit operations must be weighed against the possible increased delay for passenger vehicles. Some systems, such as the optically activated priority control system can provide both preemption for emergency vehicles and priority control for transit vehicles.

4.8 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. Railroad preemption results in a special traffic signal operation depending on the relation of the railroad tracks to the intersection, the number of phases in 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

Railroad preemption is a method of ending conflicting phases, then clearing and inhibiting movements that cross the railroad tracks until the train has cleared the crossing.

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. 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. An engineering study at each preempted location may be required to determine these factors.

Intersections closer than 200' to a crossing must use preemption. An engineering study should be conducted to determine the need for preemption when a crossing is near, but greater than 200' from a traffic signal.



EXAMPLE CHART TO BE INCLUDED IN PLANS

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

Tennessee Department of Transportation
Traffic Design Manual

Emergency Vehicle Preemption Example

Figure 4.24

4.8.1 Railroad Preemption Warrant – The coordination of the operation of a traffic signal with a nearby highway-rail grade crossing equipped with flashing lights is justified under the following conditions.[36]

1. Where the highway-rail grade crossing is located within 200 feet of the traffic signal, preemption should be used. This distance is defined as the clear storage distance (CSD) and is measured from the intersection stop line to the railroad stop line on the near side of the tracks (typically 6 feet from the rail).

2. However, 200 feet may not be sufficient for some locations. Where the highway-rail grade crossing is located more than 200 feet from the traffic signal, but traffic from the signal is anticipated to back up across the railroad tracks, preemption should be used. Calculation of the traffic backup is determined with approximately 95% certainty using Equation 4.10 or 4.11. The traffic back up in the thru lanes as well as turn lanes should be checked.

Back Up Queue Calculation (Approach v/c < 0.90)

Equation 4.10 [37]

L = $2qr(1+P)(25)$

Where: L = Length of Queue (ft./lane)

q =Average flow rate

r =Effective red time (approach clearance + red)

P =Proportion of Trucks (as a decimal)

Back Up Queue Calculation (Approach v/c $\geq$ 0.90 but less than 1.0)

Equation 4.11 [38]

L = $(2qr + \Delta x)$(1 + P)(25)

Where: L = Length of queue (ft./lane)

q = Average flow rate

r = effective red time (approach clearance + red), (sec)

Δ x = 100 $\left(\frac{v}{c} ratio - 0.90\right)$

P = Proportion of trucks (as a decimal)

3. When traffic stopped for a train at the highway-rail grade crossing frequently backs up into a nearby signalized intersection, preemption may be used.

[36] MUTCD, FHWA, 2003, p. 8D-7.
[37] Northwestern University Traffic Institute, Railroad Grade Crossing Workshop. 2003.
[38] Ibid.

4.8.2 Pre-Signals – A pre-signal provides a signal display on the near side of the track, supplementing the normal head placement. This operates as part of the highway intersection traffic signal, controlling traffic approaching the highway-rail grade crossing and signalized intersection.

A pre-signal is a set of supplemental traffic signal faces located in a position that controls traffic approaching the highway-rail grade crossing in advance of the intersection.

Pre-signals should be considered when:

1. The highway intersection is less than 50 feet from the highway-rail crossing (75 feet for a road that is regularly used by multi-unit vehicles).
2. Where the clear storage distance (CSD) is greater than 75 feet and an engineering study determines the need[39].

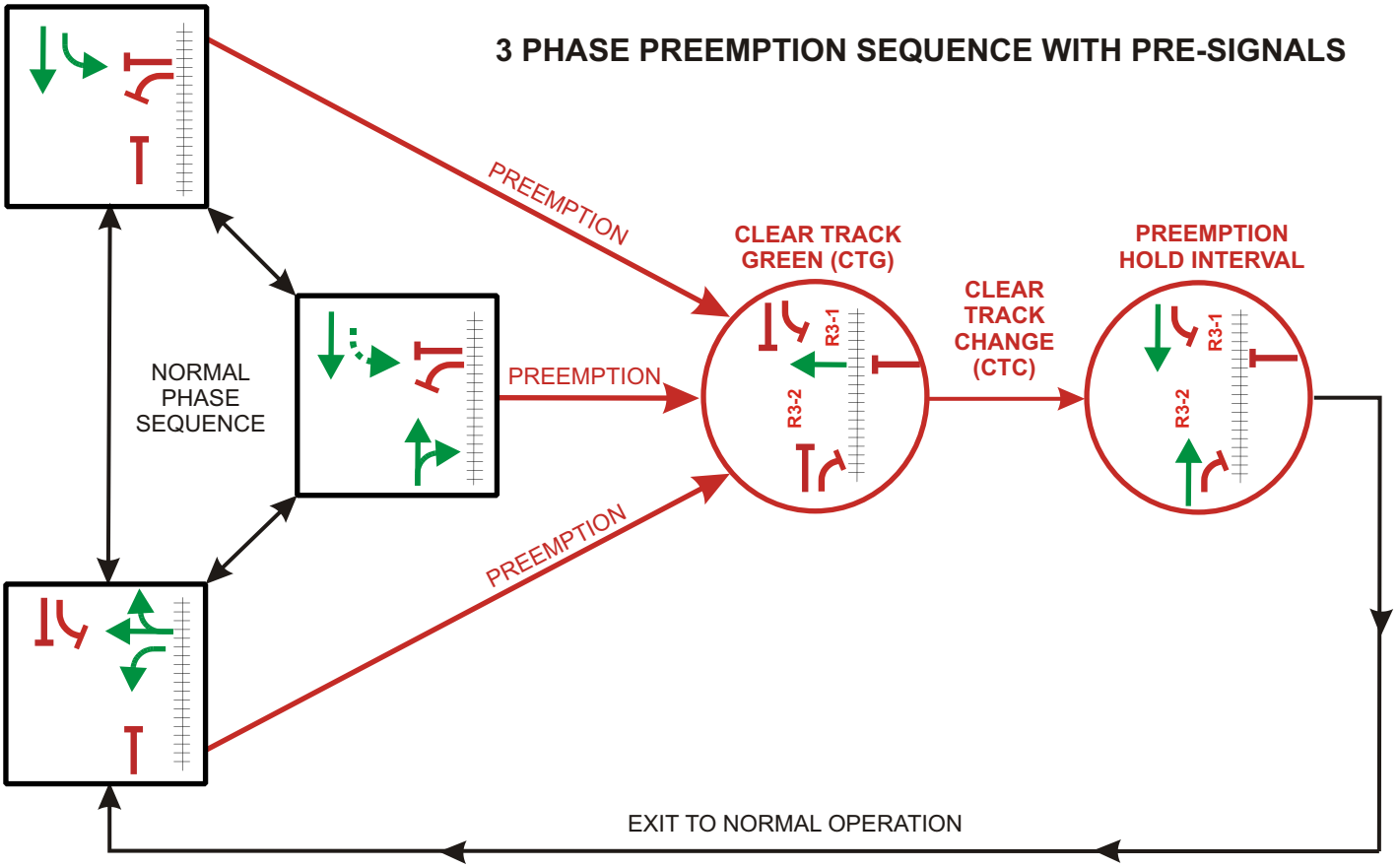
In general, a pre-signal should be considered when the clear storage distance (CSD) as defined in 4.8.1 is not sufficient to safely store the design vehicle, such as the largest legal truck combination, or if vehicles regularly queue across the tracks.[40]

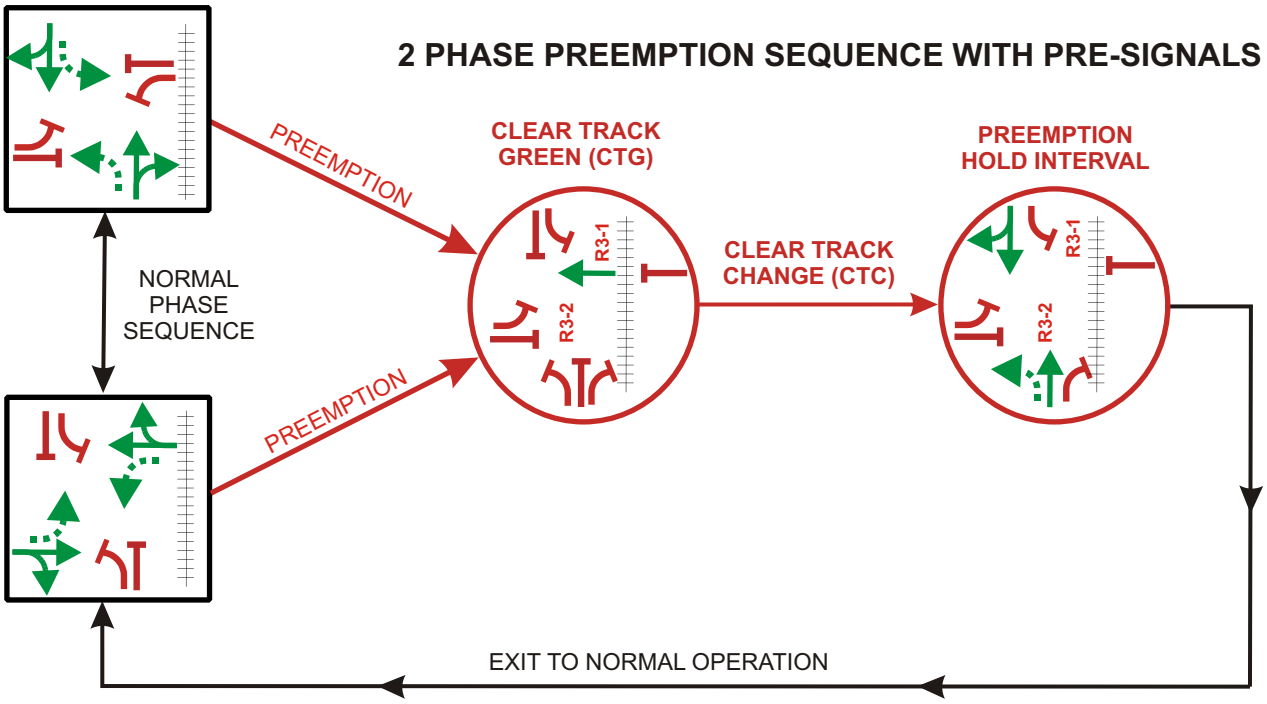
The pre-signal phase sequencing should be progressively timed with an offset adequate to clear vehicles from the track area and downstream intersection. The signal heads at the far side of the intersection (away from the crossing) should be programmable so as to limit their visibility from vehicles before the tracks[41].

When the design vehicle cannot be safely stored in the CSD, or if no gates are present, a NO TURN ON RED (R10-11) shall be installed on the approach with the pre-signal to prevent trapping a vehicle[42].

4.8.3 Railroad Preemption Sequence – The preemption sequencing of two-phase and three phase traffic signals are shown in Figure 4.25. Railroad preemption for an eight phase intersection is shown in Figure 4.26. 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).

[39] Guidance on Traffic Control Devices at Highway-Rail Grade Crossings, FHWA, 2002, p.24.
[40] Traffic Control Devices Handbook, ITE, 2001, p. 392.
[41] Guidance on Traffic Control Devices at Highway-Rail Grade Crossings, FHWA, 2002, p.24.
[42] MUTCD FHWA, 2003. p. 8D-7.





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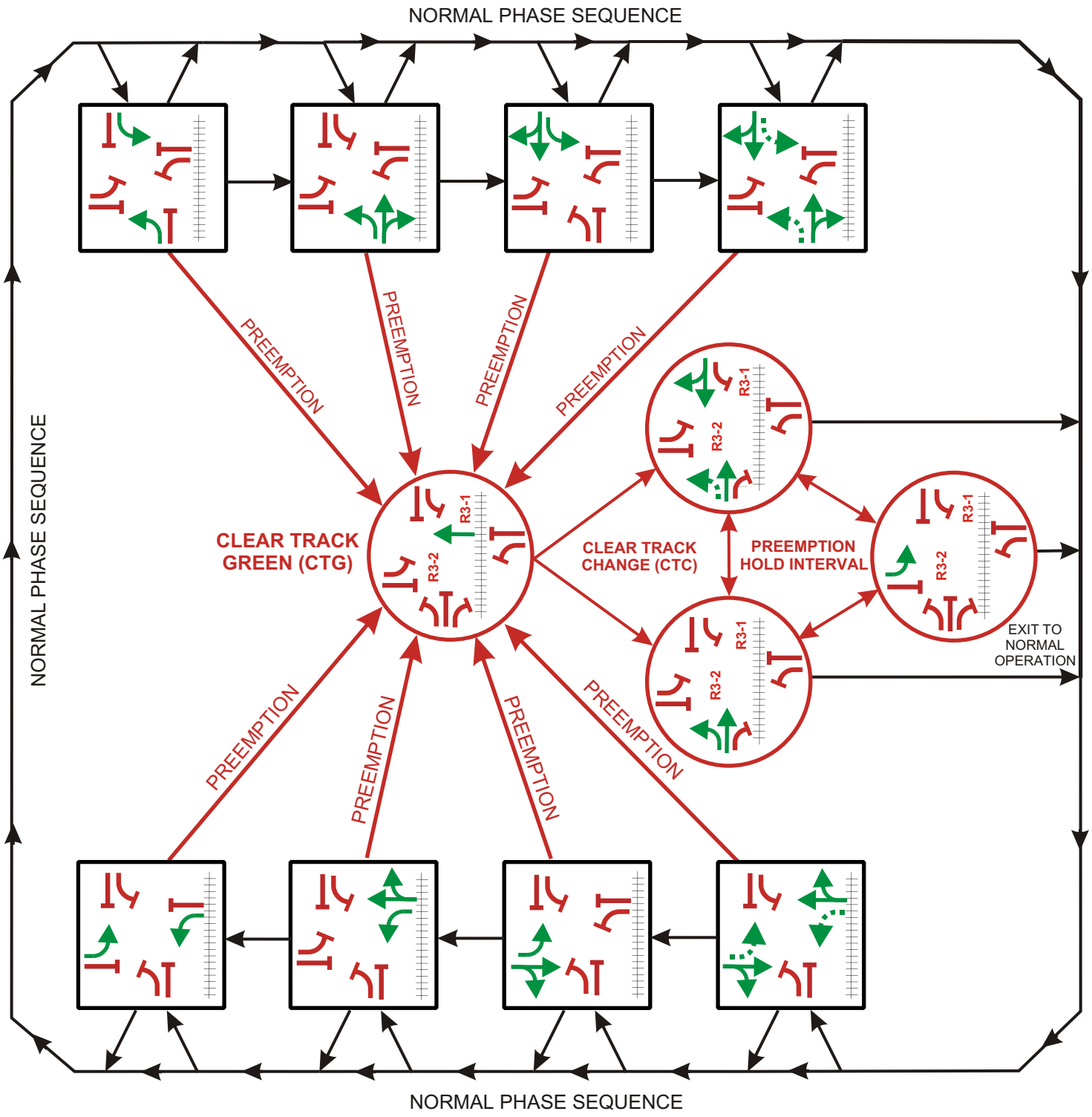
Railroad Preemption Sequence
(2 and 3 Phase Operation w/ Pre-Signal)

Figure 4.25



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Railroad Preemption Sequence
(8-Phase Operation with Pre-Signal)

Figure 4.26

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:

A. 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 extinguished.

B. Revert to limited operation with those signal indications controlling thru and left turn approaches towards the railroad tracks displaying steady red. Permitted pedestrian signal phases shall operate normally.

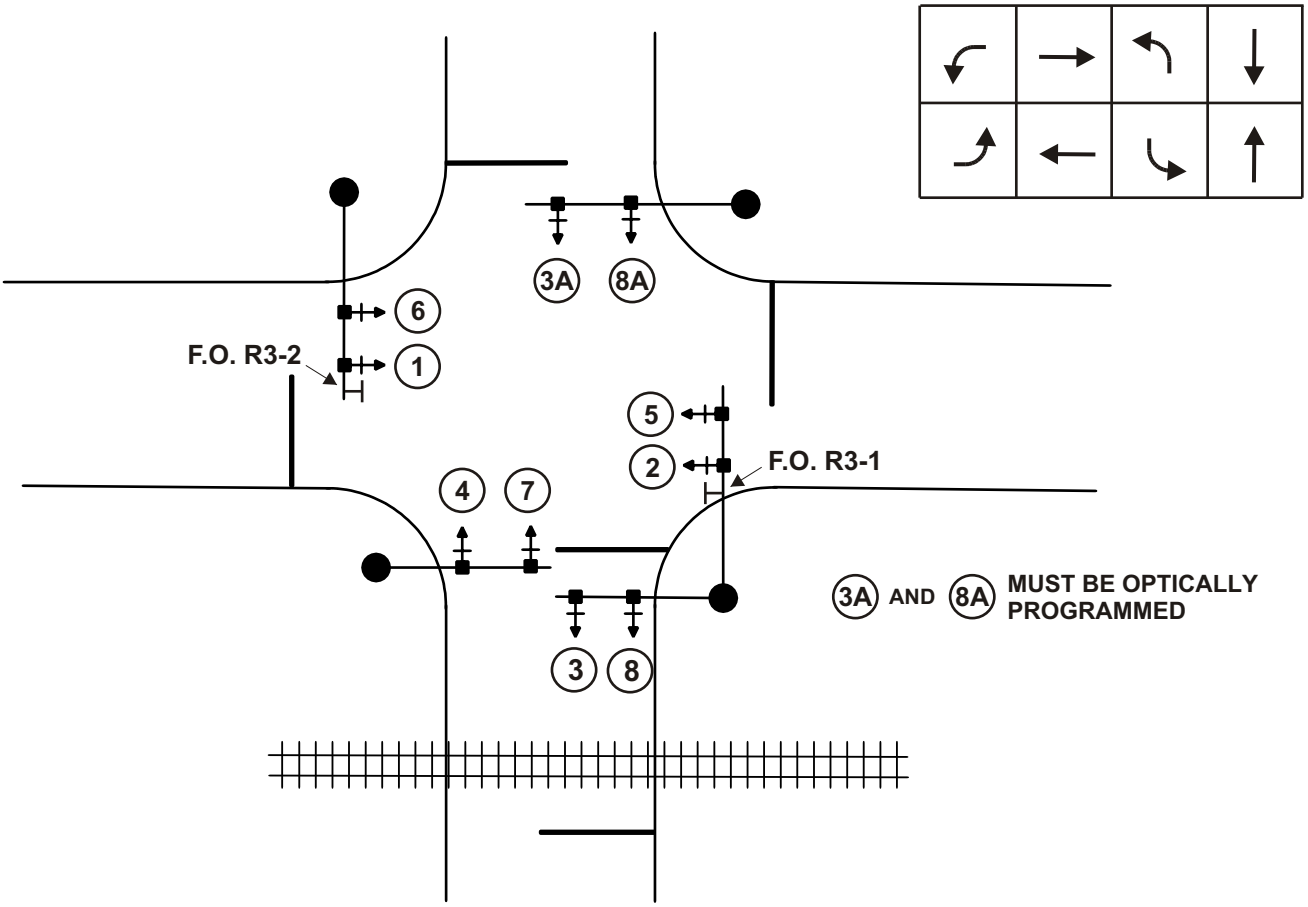
4. The traffic signal shall return to normal operation following release of preemption control.

The typical information to be shown on traffic signal construction plans for railroad preemption is shown in Figure 4.27.

4.8.4 Railroad Preemption Warning Timing[43] **–** The total time to transfer right-of-way (including Pedestrian Change Intervals) plus the queue clearance plus the separation time is the preemption time setting. This time should be greater than the railroad warning time (the time for the circuit to activate warning devices in advance of the train arrival).

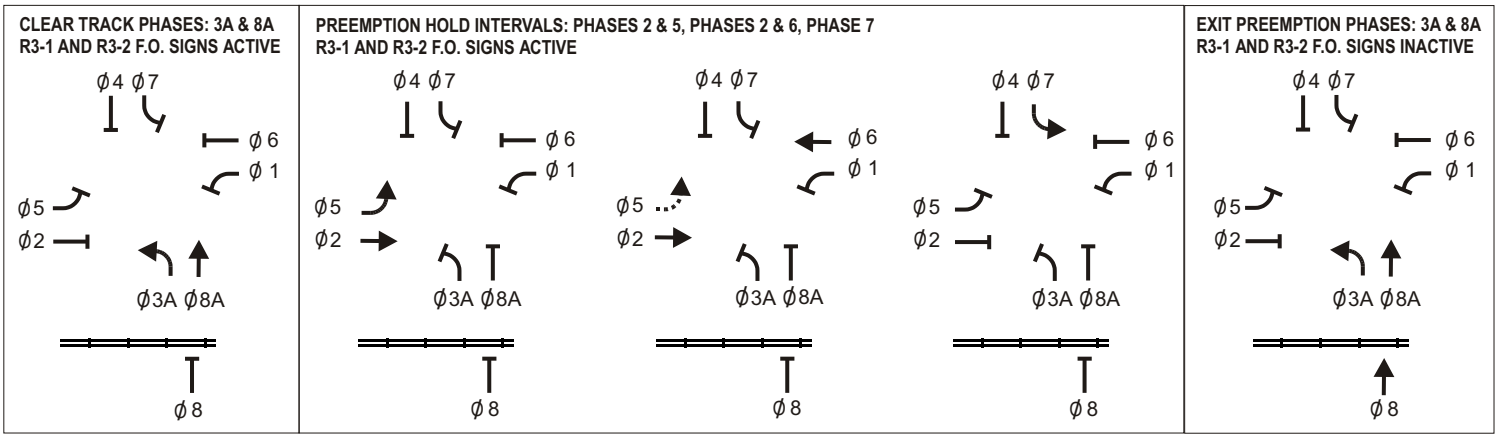
4.8.5 Blank Out Signs – These types of signs display a blank face unless internally illuminated upon activation for a specific circumstance. Such signs displaying the message/symbol "NO LEFT TURN" or "NO RIGHT TURN" are useful as part of the railroad preemption sequence at signalized intersections immediately 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 intersection and eventually blocking the intersection itself. These signs are activated upon initiation of the railroad preemption and deactivated after the preemption is completed.

[43] Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices, ITE, 1997. p. 15



EXAMPLE CHART TO BE INCLUDED IN PLANS

RAILROAD PREEMPTION SEQUENCE



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Traffic Design Manual

Railroad Preemption Example

Figure 4.27

4.9 Traffic Signal Heads – Signal heads shall comply with standards of the MUTCD.

4.9.1 Lens Size and Type – Twelve inch (12") diameter lenses are required on all new signal heads. Today, traffic signal indications and pedestrian indications are usually illuminated by light emitting diode (L.E.D.) lamps. Conventional incandescent lamps consume up to 150 watts of power and require routine maintenance due to filament burn out. The use of LED lamps can conserve energy and reduce maintenance costs. An LED is a current operated, semiconductor light source. Power requirements are considerably less than incandescent lamps. The life expectancy of an LED lamp is 45,000 hours or 10 years of operation.

All new signal heads should be 12" diameter lenses using LED lamps.

4.9.2 Signal Housing – Vehicular signal heads are manufactured in either aluminum or polycarbonate plastic. The choice of which material to use should be made by the local agency. Because of their light weight, polycarbonate signal heads must either be tethered or rigidly mounted so wind sway will not be a factor. Signal heads shall be constructed of aluminum, unless the local agency prefers polycarbonate materials. Signal head housings shall be yellow unless otherwise specified by the local agency. Because agencies use different combinations of signal housing colors, the housing colors to be used at the intersection shall be noted on the plans if signal heads are not all yellow.

Signal heads should be aluminum unless the local agency desires polycarbonate signal heads.

Tethered signal heads must have breakaway clamps so the head will swing free during heavy wind conditions.

4.9.3 Backplates – Signal backplates increase the contrast between the signal indications and the signal background. A rising or setting sun or intensive advertising signing can lead to visibility problems. Backplates shall be used on all rural or high speed locations or urban locations where glare or other visual distractions are present. Where used, backplates shall have a dull black finish.

Backplates should be installed at all rural, high speed or visually distracting locations.

4.9.4 Number of Signal Faces[44]

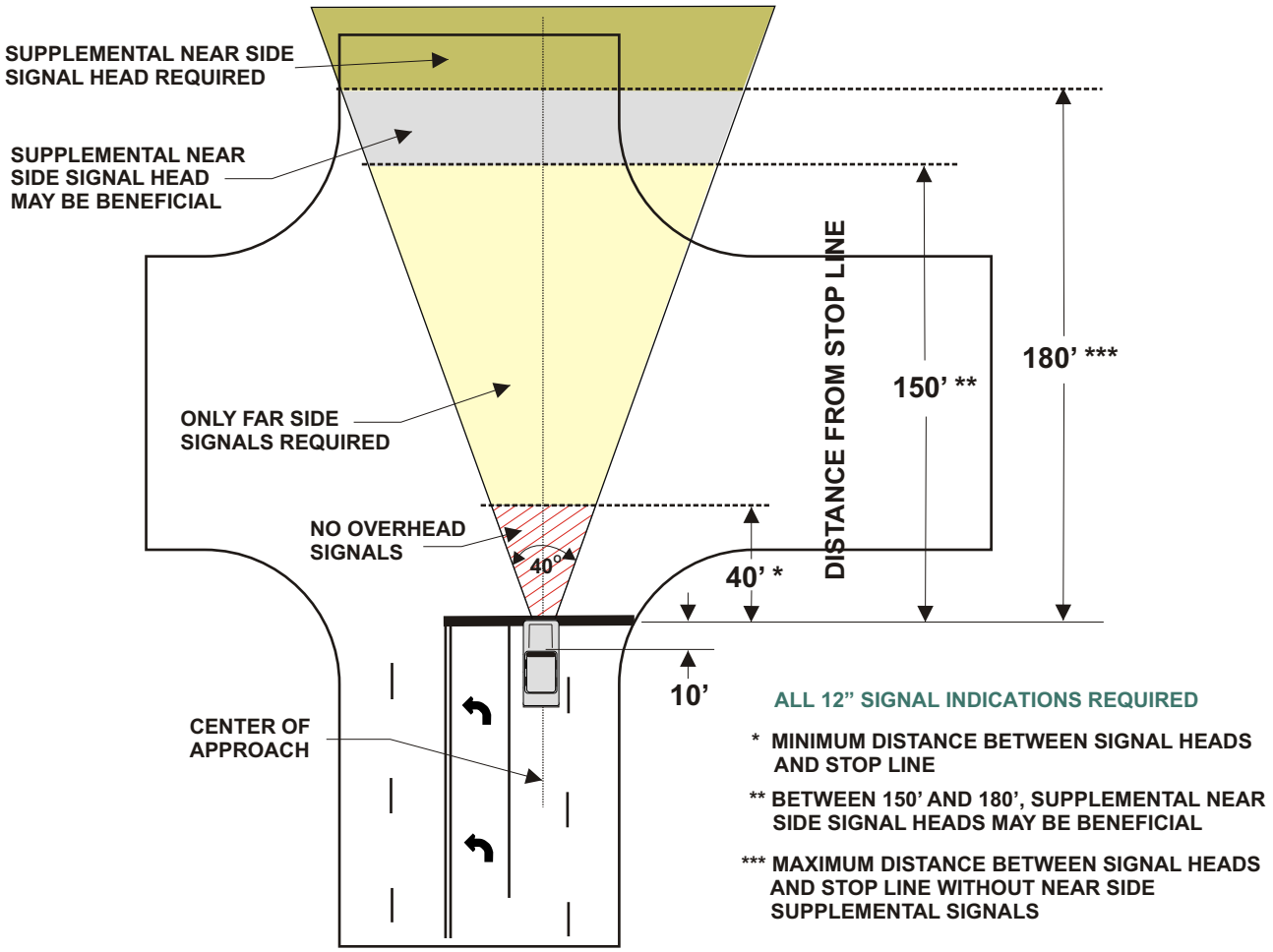
A. Major Movement – A minimum of two signal faces are to be provided for the major movement on each approach, even if the major movement is a turning movement.

B. Supplemental Face – If the signal faces are more than 180 feet beyond the stop line, a supplemental near side signal face is required.

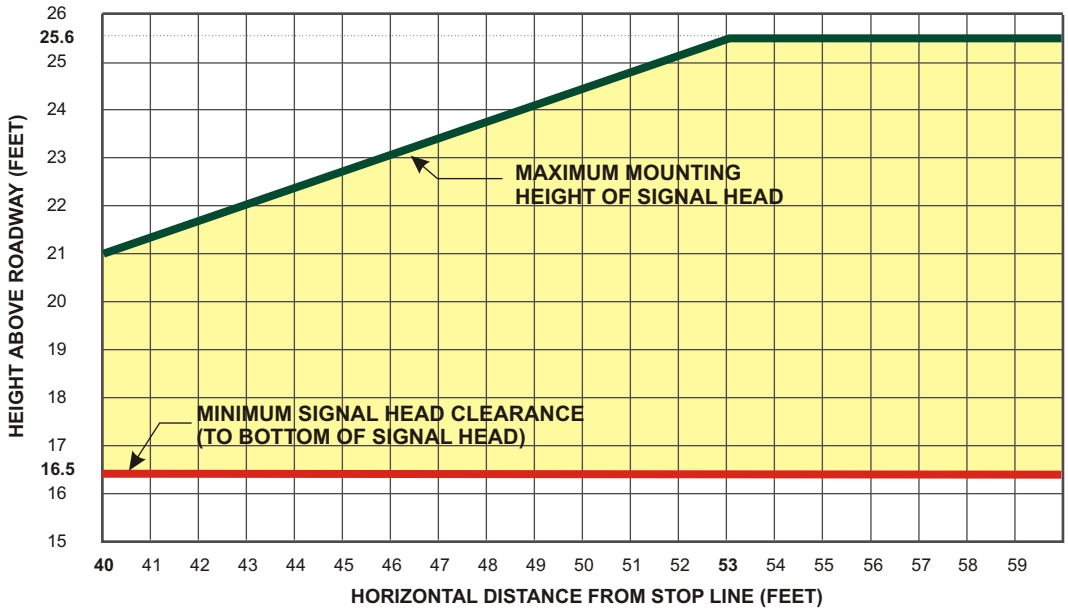
C. Dual (or Multiple) Left Turns – Where two or more separate left turn lanes are provided, a separate left turn face shall be provided for each lane.

[44] MUTCD, FHWA, 2003, p. 4D–12

HORIZONTAL SIGNAL HEAD PLACEMENT



VERTICAL SIGNAL HEAD MOUNTING HEIGHT



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Traffic Design Manual

Horizontal and Vertical Locations of Overhead Vehicle Signal Heads

Figure 4.28

4.9.5 Positioning Relative to the Stop Line – At least one, if not both, of the signal faces required in paragraph 4.9.4.A above should be located at a distance between 40-180 feet from the stop line. If both signal faces are more than 180 feet from the stop line, a supplemental near side signal face is required (see Figure 4.28).

Intersections with signal heads located more than 180' from the stop line require supplemental near side signal heads.

4.9.6 Horizontal Placement – At least one, if not both, signal faces required in paragraph 4.9.4.A above shall be placed in the area defined in Section 4D.15 of the MUTCD (see Figure 4.28).

A. Lane Alignment – In general, signal heads should be centered over the lanes to which they apply or on lane lines between lanes. Figures 4.29 thru 4.31 show typical left turn signal head applications and Figure 4.32 shows signal head placement for various split-phase intersections.

B. Adjacent Signal Faces[45] – Adjacent signal faces on the same span wire or mast arm should typically be placed 12 feet apart and shall be placed no closer than 8 feet apart.

C. Signal Faces – Left turn signals shall be the left most signal head and right turn signals shall be the right most signal head in the signal head arrangement for the approach (see typical examples in Figures 4.29 thru 4.32).

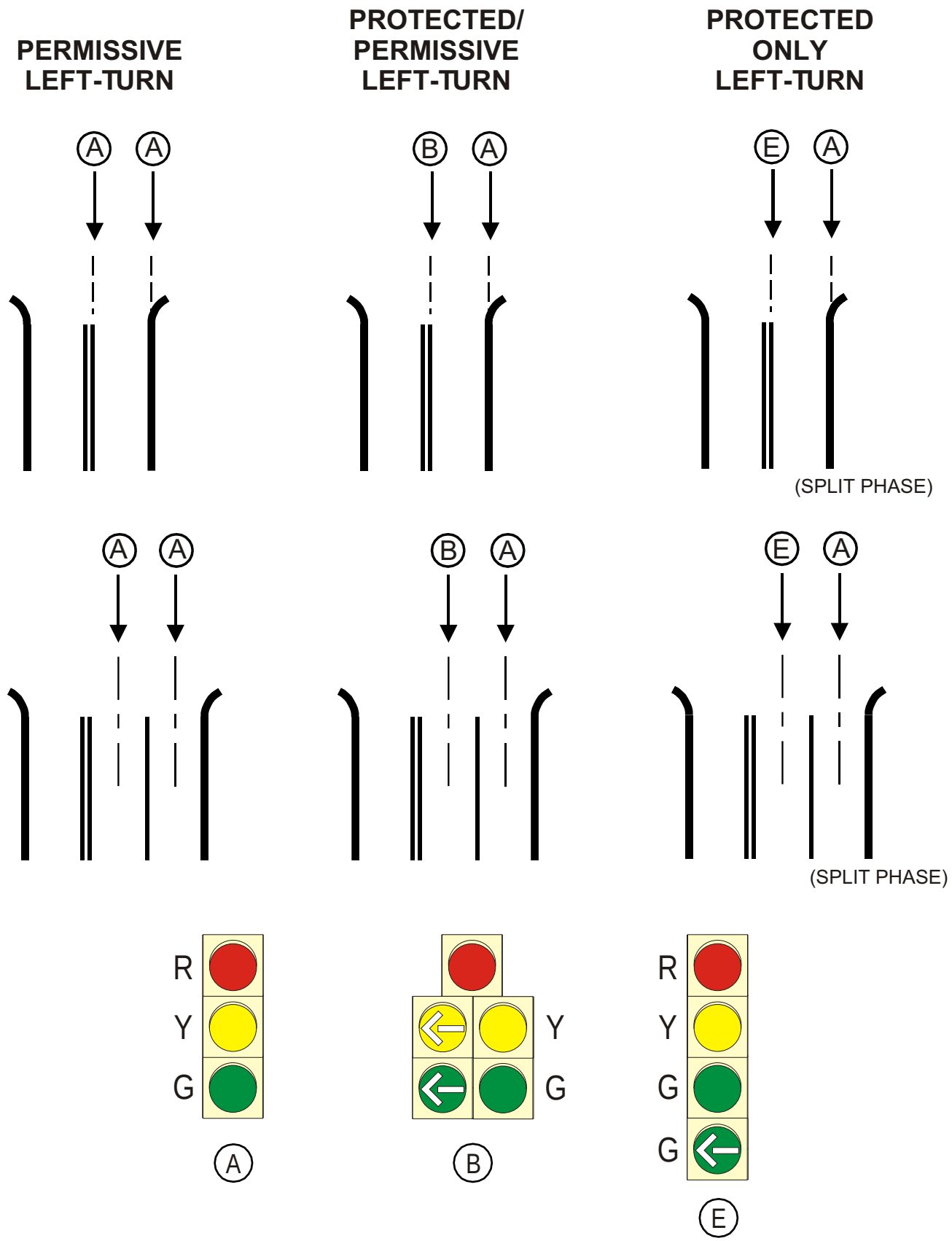
4.9.7 Vertical Placement – The placement of the signal head over the roadway shall be such as to provide a minimum 17.5 foot vertical clearance from the bottom of the signal head to the roadway. Where this is impractical, the minimum clearance shall be 16.5 feet. RED signal indications should be approximately the same height.

Signal heads shall be mounted with a minimum 16.5' (17.5' preferred) vertical clearance.

A maximum mounting height to the top of the signal housing for overhead signals is important to ensure visibility for signal heads that are near the stop line. The maximum mounting height shall be determined from Section 4D.15 of the MUTCD. In general, the maximum mounting height for signals can be determined on a sliding scale of 21 feet for signal heads 40 feet from the stop line and 25.6 feet for signal heads 53 feet from the stop line. For signal heads between 53 feet and 180 feet, the maximum mounting height shall be 25.6 feet (see Figure 4.28).

4.9.8 Face Arrangement – Individual signal sections shall be arranged vertically rather than horizontally unless sight distance or vertical clearance concerns dictate.

[45] MUTCD, FHWA, 2003,p. 4D-13



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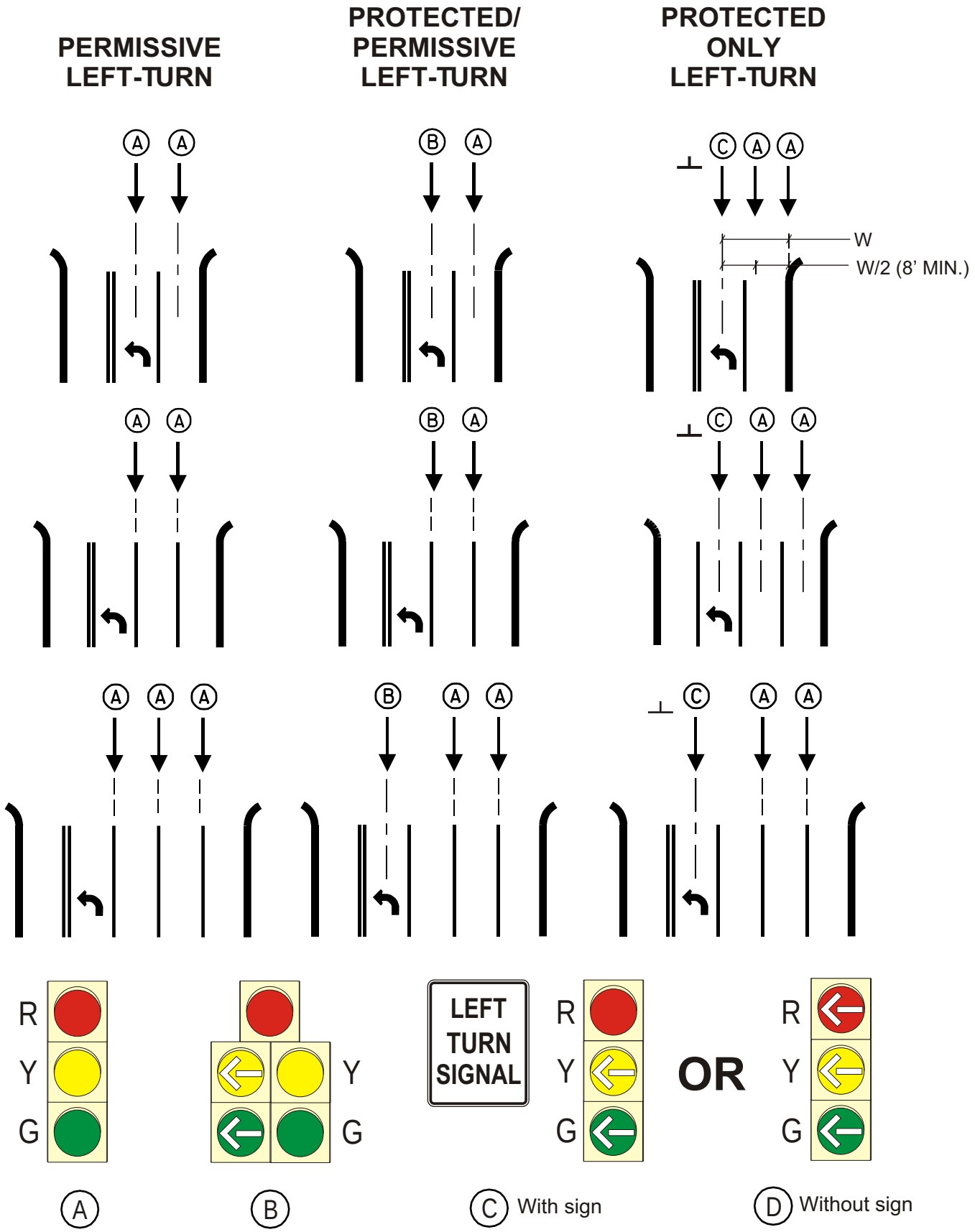
Signal Head Placement
(No Left Turn Lanes)

Figure 4.29



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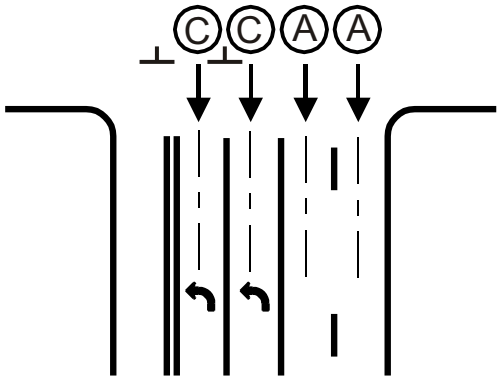
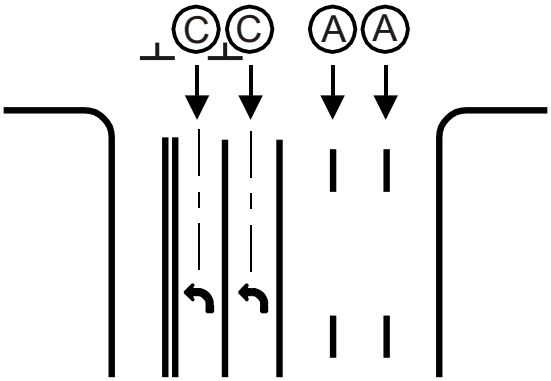
Traffic Design Manual

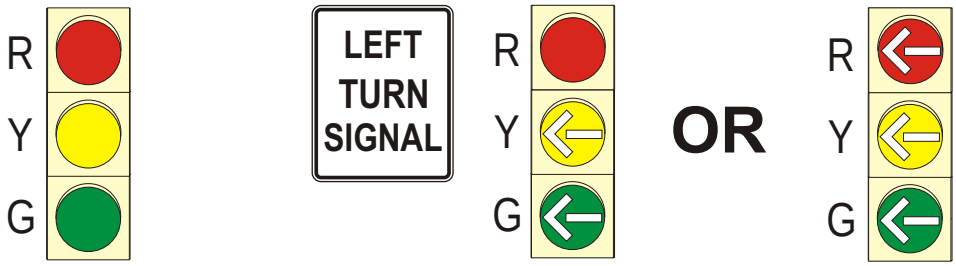
Signal Head Placement
(One Left Turn Lane)

Figure 4.30

PROTECTED ONLY
LEFT-TURN
(PERMISSIVE TREATMENTS NOT APPLICABLE)







A

C With sign

D Without sign

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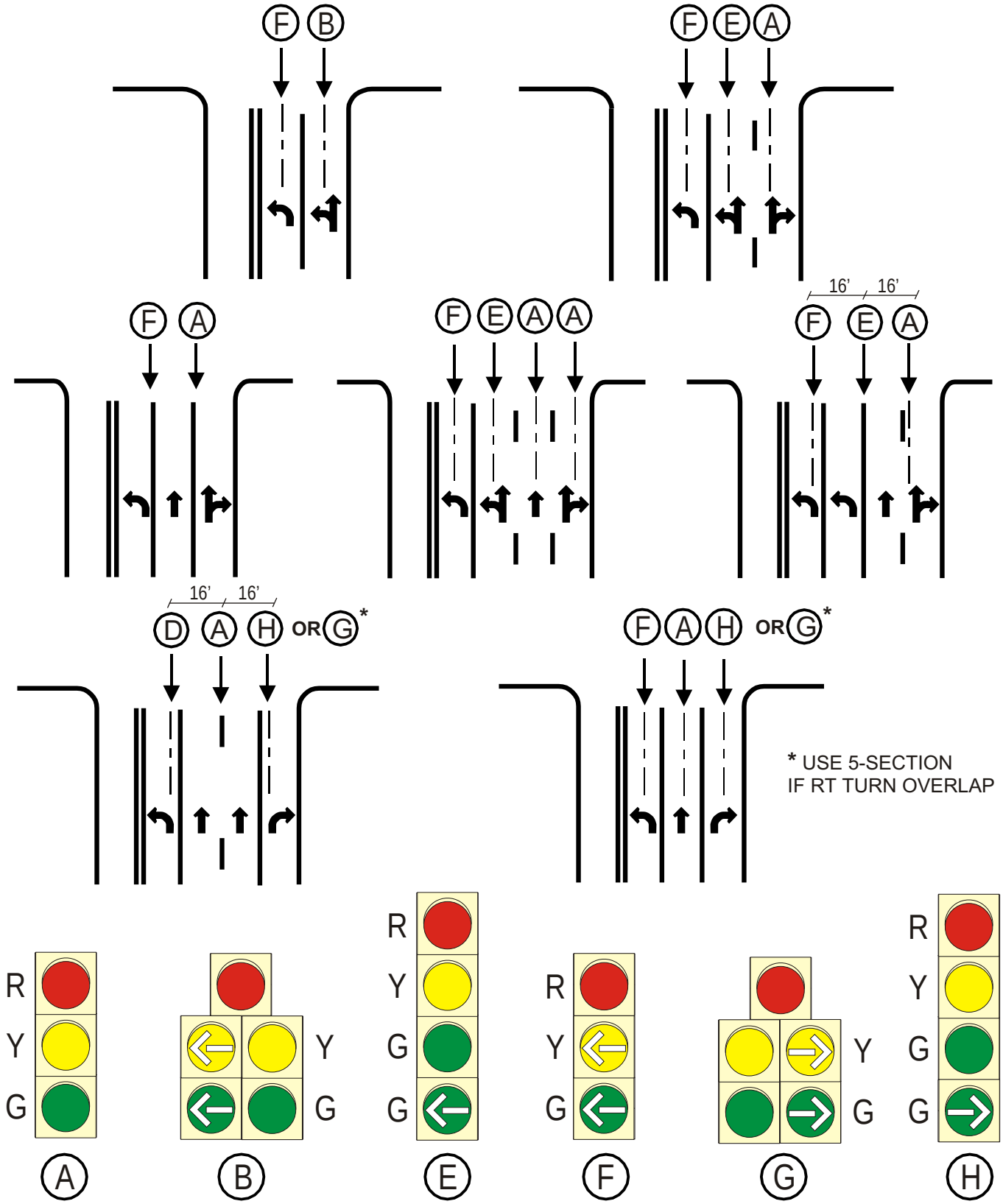
Signal Head Placement
(Two Left Turn Lanes)

Figure 4.31

SPLIT PHASE OPERATION
(PERMISSIVE TREATMENTS NOT APPLICABLE)



Tennessee Department of Transportation
Traffic Design Manual

Signal Head Placement
(Split Phase Operation)

Figure 4.32

4.9.9 Left Turn Signals – Three types of left turn signal heads are commonly used:

A. Three Section heads (R, ←Y, ←G with sign) and (←R, ←Y, ←G) – Three section left turn heads are used for "protected only" left turn operation when there exists a separate left turn lane.

B. Four Section Heads (R, Y, G, ←G) – Four section left turn heads are used where the left turn is part of a split phase operation and also at the top of some "T" intersections.

C. Five Section Heads (R, Y, G, ←Y, ←G) – Five section left turn signal heads are used both with and without a separate left turn lane, and where the left turn operation is "protected/permissive" .

4.9.10 Right Turn Signals – Right turn signals are normally provided only where there is a separate right turn lane accompanied by a right turn signal overlap with a compatible cross street left turn signal phase. Typically, a five section head (R, Y, G, Y→, G→) is used.

4.9.11 Pedestrian Signal Indications[46] – All pedestrian signal indications shall use the international symbol designations. The pedestrian countdown indication is an optional feature on pedestrian signal heads. TDOT allows only the one section integrated pedestrian head on new signal installations. The bottom of the housing shall be located 7-10 feet above the sidewalk. Section 4.4 provides more information on pedestrian signals. Figure 4.33 shows several pedestrian signal mounting arrangements.

A. Walking Person Symbol (see Figure 4.17)

- **Meaning –** Walk
- **Color –** White
- **Size –** The symbol shall be approximately 12" tall.
- **Location –** Integral with and to the right of the upraised hand symbol.

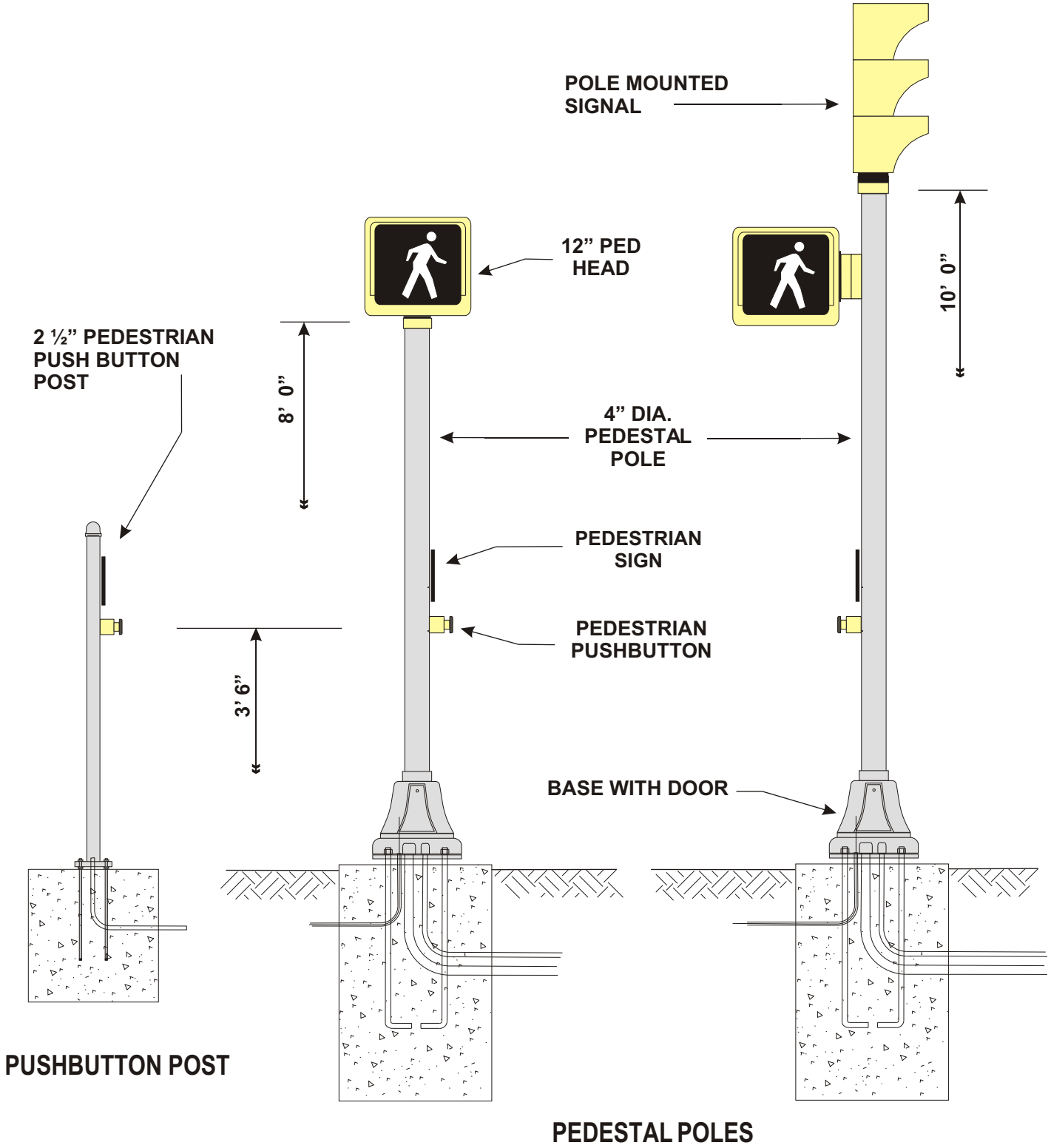
B. Upraised Hand Symbol (see Figure 4.17)

- **Meaning**

  Flashing – Pedestrian Clearance

  Steady – Don't Walk
- **Color –** Portland Orange
- **Size –** The symbol shall be approximately 12" tall.
- **Location –** Integral with and to the left of the walking person symbol.

[46] MUTCD, FHWA, 2003, p. 4E-1.



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Typical Pedestrian Signal Details

Figure 4.33

C. Pedestrian Countdown Indication (see Figure 4.17)

- **Meaning**

  Flashing – Countdown of Pedestrian Change Interval
- **Color –** Portland Orange
- **Size –** The digits shall be approximately 8" tall.
- **Location –** Integral with and right of the upraised hand symbol.

4.9.12 Signal Head Shielding – As a minimum, all signal indications shall be equipped with cut away (partial) visors to prevent the sun phantom effect (signal appearing to be on due to the sun reflecting on the signal indication lens).

4.9.13 Programmable Signal Heads – Other installation problems may exist that would require the signal head to be shielded or to have its visibility limited. A programmable signal head utilizes a special optical lens that can be "programmed" to provide the signal display to only desired portions of the roadway. The programming is accomplished by masking (with tape) portions of the lens through the rear of the housing. Because the lens is programmed to be visible from certain areas, the signal head should be rigid mounted or tethered. Programmable signal heads are much more expensive than a regular signal head and require correct masking or they will not work as desired. The most common uses are as follows.

Programmable signal heads should be used for any movement where drivers could mistakenly see a signal indication that is intended for another movement.

A. Closely Spaced Traffic Signals – Where traffic signals are closely spaced and simultaneously display conflicting color indications to approaching motorists, optically programmed visibility lenses should be installed on the far signal heads.

B. Acute Angle Intersections – Where the intersection of two roadways is less than 90 degrees causing conflicting signal indications on one street to be seen by motorists on the other street, either optically programmed visibility lenses or full tunnel visors with louvers should be used on the signals heads.

C. Railroad Crossings with Pre-Signals – The signal heads at the far side of the intersection (beyond the pre-signals) should be programmable so as to limit their visibility from vehicles before the tracks.

4.10 Controllers and Cabinets

4.10.1 Traffic Signal Controllers – The standard controller to be used at all new signalized intersections shall be an 8-phase, NEMA solid state controller that meets current TDOT standards and specifications.

Eight phase dual-ring controllers should be used at all new traffic signals.

Presently, most cities in Tennessee use NEMA TS-2, Type 2 cabinets and controllers. An 8-phase controller should be used even when four phase cabinets are installed. Limited interchangeability of controller equipment is possible between different manufacturers of NEMA controllers. Many larger cities standardize on one NEMA controller brand. All controllers within a system must be of the same brand to achieve system operation.

4.10.2 Controller Cabinets

To prevent problems for sight impaired pedestrians, pole mounted cabinets should not be used within a sidewalk.

A. Cabinet Types:

- **Pole mounted cabinets –** should only be used for four phase intersections.
- **Ground mounted cabinets –** should be used for all 8-phase intersections or locations that house a master controller or significant auxiliary equipment such as video detection equipment. They may also be used for four phase intersections.

B. Interconnect/Communications – Where installed in a system, the controller cabinet shall have facilities for the appropriate communications.

C. Orientation – The controller cabinet shall be so oriented that the traffic personnel can observe the intersection while working in the cabinet.

D. Service Pad – 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.

E. Location – Controller 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. Cabinets should not be placed within the pedestrian walkway portion of a sidewalk. Consideration should also be given to the effect of cabinet placement on sight distance.

F. Cabinet Construction – Cabinets shall be constructed of aluminum. Standard cabinet sizes are shown in TDOT's Standard Drawings.

G. Grounding Requirements – All controller cabinets shall be grounded separately from support poles.

4.10.3 Power Supply

A. Location – If possible, controller cabinet should be located in the same quadrant as the electrical service.

B. Quantity – In quantity calculations, the term "electrical service" or "power supply" includes the pole, circuit breaker, ground rod, conduit (riser) and conductors on the utility company's pole and/or conduit (riser) and conductor on the service pole. A separate 1"

conduit rigid steel conduit (RGS) riser must be provided where the power is brought down a wooden pole.

C. **Street Lights –** 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.

D. **Cable Routing –** If the power supply cable travels underground, it shall be run in a separate rigid steel conduit (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.

4.11 Traffic Signal Supports – The two basic types of traffic signal supports are strain poles and mast arm poles.

- **Strain Pole –** A strain pole is a pole to which span wire is attached for the purpose of supporting the signal wiring and signal heads (see Figure 4.34).
- **Mast Arm Pole –** A mast arm pole is a cantilever structure that permits the overhead installation of the signal heads without overhead messenger cables and signal wiring, which is run inside the arm structure (see Figure 4.35)

Traffic signal supports, including steel strain poles, concrete strain poles and mast arm poles, shall be in accordance with TDOT specifications. 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.

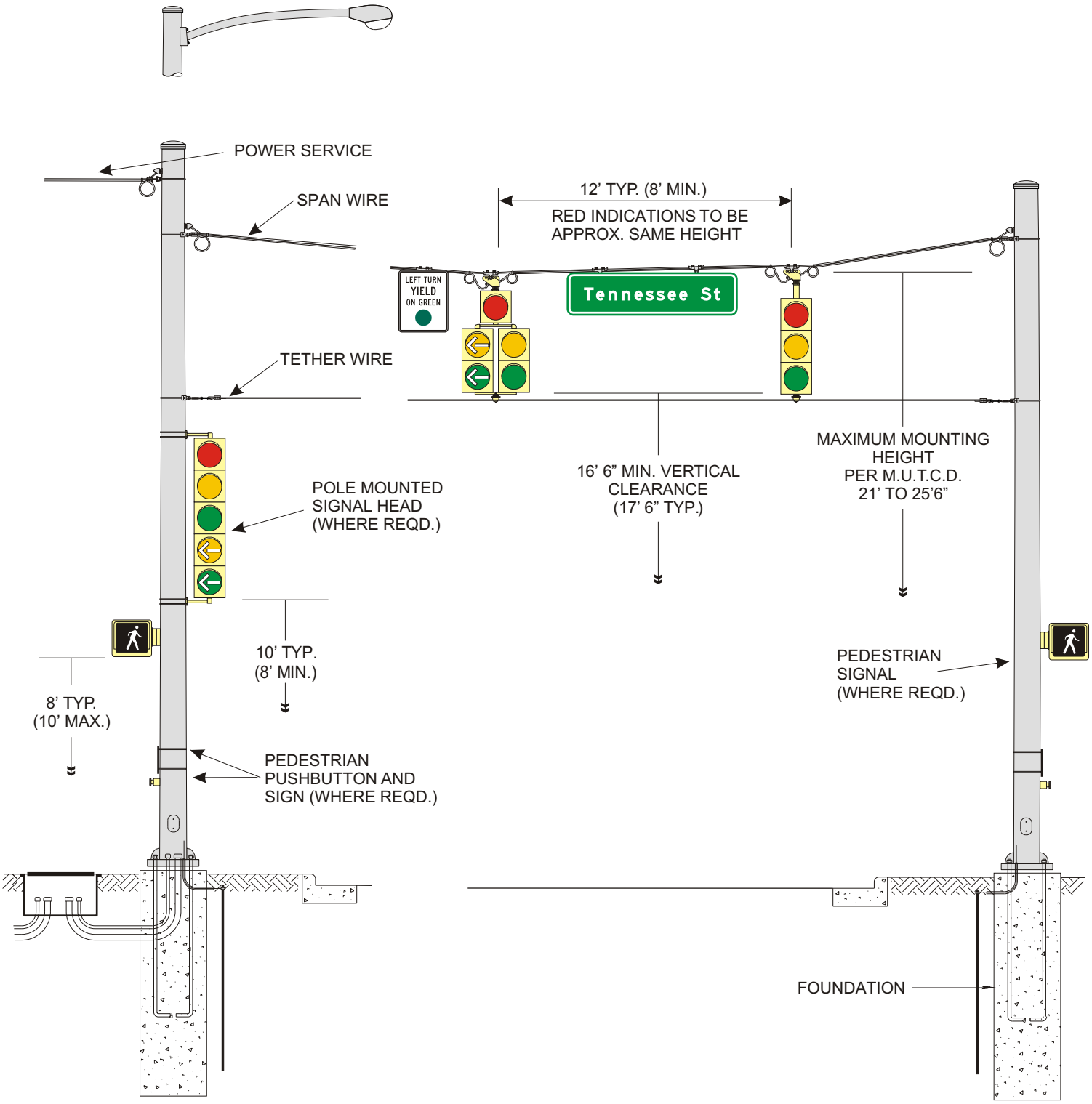
4.11.1 Selection of Support Type – Wood poles with guy wires should be considered as an option when selecting traffic signal support poles.

Steel or concrete strain poles should always be considered when span lengths exceed 90 feet or easements or right-of-way will be required for guy wires. Steel or concrete strain poles should also be considered when utilizing a box span arrangement to provide additional strength.

Mast arm poles should be considered when aesthetics are an issue. Double mast arm poles should be considered when some corners lack room for poles. Steel or concrete strain poles or mast arm poles should also be considered for areas without overhead utilities.

The major advantages of wood poles are their lower cost and relatively shorter delivery time. However, wood poles require guy wires and conduit risers, which may become maintenance issues over time.

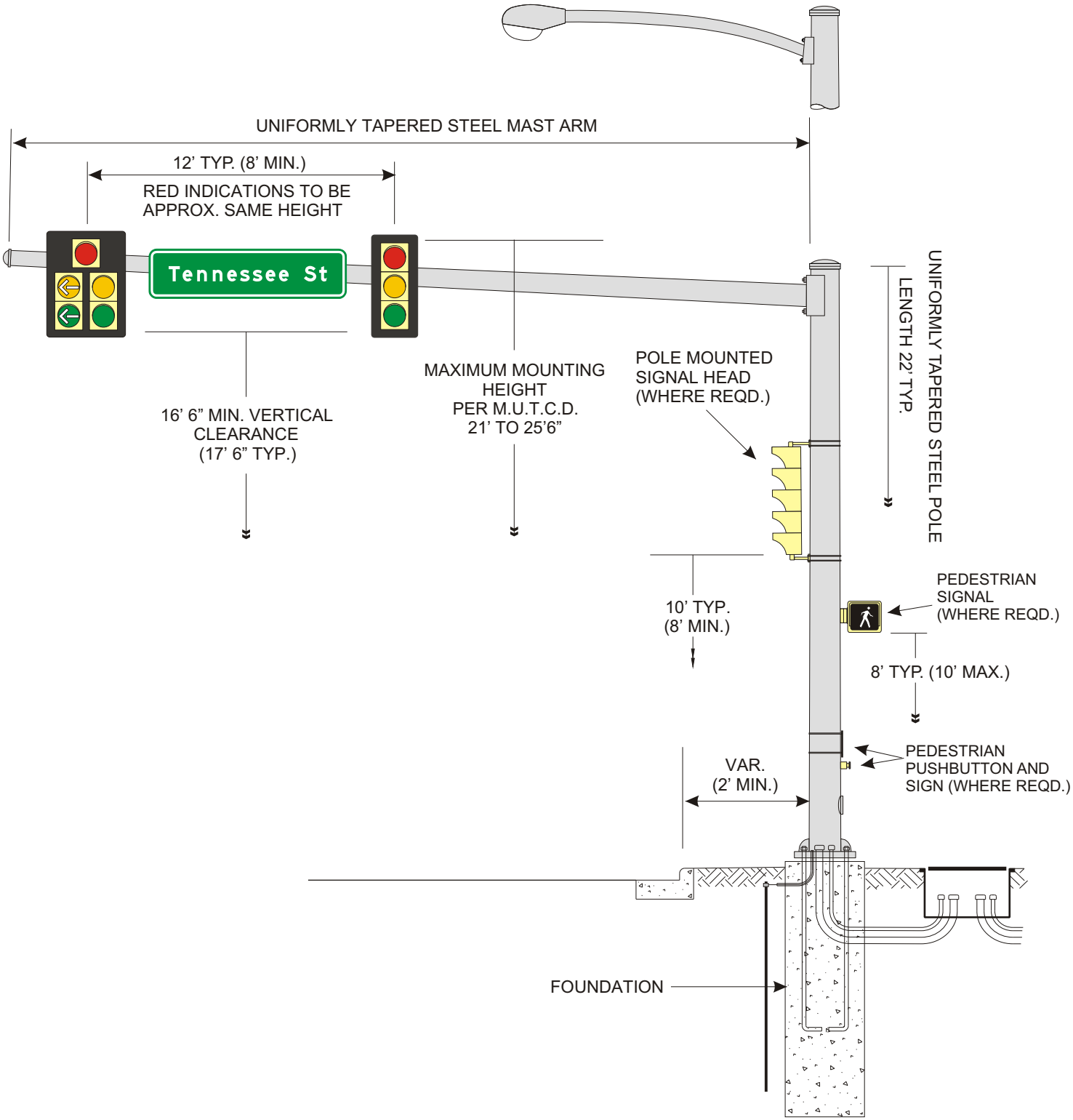
The primary advantages of steel or concrete poles are better long term maintenance, aesthetics and ability to handle longer spans or heavier loads. However, they are more costly and have longer delivery times.



Tennessee Department of Transportation
Traffic Design Manual

Typical Strain Pole Details

Figure 4.34



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Typical Mast Arm Pole Details

Figure 4.35

4.11.2 Strain Poles (Wood, Steel or Concrete)

A. **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.

B. **Span Wire Arrangements –** Span wire arrangements in general allow for further pole setbacks from the roadway than do mast arm installations. In addition, they eliminate the need for jacking and boring under the roadway by allowing signal and detector cables to be run overhead on the signal span wire. The following are the most common span wire arrangements:

Typical intersections will use strain poles in a box span arrangement.

C. **Box Span Arrangement** (see Figure 4.36) **–** This signal arrangement places strain poles on each of the four corners of the intersection.

Box Span Advantages:[47]

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

Box Span Disadvantages:[48]

1. Requires four poles.
2. Could require supplemental signal heads if the signal heads are more than 180 feet beyond the approach stop line.

D. **Suspended Box Arrangement** (see Figure 4.36) **–** 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 heads and the stop line. A variation where two corners of the box are connected by diagonal spans and two directly to poles is often used for skewed intersections.

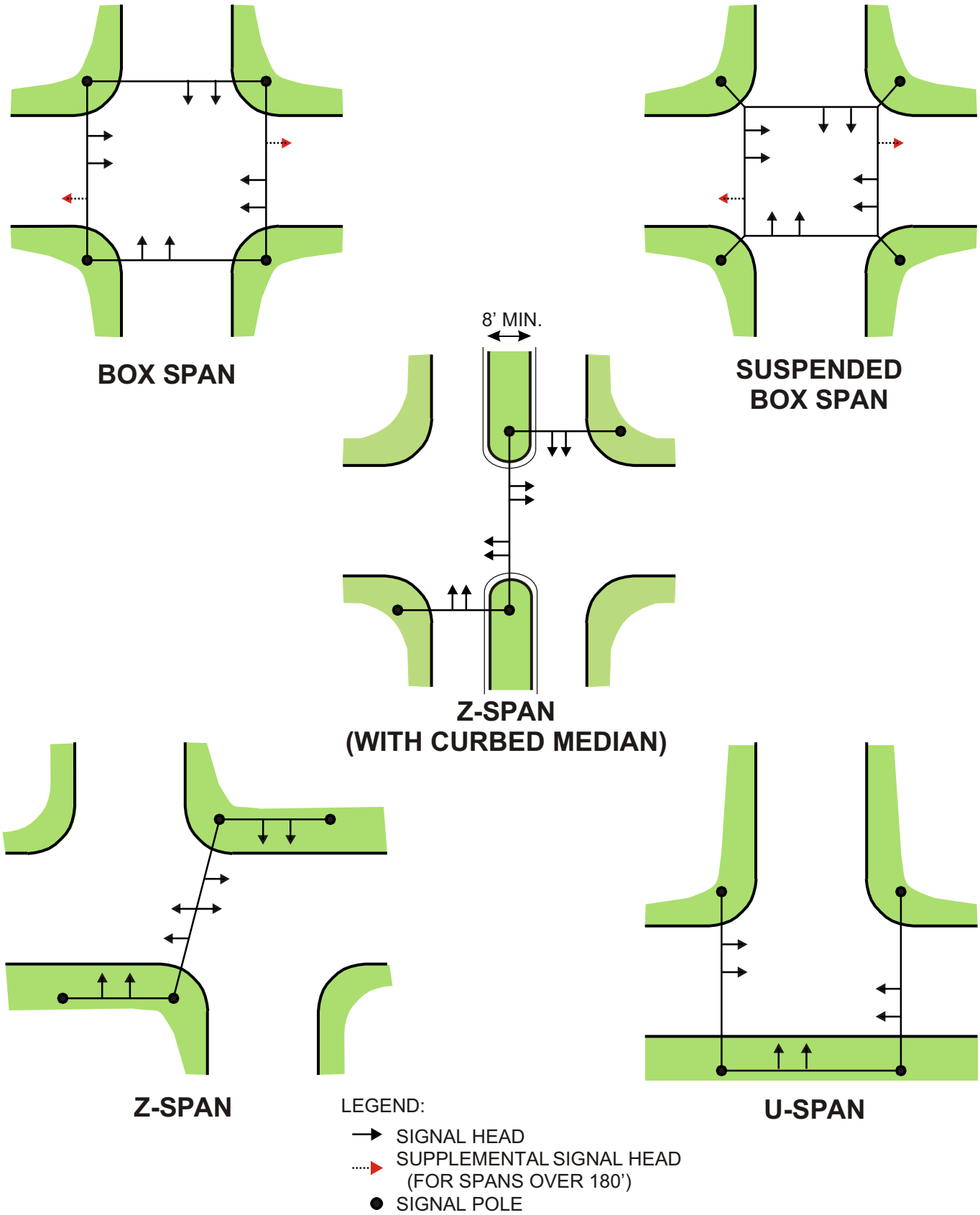
Suspended Box Advantages:

1. Same advantages as box arrangement (see 4.11.2.C).
2. Decreased distance between the signal heads and stop line.

Suspended Box Disadvantages:

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

[47] Traffic Engineering Handbook, ITE, 1999, p. 506.
[48] Ibid.



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Traffic Design Manual

Typical Strain Pole (Span Wire) Layouts

Figure 4.36

E. **Z Span Arrangement** (see Figure 4.36) **–** Z spans are applicable at offset intersections. Z span installations may be applicable on divided roadways where median clear zone requirements can be met.

Z Span Advantages:

1. On divided roadways, shorter span wires are required across the street with the median.
2. Provides good signal head placement for offset intersections.

Z Span Disadvantages:[49]

1. 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.
2. On divided roadways, additional pedestal poles may be needed if pedestrian signals and detectors are required.
3. On divided roadways, pedestrians cannot see the parallel signal indications once they get to the median area.

F. **Diagonal Span Arrangement –** A diagonal span installation may be applicable at some locations, but generally presents problems with visibility for signal heads.

Because diagonal spans tend to create signal head visibility problems, they should not be used unless other span arrangements are not feasible.

Diagonal Span Advantages:

1. Only two poles are required.

Diagonal Span Disadvantages:

1. All loads are concentrated and place extreme pressure on poles.
2. Pedestal poles are required when pedestrian indications are used.
3. Very difficult to obtain horizontal distance requirements and vertical visibility for signal heads.

G. **Pole Height Determination –** The height of a strain pole is determined by Equation 4.12. 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

[49] Traffic Engineering Handbook, ITE, 1999, p. 507.

area. Consideration must be made to ensure an adequate pole length is specified in such a situation.

Equation 4.12

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

Where: PH = Pole height (feet)

L_s = maximum span length (feet)

S = design sag (usually 5%)

c = clearance above road (17.5' typical)

H = height of signal head with backplate (usually 4.5')

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 (26, 28, 30, etc.).

H. **Pole Location –** Generally, strain poles should be located outside of the clear zone.

- **Signal Location –** Strain poles should be located so that signal heads 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 travel lane without adversely affecting signal visibility.[50]
- **Pedestrian Considerations –** When installing a pedestrian pushbutton, poles should be located adjacent to the sidewalk within reach of pedestrians.

I. **Luminaires –** Where street lights are installed on traffic signal poles, they are to be designed integral with the pole and mounted at a minimum height of 30 feet above the roadway. Actual mounting height shall be determined by the luminaire photometrics.

J. **Tether Wires –** Tether wires shall be installed to minimize signal head movement when polycarbonate signal heads, LED or optically programmed lenses are specified or at locations where wind is a consideration. Tether wires must be able to breakaway from poles when hit or snagged.

Breakaway tether wires should be installed on any spans with LED signal heads.

[50] MUTCD, FHWA, p. 4D-20.

4.11.3 Mast Arm Poles – Mast arm supports provide a more rigid mounting for signal heads and overhead signs than do span wire installations.[51] Accordingly they are particularly applicable where programmed visibility signal heads are used. They also require less maintenance in regards to turned signal heads and signs. Mast arm installations are more aesthetically pleasing than span wire installations since there is no overhead span wire or signal wiring.

Mast arm supports should be considered when they would match adjacent signals, when utilities are underground, when they would result in fewer overall poles or when aesthetics are a primary concern.

Very long mast arms can be extremely costly. Generally, mast arms greater than 65 feet long become unrealistic. Mast arm installations are more expensive then strain poles because they require boring and jacking under the roadway to get signal and detector cables to the controller cabinet.

A. Single Mast Arm Layout – A typical single mast arm installation is shown in Figure 4.37 where it is used at the intersection of two undivided roadways.

Advantages:

1. Provides the required minimum 40 feet distance between the signal heads and the stop line of all approaches.
2. Provides good far side signal head visibility for pedestrians.
3. Provides locations for pedestrian signal indications and pedestrian detectors where needed.

Disadvantages:

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

B. Dual Mast Arms – The dual mast arm arrangement is often applicable at offset intersections and at tee intersections as shown in Figure 4.37.

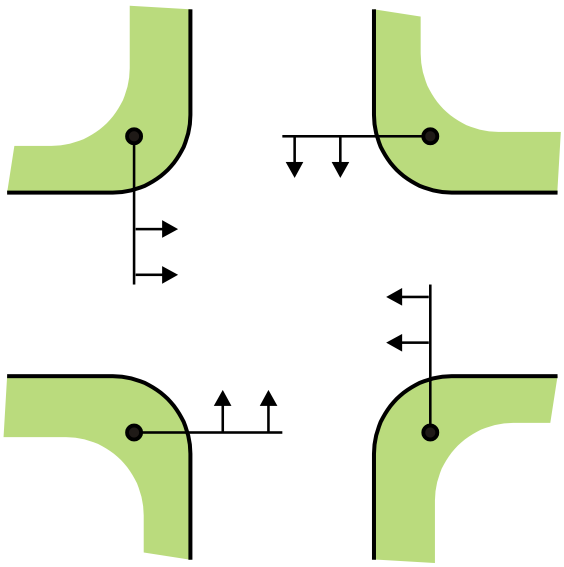
Advantages:

1. Uses fewer poles than a strain pole or single mast arm arrangement.
2. Provides good signal head placement for offset intersections.

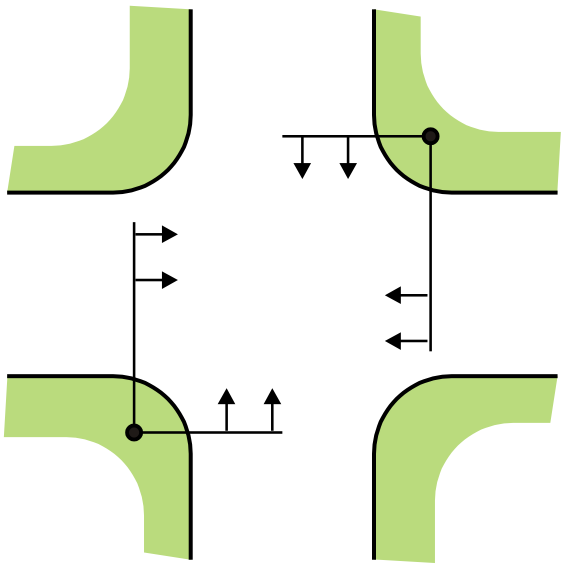
Disadvantages:

1. Additional traffic signal poles may be needed if pedestrian signals and detectors are required.
2. Sight lines to the signal heads may be obscured.

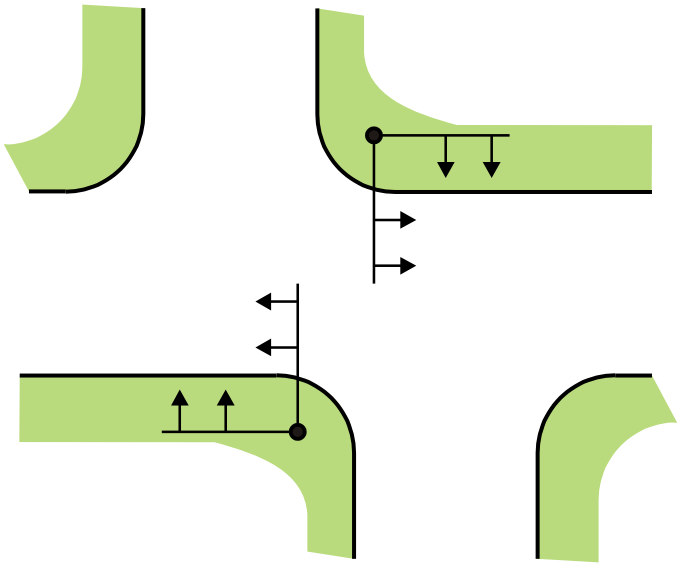
[51] Traffic Engineering Handbook. 1999. p. 508



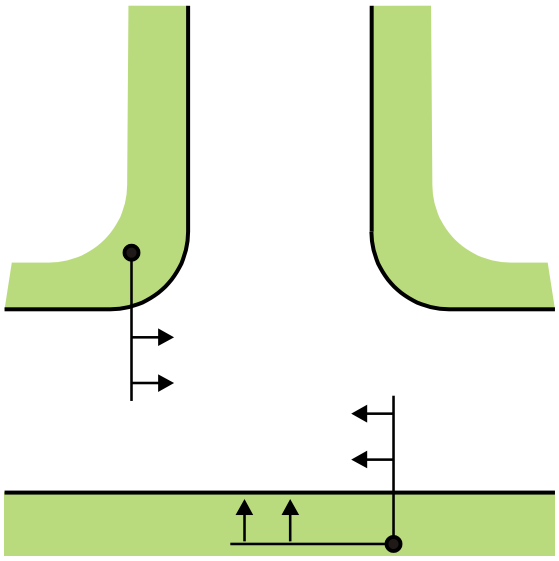
SINGLE MAST ARMS



DUAL MAST ARMS



DUAL MAST ARMS
(OFFSET INTERSECTION)



COMBINATION SINGLE/DUAL
MAST ARMS

LEGEND:

→ SIGNAL HEAD

● MAST ARM SIGNAL POLE

Tennessee Department of Transportation
Traffic Design Manual

Typical Mast Arm Pole Layouts

Figure 4.37

C. **Mast Arm Height –** Typical mast arm poles have a 22 foot shaft, unless street lighting is integral with the traffic signal pole.

D. **Mast Arm Length –** Mast arm length must be specified on signal plan sheets. The arm length is determined by taking into account signal head placement in relation to the approach travel lanes and the pole setback off the edge of the travel way. The mast arm length shall not exceed the maximum length currently feasible in construction.

Mast arm lengths should be limited to 65' or less.

E. **Mast Arm Pole Location –** The requirements are the same as those listed for the location of strain poles (see Section 4.11.2.H).

F. **Luminaires –** Street lights installed on mast arm poles are to be designed integral with the pole and they are to have a minimum mounting height of 30 feet above the roadway. Actual mounting height shall be determined by the luminaire photometrics.

4.12 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 cable shall meet the applicable requirements of IMSA and National Electric Code.

4.12.1 Signal Control Cable – All signal control cable 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.

4.12.2 Copper Communications Cable – Copper communications cable shall be 6 pair, AWG No. 19 polyethylene insulated, polyethylene jacket cable with electrical shielding meeting the requirements of IMSA Specification No. 40-2.

4.12.3 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).

4.12.4 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 or 51-3, to the detector terminals or spliced with shielded detector cable within a pull box, condulet or pole base.

4.12.5 Loop Detector Lead-In (Shielded Cable) – 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.

4.12.6 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". The home run cable shall be installed inside conduit or manufacturer's recommended enclosure between the pavement and the pull box to prevent damage in ground.

4.12.7 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.

4.12.8 Cable Sizing for Conduit – After the signal head and signal detector arrangements/placements have been determined, the necessary signal wiring required involves the following steps:

A. Signal Head Requirements – The typical wiring requirement of each individual signal head may be determined by using Figure 4.38.

B. Mast Arm/Span Wire Runs – Determine the length of wiring required for the signal heads depending on whether span wire or mast arms are used.

C. Detectors, Power and Interconnect Cable – Determine the wiring required for detectors, power, and interconnect cables where applicable.

D. Sizing Conduit – Combine the wiring requirements in 4.12.1 and 4.12.3 above and size the conduit needed for each wiring run using Table 4.7.

4.13 Conduit – 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 (risers), unless the wiring is inside of a pole or attached to a span wire or a messenger cable. Conduit used for traffic signal installation shall have the following characteristics:

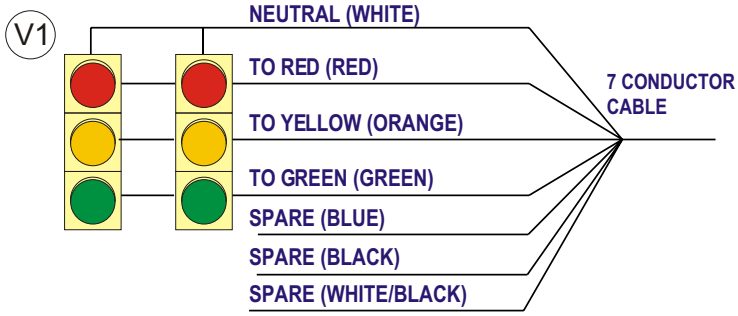
4.13.1 Conduit Material Type

A. Underground: PVC (Polyvinyl Chloride Conduit), Schedule 40 or **RGS** (Rigid Steel Conduit). Schedule 80 conduit may be permitted in certain situations.

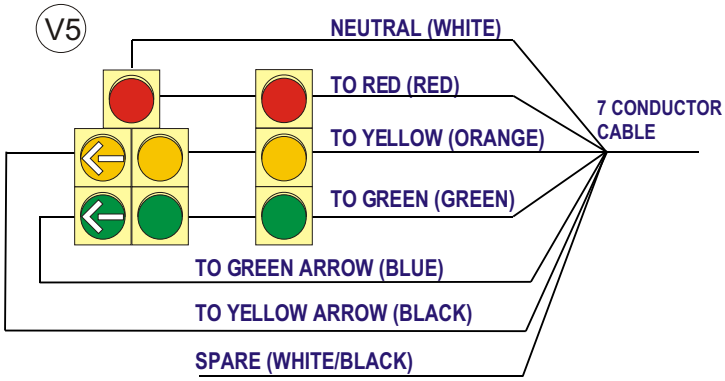
- **In Ground –** In general, typical conduit in soil should be PVC, Schedule 40. See 4.13.4, 4.13.5 and 4.13.6 for special cases.
- **Under Driveways –** When PVC conduit is shown on the plans in areas which are subject to vehicular traffic, such as under driveways, Schedule 80 PVC conduit shall be used.
- **Under Roadways:** All conduits under roadways shall be RGS.

B. Risers: All risers shall be RGS.

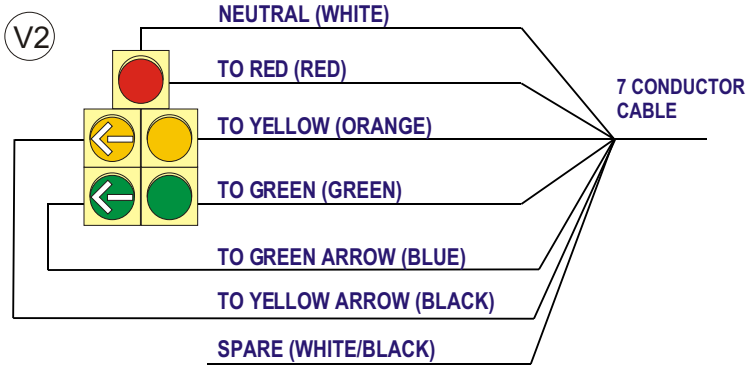
3-SECTION SIGNAL HEAD (TYPE 130)

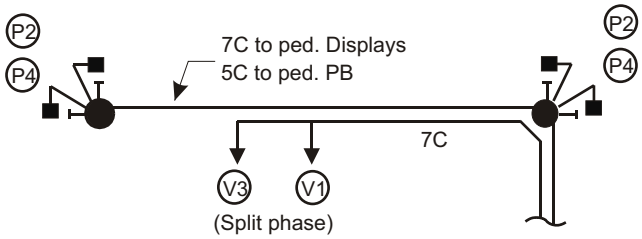


COMBINATION, TYPES 130/150A2H (LEFT TURN PERM/PROT.)

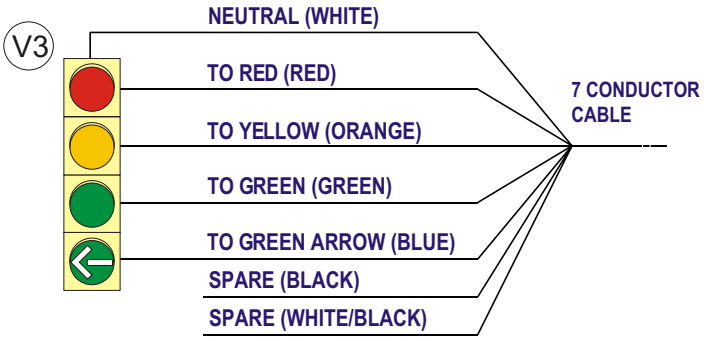


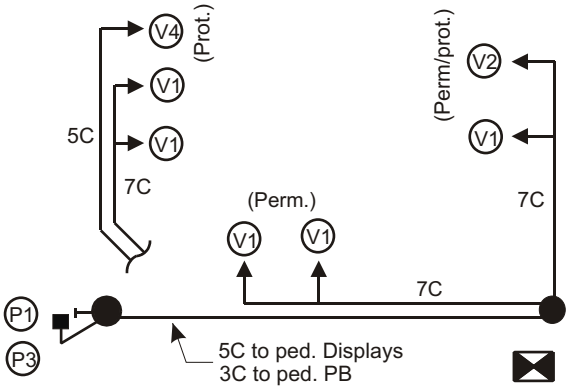
5-SECTION SIGNAL HEAD (TYPE 150 A2H OR 150 A2V)





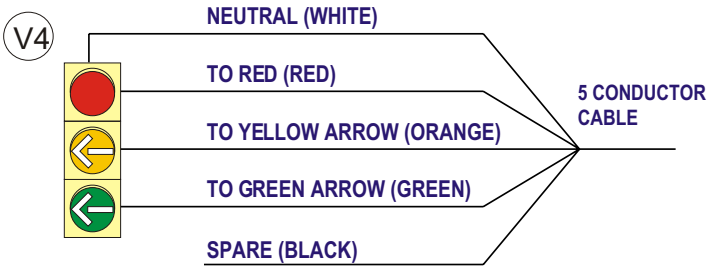
4-SECTION SIGNAL HEAD (TYPE 140A1)





TYPICAL WIRING SCHEMATIC (DEPICTING VARIOUS LEFT TURN TREATMENTS)

3-SECTION SIGNAL HEAD (LEFT TURN-TYPE 130A2 OR 130A3)



LEGEND	
⊠	CONTROLLER
●	SIGNAL SUPPORT POLE

*** 8C AND 9C MAY BE SUBSTITUTED FOR 7C CABLE**

Tennessee Department of Transportation
Traffic Design Manual

Typical Traffic Signal Wiring

Figure 4.38

Table 4.7 Typical Wire Sizes

AWG 14		
Number of Conductors	Outside Diameter (inches)	Area (in^2)
1	0.17	0.023
2	0.41	0.132
3	0.43	0.145
4	0.47	0.173
5	0.51	0.204
6	0.58	0.264
7	0.58	0.264
8	0.63	0.312
9	0.68	0.363
10	0.72	0.407
12	0.75	0.442
13	0.78	0.478
14	0.78	0.478
15	0.82	0.528
16	0.82	0.528
17	0.91	0.650
18	0.91	0.650
19	0.91	0.650
20	0.95	0.709
21	0.95	0.709
22	1.00	0.785
23	1.00	0.785
24	1.05	0.866
25	1.07	0.899
26	1.07	0.899
27	1.07	0.899
28	1.07	0.899
29	1.11	0.968
30	1.11	0.968

AWG 16		
Number of Conductors	Outside Diameter (inches)	Area (in^2)
1	0.15	0.018
2	0.34	0.091
3	0.35	0.096
4	0.38	0.113
5	0.42	0.139
6	0.45	0.159
7	0.45	0.159
8	0.49	0.189
9	0.53	0.221
10	0.60	0.283
12	0.64	0.322
13	0.67	0.353
14	0.67	0.353
15	0.70	0.385
16	0.70	0.385
17	0.74	0.430
18	0.74	0.430
19	0.74	0.430
20	0.77	0.466
21	0.77	0.466
22	0.81	0.515
23	0.81	0.515
24	0.85	0.567
25	0.91	0.650
26	0.91	0.650
27	0.91	0.650
28	0.94	0.694
29	0.94	0.694
30	0.94	0.694

Other Cables		
Type	Outside Diameter (inches)	Area (in^2)
6 pair / 19	0.53	0.221

Conduit Areas		
Conduit Size	Area (in^2)	Maximum Usable Area (40% of total)
3/4"	0.44	0.176
1" (25 mm)	0.77	0.308
1 1/2"	1.77	0.708
2" (50 mm)	3.14	1.256
2 1/2"	4.91	1.964
3"	7.07	2.828

4.13.2 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 jacking method or the directional bore 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.
- **Jacking Method –** The jacking method is generally used when the open cut method is not permitted. The jacking method pushes a pipe sleeve under a roadway, driveway, or railroad track that is 2" larger in diameter than the conduit(s) that it will be conveying. This method requires a jacking pit, which must be within the right of way. For 20-foot pipe sleeve sections, the jacking pit is 32-foot long and 6-foot wide. For 10-foot pipe sleeve sections, the jacking pit is 22-foot long and 6-foot wide.
- **Directional Bore Method –** The directional bore method is an optional method that can be used in lieu of the jacking method. The direction bore method installs conduits boring along a prescribed route under the roadway, driveway or railroad track. The directional bore method does not require a pit, as does the jacking method, however an 8-foot by 8-foot staging area is needed to install conduits less than 6" in diameter.

4.13.3 Depth Installed (Underground) – Conduit is placed 18" to 36" below the finished grade. Typically, conduit below sidewalk is placed 18" deep.

4.13.4 Conduit Sizing – The maximum size conduit to be used on traffic signal installations shall be 3". Where larger conduit capacity is required, multiple conduit runs will be used. The sizing of conduit should be such as to not fill over 40% internal area of the conduit (see Table 4.7).

Conduit for traffic signal applications shall not be larger than 3" or smaller than 1".

Typical traffic signal conduit shall be 2" diameter and detector loop conduit 1" diameter, unless otherwise indicated. Conduits smaller than 1" diameter shall not be used unless otherwise specified, except grounding conductors at service points shall be enclosed in 3/4"diameter conduit. No reducing couplings will be permitted. The conduit between a saw cut and a pull box for loop lead-ins shall be 1" diameter and not be measured for separate payment, but will be absorbed in other conduit items.

4.13.5 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" diameter.

4.13.6 Power Cable Conduit – Conduit for power supply shall be run in a separate 1" diameter RGS conduit.

4.13.7 Bored and Jacked Conduit – All bored and jacked conduit shall be rigid (RGS). The estimation of the amount of boring is critical. Care should be taken for a realistic estimate (overestimation is preferred).

4.13.8 Conduit Radii – All conduit bends shall be large radius to facilitate cable pulling (6" minimum radius).

4.13.9 Spare Conduit – Spare conduit stubs for future use shall always be installed in all new controller cabinet bases and pole foundations. These stubs shall not be measured for separate payment, but will be absorbed in other conduit items.

4.13.10 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.

4.14 Pull Boxes – A pull box is an underground compartment made of various materials such pre-cast concrete or polymer concrete (composite). Pull boxes used in traffic signal installations shall meet current TDOT standard specifications.

When possible, pull boxes should be located adjacent to sidewalks rather than in the sidewalk.

4.14.1 Purpose of Pull Boxes:

- 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.

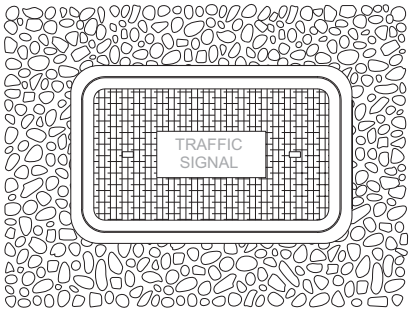
4.14.2 Type/Size/Use – Figure 4.39 shows the various size pull boxes and their normal application or use. Type A Pull Boxes shall be used exclusively for splicing loop wires to shielded cable only. Type B Pull Boxes shall be used for all other traffic signal cable applications.

Pull boxes for fiber optic cable must be larger than standard pull boxes due to the large bending requirements of fiber optic cable.

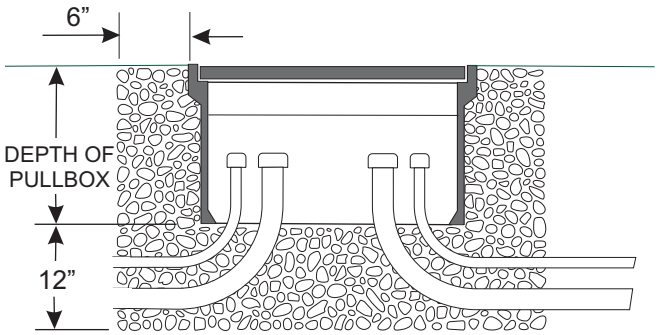
4.14.3 Spacing – Pull boxes shall be located at 150 foot intervals for signal cable and detector cable runs. Pull boxes for copper interconnect cable runs shall be located at 300 foot intervals. Fiber optic pull boxes should be located every 1,000 feet for fiber optic cable runs.

4.14.4 Material – Pull boxes and covers are to be of load bearing design in accordance with TDOT standard specifications. In general, all pull boxes shall be traffic load bearing.

TRAFFIC SIGNAL PULL BOX DETAILS



TOP VIEW



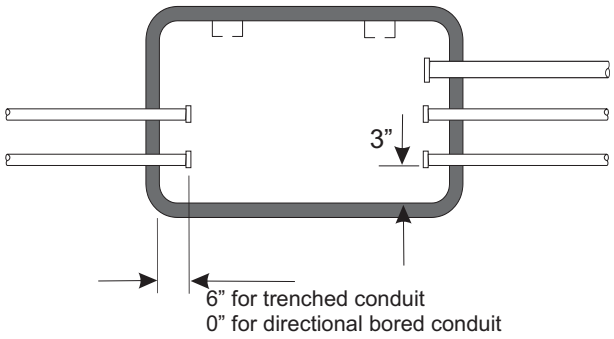
SIDE VIEW

TYPE	MIN. DIMENSIONS		
	LENGTH	WIDTH	DEPTH
A	12”	12”	6”
B	28”	16”	12”

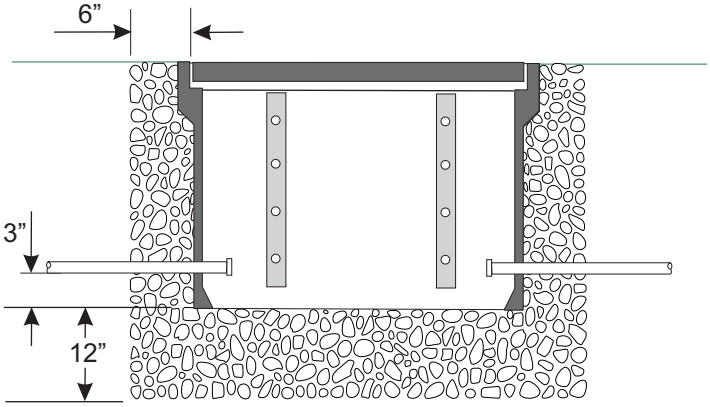
Type “A” Pull Boxes are used for splicing loop lead-ins.

Type “B” Pull Boxes are used for all signal cable routing.

FIBER OPTIC PULL BOX DETAILS



TOP VIEW



SIDE VIEW

F.O. TYPE	MIN. DIMENSIONS		
	LENGTH	WIDTH	DEPTH
A	36”	26”	32”
B	49”	32”	36”

F.O. Type “A” Pull Boxes are used when no splicing is required in the pull box.

F.O. Type “B” Pull Boxes are used when splicing is required in the pull box.

4.15 Street Lighting on Traffic Signal Supports at Intersections (see Chapter 7 for more information)

4.15.1 Justification – Street lighting may be justified at signalized intersections as follows:

A. Urban Locations – In urban areas where street lighting already exists along the highway.

B. Rural Locations – In rural locations where street lighting at the intersection would have a positive effect on the nighttime safety of the intersection.

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

4.15.3 Mounting Height – Typically 30 foot minimum above roadway. The actual mounting height shall be determined by the luminaire photometrics.

4.15.4 Wiring Requirements

A. Circuit Breaker – A disconnect and fuse shall be located at the power pole location.

B. Wire Type – 1-2 conductor, #6 AWG

C. Conduit Size – one inch diameter RGS

D. Isolation – Street light conductors shall not be routed through the controller cabinet and shall have its own conduit and pull boxes.

E. Pull Boxes – Pull boxes used in lighting applications should be a maximum of 300’ apart.

4.16 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.

All traffic signals are capable of flashing indications. Flashing operations of a traffic signal shall comply with Sections 4D.11 and 4D.12 of the MUTCD.

4.16.1 Types of Flashing Operation

A. Emergency Flash – Emergency flash mode is used when the conflict monitor (malfunction management unit) senses a malfunction. Emergency flash should use all-red flash exclusively.

B. 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.

C. 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.

D. Scheduled Flash – Traffic signals can operate in scheduled flash mode as a time-of-day operation (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.

4.16.2 Signal Display

A. 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.

B. Yellow-Red Flash – This type 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.

C. Protected Only Left Turn Signals (3 Section Heads) – These signal heads shall be flashed red regardless of what color indication the adjacent signal heads are flashing.

D. Protected/Permissive Left Turn Signals (5 Section Heads) – These signals shall flash a circular indication of the same color as indications flashed in the adjacent thru signal head(s).

4.16.3 Dimming LED Signal Indications – 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.

4.17 Stop Signs at Signalized Intersections – The MUTCD prescribes 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.

4.18 Signal Control for Driveways within Signalized Intersections – Traffic signal control for a driveway should be provided only if the driveway serves a commercial or multi-residential development. Signal control may also be provided for driveways serving non-profit land uses with significant traffic generation such as churches. Split-phase operation for these low volume driveways should be considered and detection should always be provided for the approach to avoid unnecessary delays for other approaches.

4.19 New Traffic Signal Inspection – Before allowing a new traffic signal to be turned on to traffic, a thorough inspection shall be completed to determine conformance with construction plans and specifications and proper and safe operation of the signal. Listed below are some of the items that should be inspected:

1. Confirm that all signal displays are appropriate, non-conflicting and in concurrence with the MUTCD.

2. Confirm that all controller and cabinet accessories, including controllers and conflict monitors, are in compliance with all plans, specifications and relevant national standards.

3. Confirm that signal phasing is appropriate and in concurrence with the construction plans and that no conflicts in phasing occur.

4. Confirm that pedestrian phases are appropriate with prescribed clearance phasing and not in conflict with protected left (or right) turns.

5. Confirm that all vehicular detection as specified on the plans, whether loops, video or otherwise, is properly working under all conditions, including dark and/or inclement weather.

6. If installed, confirm that system communications are working.

7. If installed, confirm that any emergency vehicle preemption is working by testing with an actual emergency vehicle and that the timings are adequate to move the vehicle through the intersection.

8. If installed, confirm that any Railroad Preemption activation circuitry activates as soon as the Railroad Crossing Equipment indicates the presence of a train. This test should be performed in the presence of appropriate railroad officials and with local law enforcement for safety. The test should assure that any phase not associated with the track clearance phase is immediately terminated through an appropriate vehicle clearance interval, the track clearance interval is of sufficient time to clear exposed vehicles, all illuminated turn restriction signs are properly activated and the dwell phase will activate after the track clearance phase also clears through an appropriate interval.

4.20 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:

4.20.1 Advance Flash Period – A new traffic signal installation should be put on flash operation for a period of seven weekdays prior to the activation of normal "stop and go" operation, so as to make motorists aware of its presence.

4.20.2 Publicity – The date and time of the activation of "stop and go" operation should be advertised in both the local newspaper and on local radio stations both prior to and on the date of activation.

4.20.3 Activation – The actual activation of normal "stop and go" operation should be made during an off peak traffic period.

4.20.4 Technical Support – The contractor shall be on-hand for all new traffic signal activations to immediately trouble shoot or fix any problems that arise.

4.20.5 Signing Adjustments – Once the traffic signal is turned on normal "stop and go" operation, remove the stop signs that the traffic signal replaces.

4.20.6 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.

4.20.7 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.

4.20.8 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 to assure the adequacy of the signal's timing parameters.

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CHAPTER 5

OTHER TYPES OF TRAFFIC SIGNALS

5.0 Highway Traffic Signals – The primary type of traffic signal device in use is the traditional traffic control signal at an intersection (see Chapter 4 for detail on traffic control signals). However, a traffic signal can be a device other than a typical traffic control signal.

Other types of traffic signals are:

A. Emergency Vehicle Traffic Control Signals – a special traffic control signal that assigns the right-of-way to an authorized emergency vehicle.

B. Lane-Use Control Signals – 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.

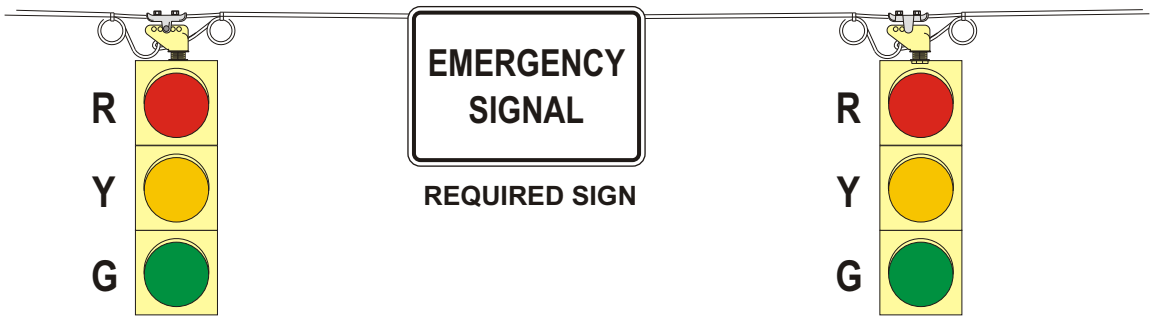
C. Ramp Control Signal – a highway traffic signal installed to control the flow of traffic onto a freeway at an entrance ramp or at a freeway-to-freeway ramp connection.

D. Flashing Beacons – a highway traffic signal with one or more signal sections that operates in a flashing mode.

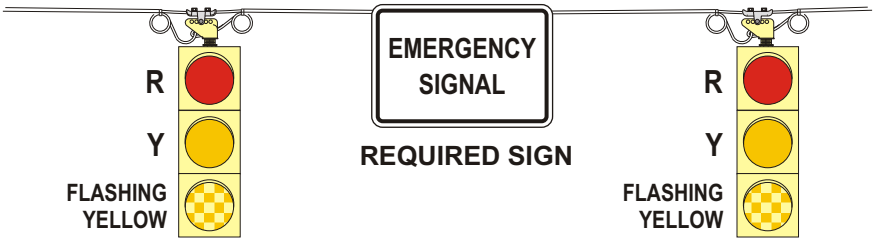
- **Intersection Control Beacon –** a beacon used only at an intersection to control two or more directions of travel.
- **Speed Limit Sign Beacon –** a beacon used to supplement a SPEED LIMIT sign.
- **Stop Beacon –** a beacon used to supplement a STOP sign, a DO NOT ENTER sign, or a WRONG WAY sign.
- **Warning Beacon –** a beacon used only to supplement an appropriate warning or regulatory sign or marker.

5.1 Emergency Vehicle Traffic Signals – Emergency signals may be installed to permit access from a location housing an emergency vehicle (e.g. fire station) in the absence of other warrants.

5.1.1 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 (see Figure 5.1). 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.



TYPICAL EMERGENCY VEHICLE TRAFFIC SIGNAL LAYOUT (GREEN REST)



ALTERNATE EMERGENCY VEHICLE TRAFFIC SIGNAL LAYOUT (FLASHING YELLOW REST)

REQUIRED ADVANCE WARNING SIGN

5.1.2 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.

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

A. 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.[1]

B. An EMERGENCY SIGNAL (R10-13) sign shall be mounted adjacent to a signal face on each street approach.[2]

5.2 Flashing Beacons – A flashing beacon is composed of one or more traffic signal sections operating in a flashing mode. If LED signal indications are used, an automatic dimming feature may be used to reduce the nighttime brightness.

5.2.1 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 5.2). 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.

STOP signs shall be installed for approaches to which a flashing red indication is shown. Individual intersection control beacons shall flash for each approach shall flash simultaneously, similar to intersection traffic signals.

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.[3]

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.

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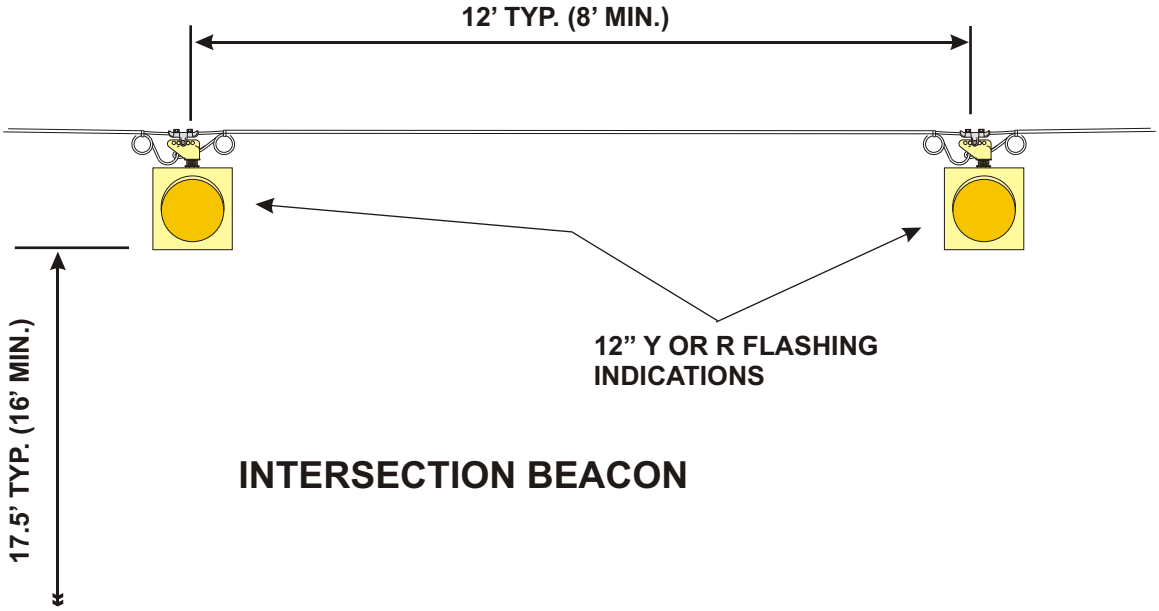
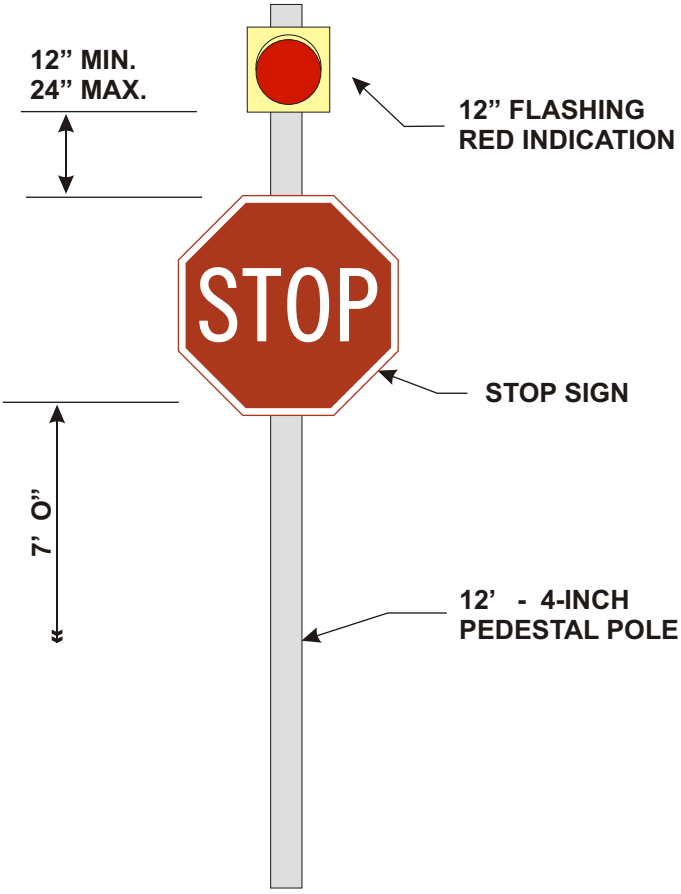
[1] MUTCD, FHWA, 2003, p. 4F-1
[2] Ibid.
[3] MUTCD, FHWA, 2003, p. 4K-1



INTERSECTION BEACON



STOP BEACON

Tennessee Department of Transportation
Traffic Design Manual

Intersection Beacon and Stop Beacon

Figure 5.2

5.2.2 Speed Limit Sign Beacons – A speed limit sign beacon consists of one or more signal sections with 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" or 12" and they shall flash alternately.[4]

5.2.3 School Zone Speed Limit Beacons – A special type of speed limit sign beacon is a school zone speed limit sign beacon. A school zone flashing beacon consists of two (2) 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). Figure 5.3 display the typical layout in Tennessee. Eight inch lenses may be used and install within the borders of the sign. If 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.

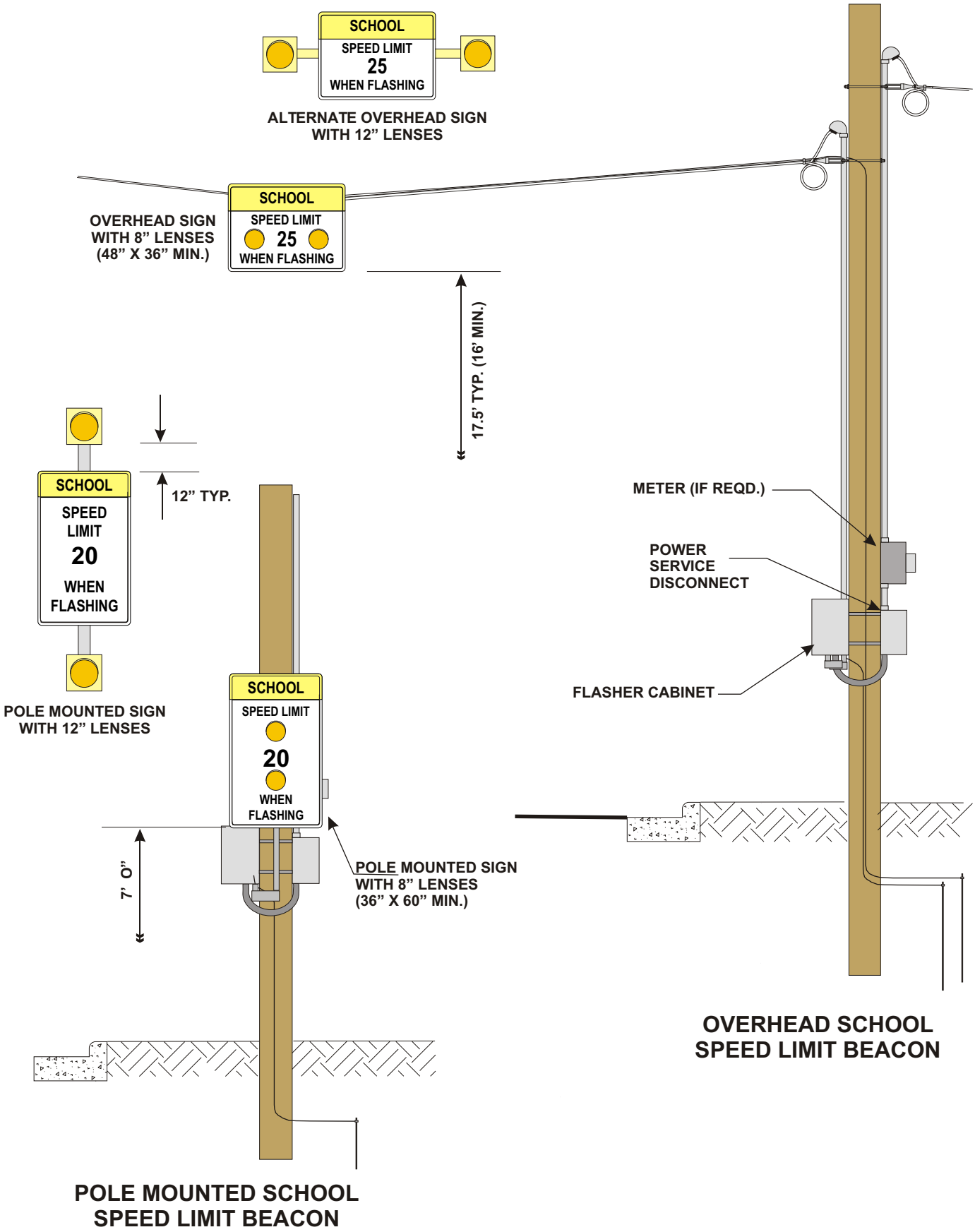
5.2.4 Stop Beacons (Red) – Stop beacons are a beacon used to supplement a STOP sign, a DO NOT ENTER sign, or a WRONG WAY sign. Stop sign beacons consist of one or more signal sections having flashing red 12" signal indications and are mounted above a STOP sign (see Figure 5.2). If two flashers are used on one sign, they shall flash simultaneously if mounted horizontally and alternately if mounted vertically.[5]

Stop beacons can be justified for STOP signs and may be used where:

A. Violations – A significant number of vehicles violate the stop condition.

B. Crashes – A crash rate exists that indicates the presence of a special need.

[4] MUTCD, FHWA, 2003, p. 4K-2.
[5] Ibid.



Tennessee Department of Transportation
Traffic Design Manual

School Speed Limit Beacons

Figure 5.3

5.2.5 Warning Beacons (Yellow) – Warning beacons are used only to supplement an appropriate warning or regulatory sign or marker (see Figure 5.4). 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:

A. 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 markings. Such obstructions could include guardrail at "T" intersections, bridge supports in or near the roadway, etc.

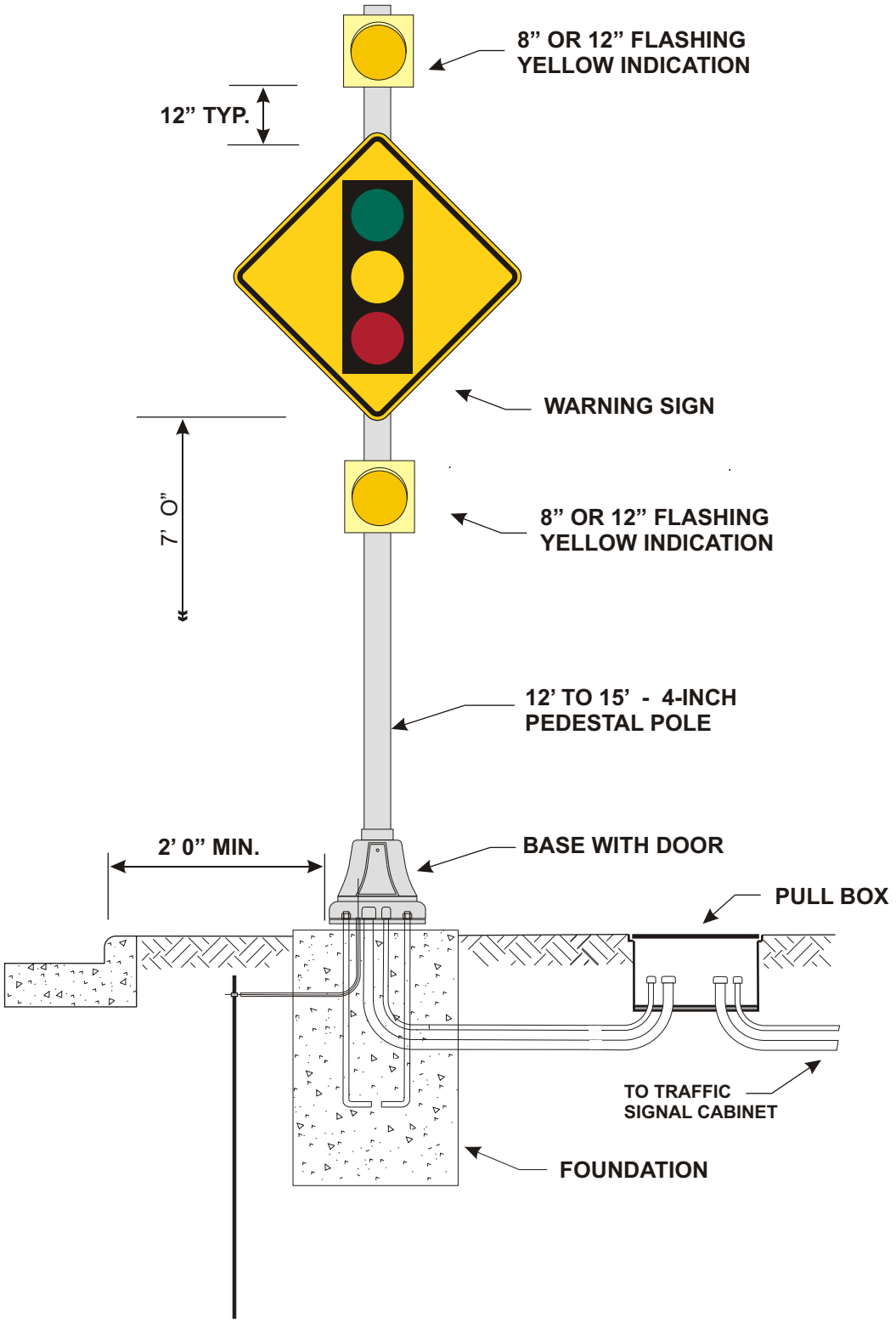
B. Supplement To Advance Warning Signs – A flashing beacon may be used to supplement advance warning signs for a variety of conditions where crash experience or field observation reveals that the warning signs alone are not effective. Such conditions could include sharp curves, obscured stop conditions, weather-related hazards such as fog and ice, obscured railroad crossings, truck crossings, plant entrances, etc.

5.2.6 Signal Ahead Beacons – Signal ahead beacons consist of one or more signal sections, each having alternately flashing yellow signal indications (see Figure 5.4). 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 high speed (45 mph or greater) highways 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 high speed (45 mph or greater) approaches to a traffic signal whose signal visibility is less than that called for in Part 4 of the Manual on Uniform Traffic Control Devices, Table 4D-1.



SIGNAL AHEAD BEACON

Tennessee Department of Transportation
Traffic Design Manual

Flashing Warning Sign Beacon

Figure 5.4

CHAPTER 6
SIGNING AND PAVEMENT MARKINGS

6.0 GENERAL

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

- Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD is the obligatory guide for signing and pavement marking. It is published by Federal Highway Administration (FHWA) in conjunction with the Institute of Transportation Engineers (ITE), American Traffic Safety Services Association (ATSSA), and American Association of State Highway and Transportation Officials (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 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 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 the Department for work methods, materials, and basis of payment used in construction. The Standard Specifications are intended for general and repetitive use. They provide Department 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 Design Guidelines. These Guidelines establish uniform procedures for roadway design activities within the Department and provide guidance in the preparation of roadway plans and estimates.

6.1 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.

6.1.1 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" and "Guidance" categories. These categories are sometimes modified by the "Option" category. Where TDOT has elected to adopt the "Option" condition, the designer will be required to meet the "Option" criteria presented in the MUTCD. "Support" statements provide additional information on the topic and do not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. The designer should review the "Support" statements for a better understanding of when and where to use the traffic control device.

6.1.2 Application

Signs should be used only where justified by engineering judgment or studies, as provided in Section 1A.09 of the MUTCD. 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.[1]

6.1.3 Sign Layouts

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

6.1.4 Conventional Highways (Non-Access Controlled) Signs

6.1.4.1 Directional and Route Signing at Intersections

The following figures illustrate typical sign assemblies for directional assemblies and route signing at intersections:

1. Figure 6.1 — Intersection of Two Major Routes (4-Way Intersection)
2. Figure 6.2 — Intersection of Two Major Routes (3-Way Intersection)
3. Figure 6.3 — Intersection of Two Major Routes with Overlapping Route Numbers
4. Figure 6.4 — 4-Way Intersection Route Signing with Scenic (Bird) Route
5. Figure 6.5 — 3-Way Intersection Route Signing with Scenic (Bird) Route
6. Figure 6.6 — 3-Way Intersection Route Signing with Scenic (Bird) Route with Overlapping Route Numbers

[1] 2009 MUTCD, FHWA, Section 2A.03 "Standardization of Application"

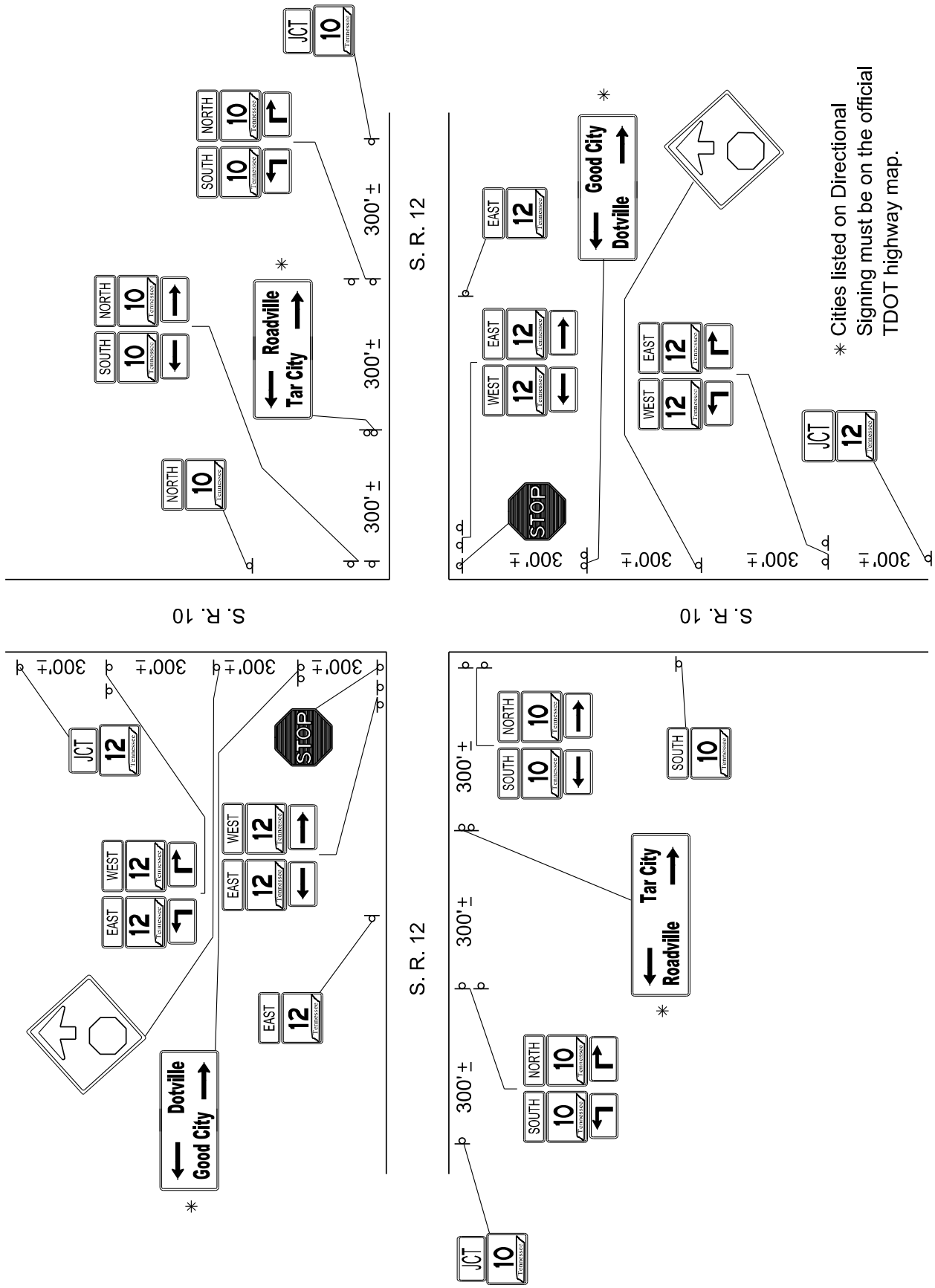


Figure 6.1 — Intersection of Two Major Routes (4-Way Intersections)

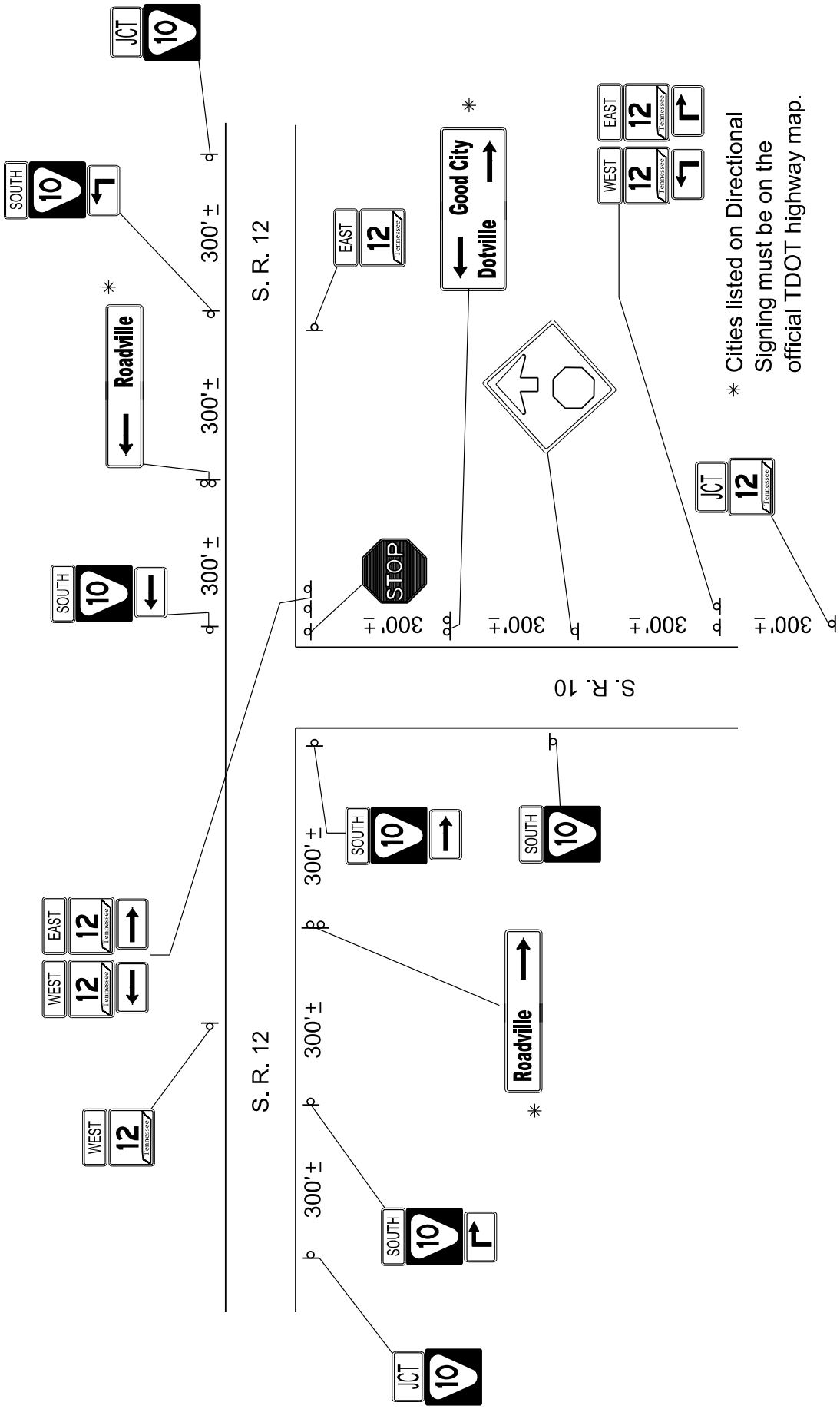
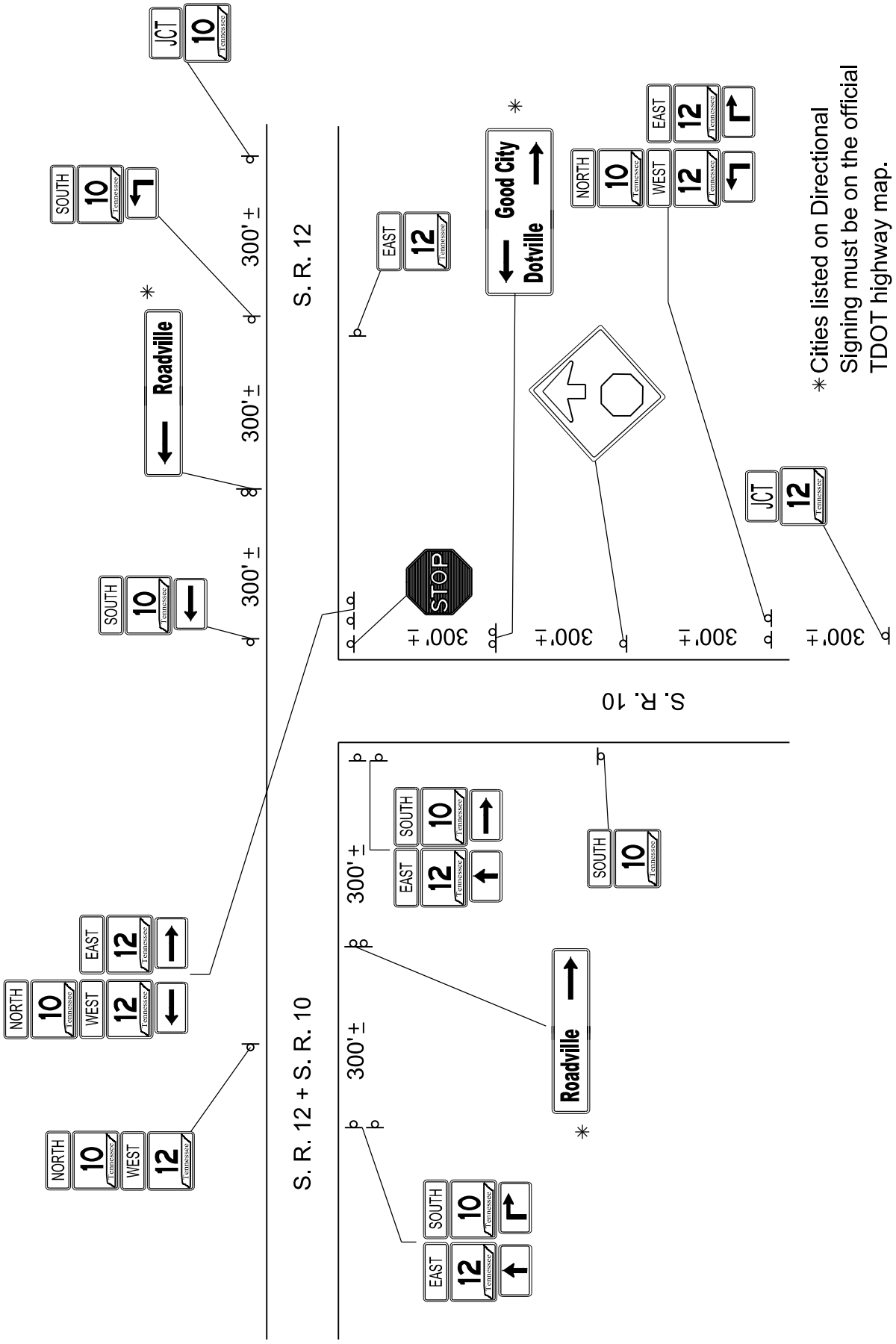


Figure 6.2 — Intersection of Two Major Routes (3-Way Intersections)



✳ Cities listed on Directional Signing must be on the official TDOT highway map.

Figure 6.3 — Intersection of Two Major Routes With Overlapping Route Numbers

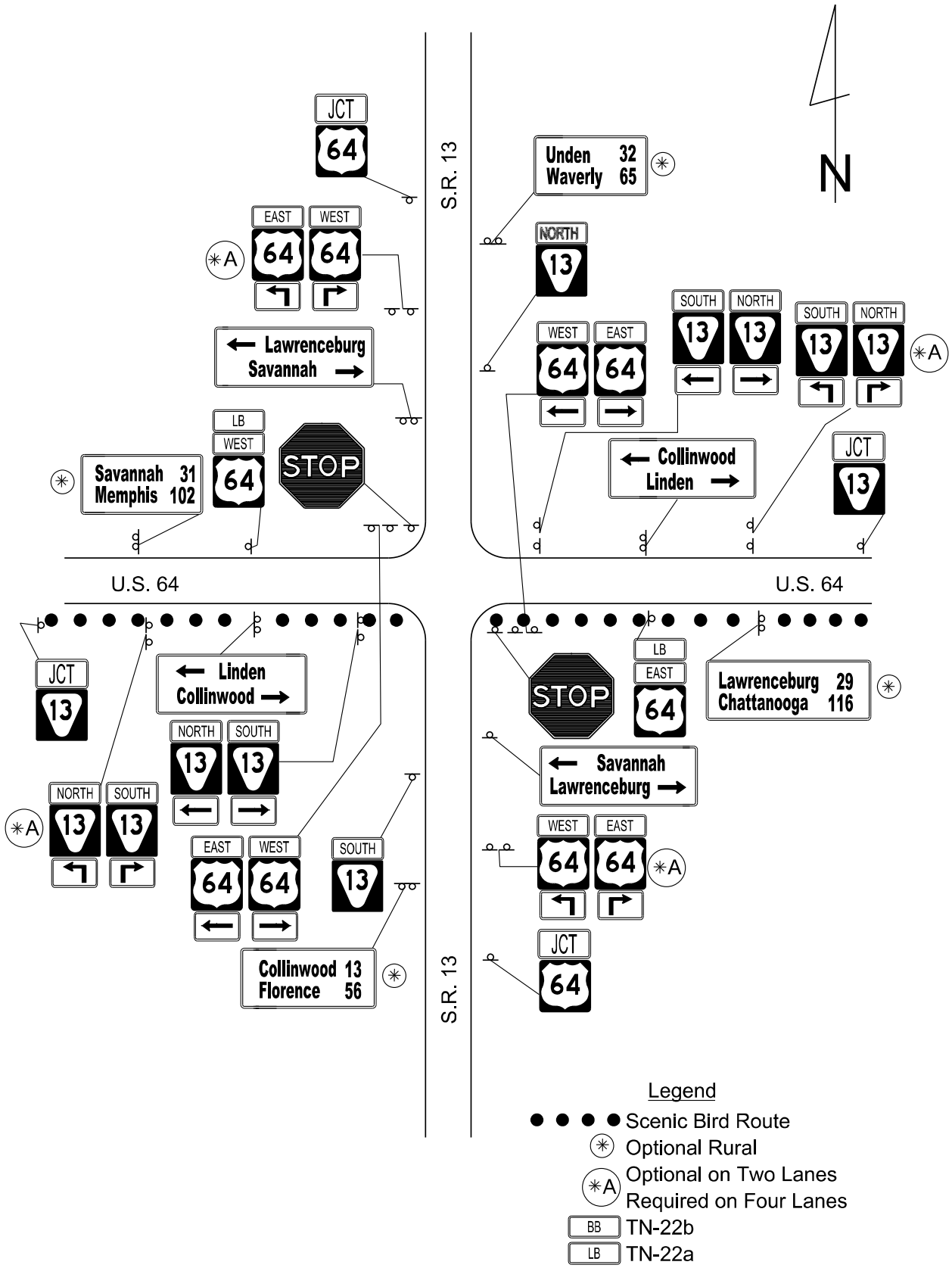


Figure 6.4 — 4-Way Intersection Route Signing With a Scenic (Bird) Route

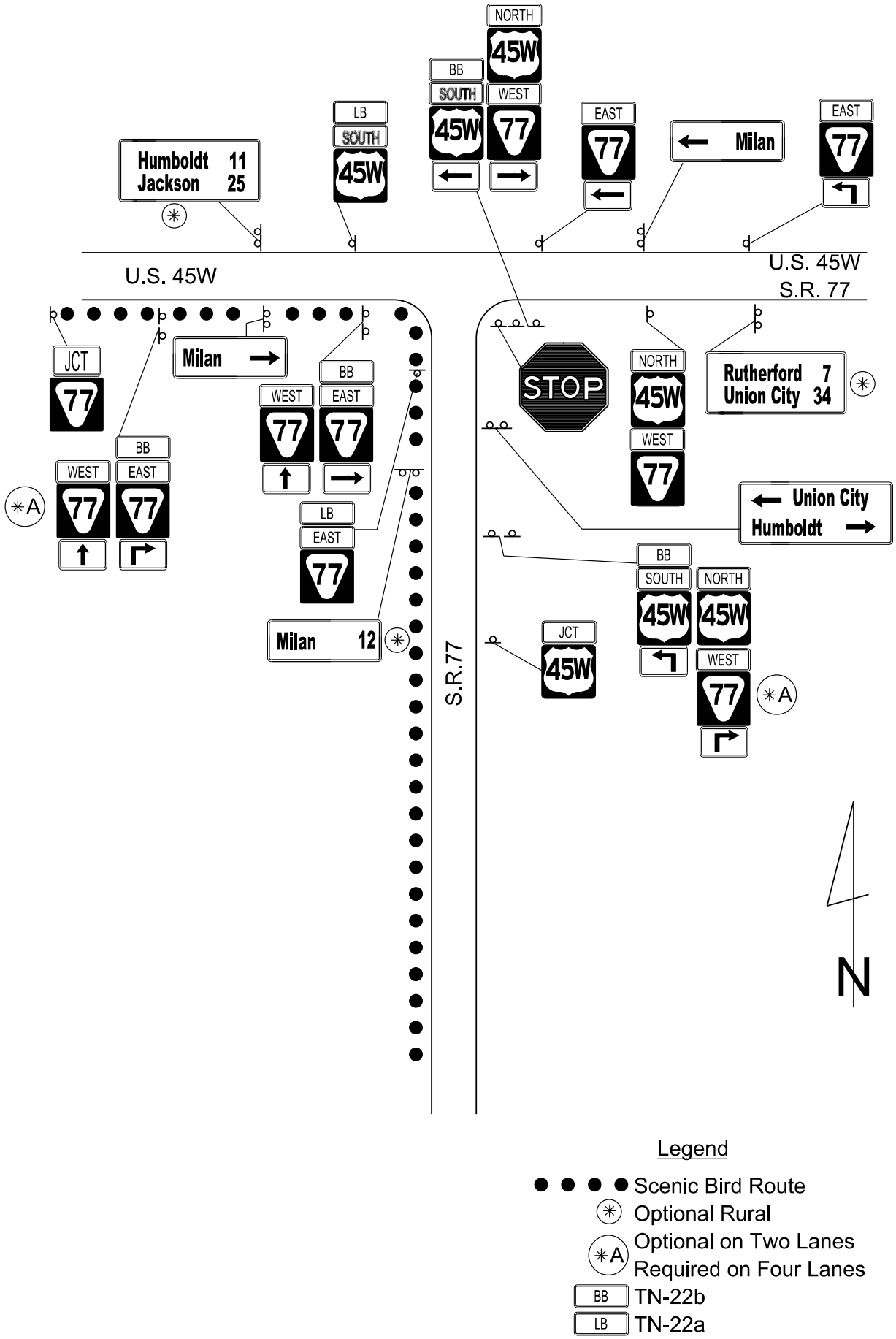


Figure 6.5 — 3-Way Intersection Route Signing With a Scenic (Bird) Route

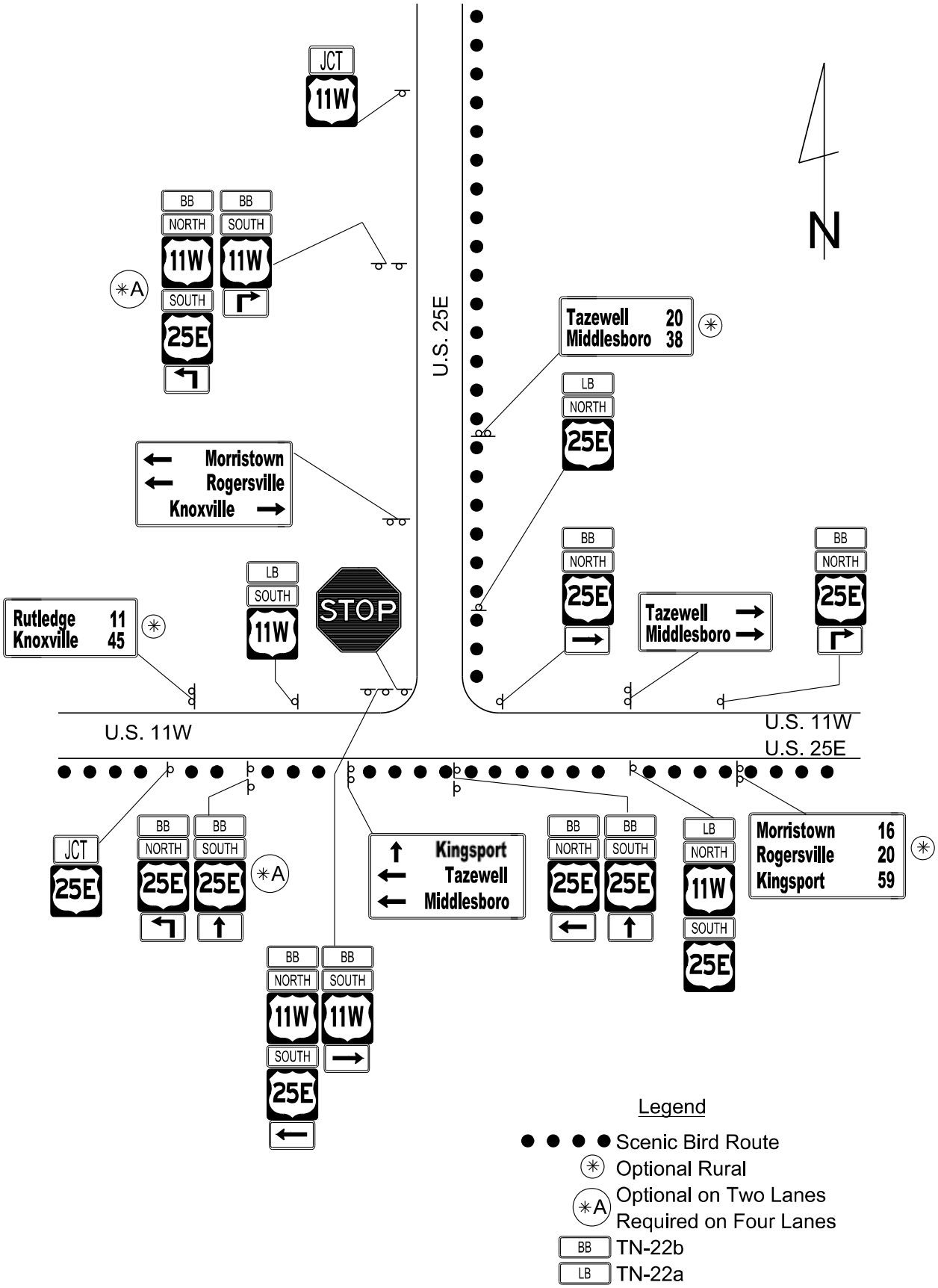


Figure 6.6 — 3-Way Intersection Route Signing With a Scenic (Bird) Route With Overlapping Route Numbers

6.1.4.2 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:

1. Figure 6.7 — Crossroad Signing, Medians less than 30 feet, One-Way and Wrong-Way Signing
2. Figure 6.8 — Signalized Intersection, Medians less than 30 feet, One-Way and Wrong-Way Signing
3. Figure 6.9 — “T” Intersection Right, Medians less than 30 feet, One-Way and Wrong-Way Signing
4. Figure 6.10 — “T” Intersection Left, Medians less than 30 feet, One-Way and Wrong-Way Signing
5. Figure 6.11 — Median Crossover, Medians less than 30 feet, One-Way and Wrong-Way Signing
6. Figure 6.12 — Crossroad Signing, Medians 30 feet or greater, One-Way and Wrong-Way Signing
7. Figure 6.13 — Signalized Intersection, Medians 30 feet or greater, One-Way and Wrong-Way Signing
8. Figure 6.14 — “T” Intersection Right, Medians 30 feet or greater, One-Way and Wrong-Way Signing
9. Figure 6.15 — “T” Intersection Left, Medians 30 feet or greater, One-Way and Wrong-Way Signing
10. Figure 6.16 — Median Crossover, Medians 30 feet or greater, One-Way and Wrong-Way Signing

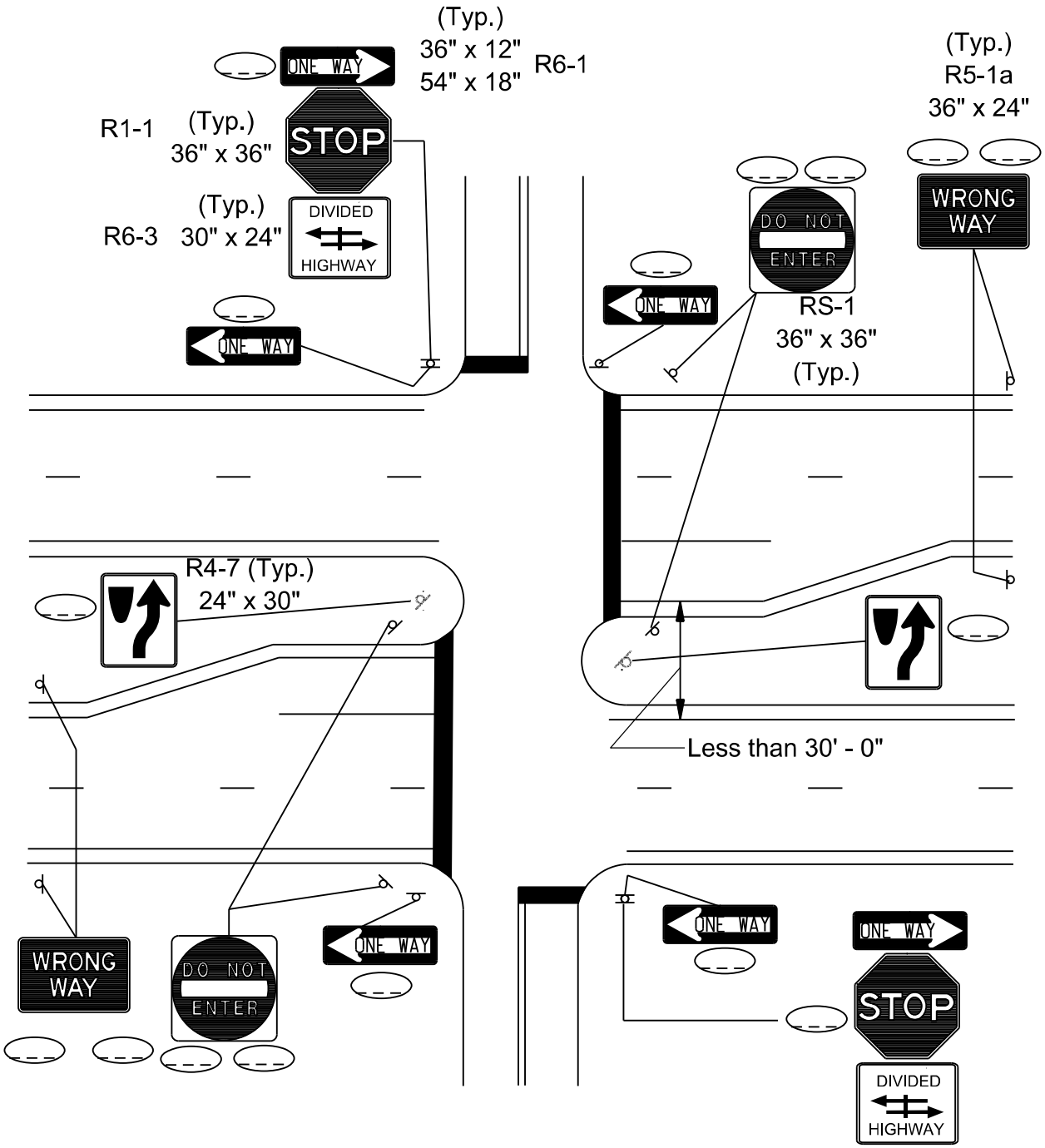


Figure 6.7 — Crossroad Signing, Medians Less Than 30 feet, One-Way and Wrong-Way Signing

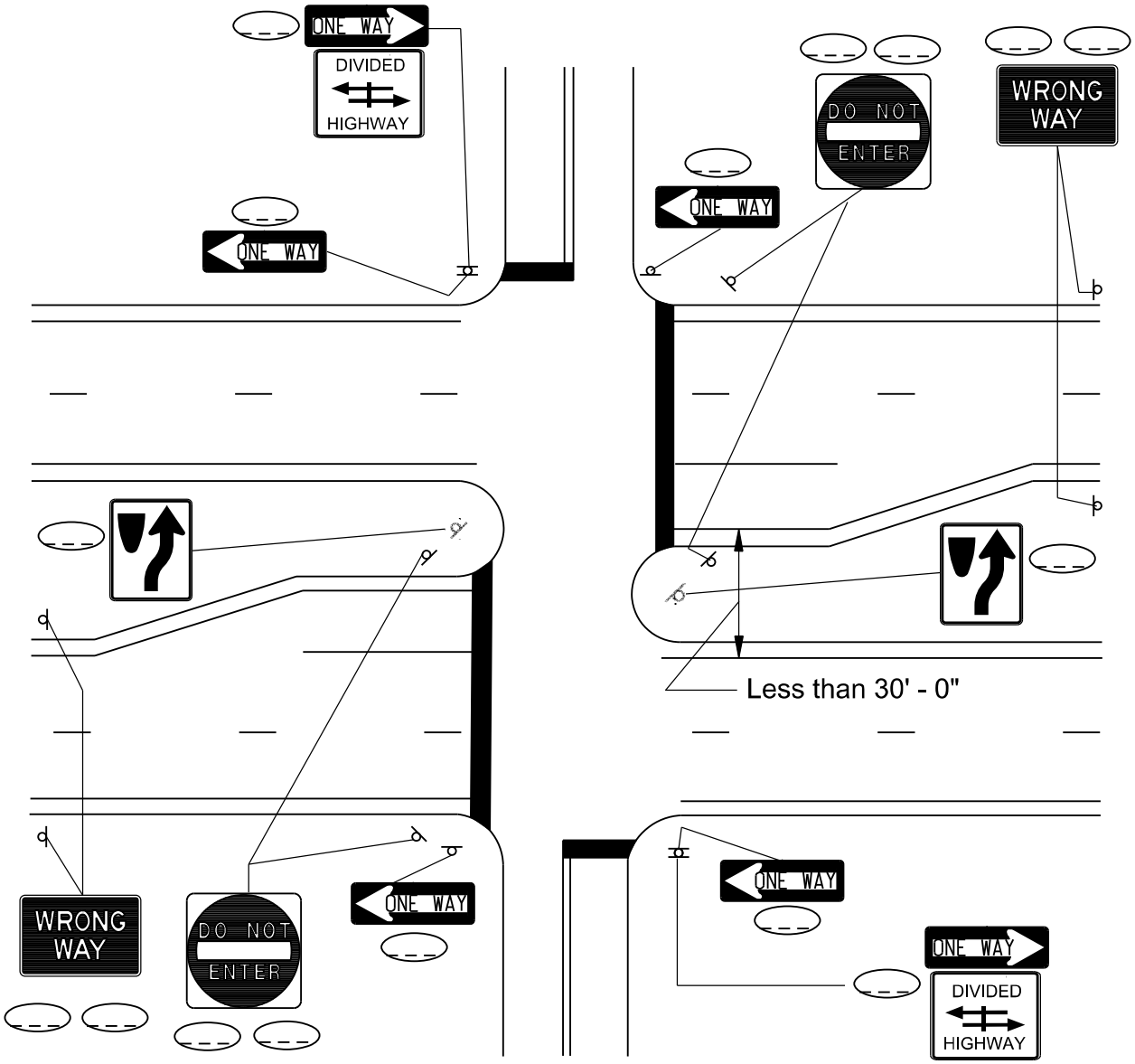


Figure 6.8 — Signalized Intersections, Medians Less Than 30 feet, One-Way and Wrong-Way Signing

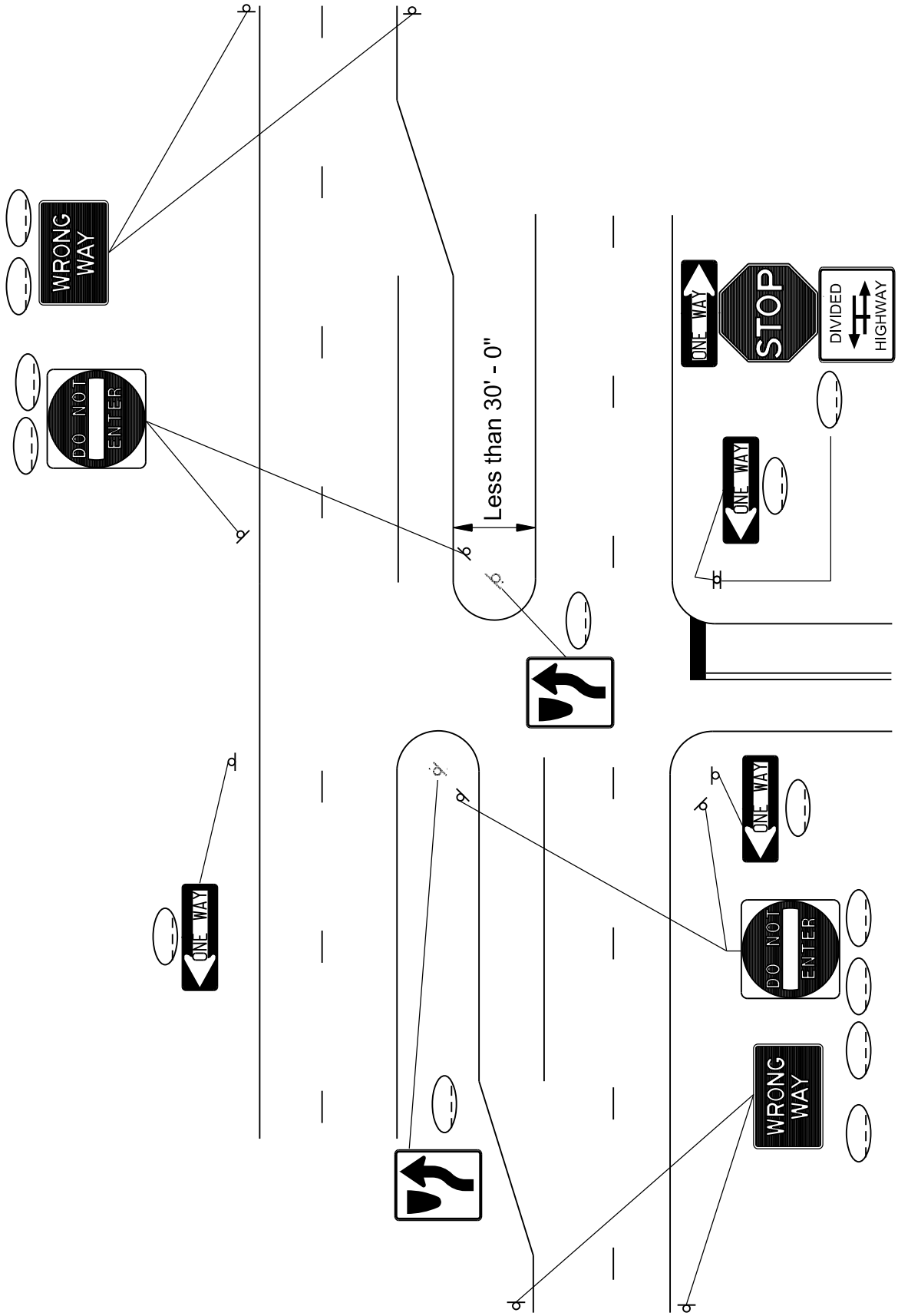


Figure 6.9 — "T" Intersection Right, Medians Less Than 30 feet, One-Way and Wrong-Way Signing

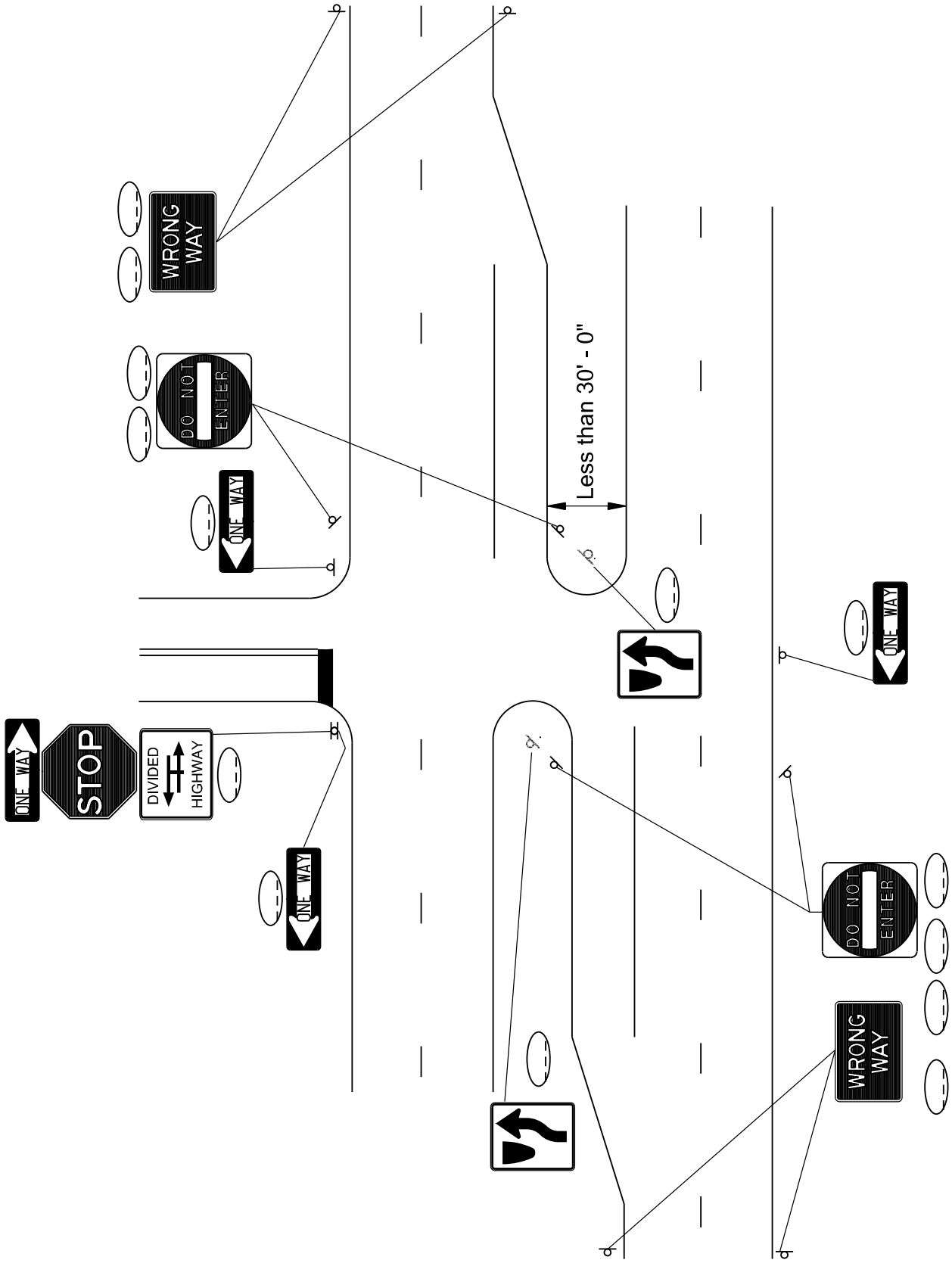


Figure 6.10 — "T" Intersection Left, Medians Less Than 30 feet, One-Way and Wrong-Way Signing

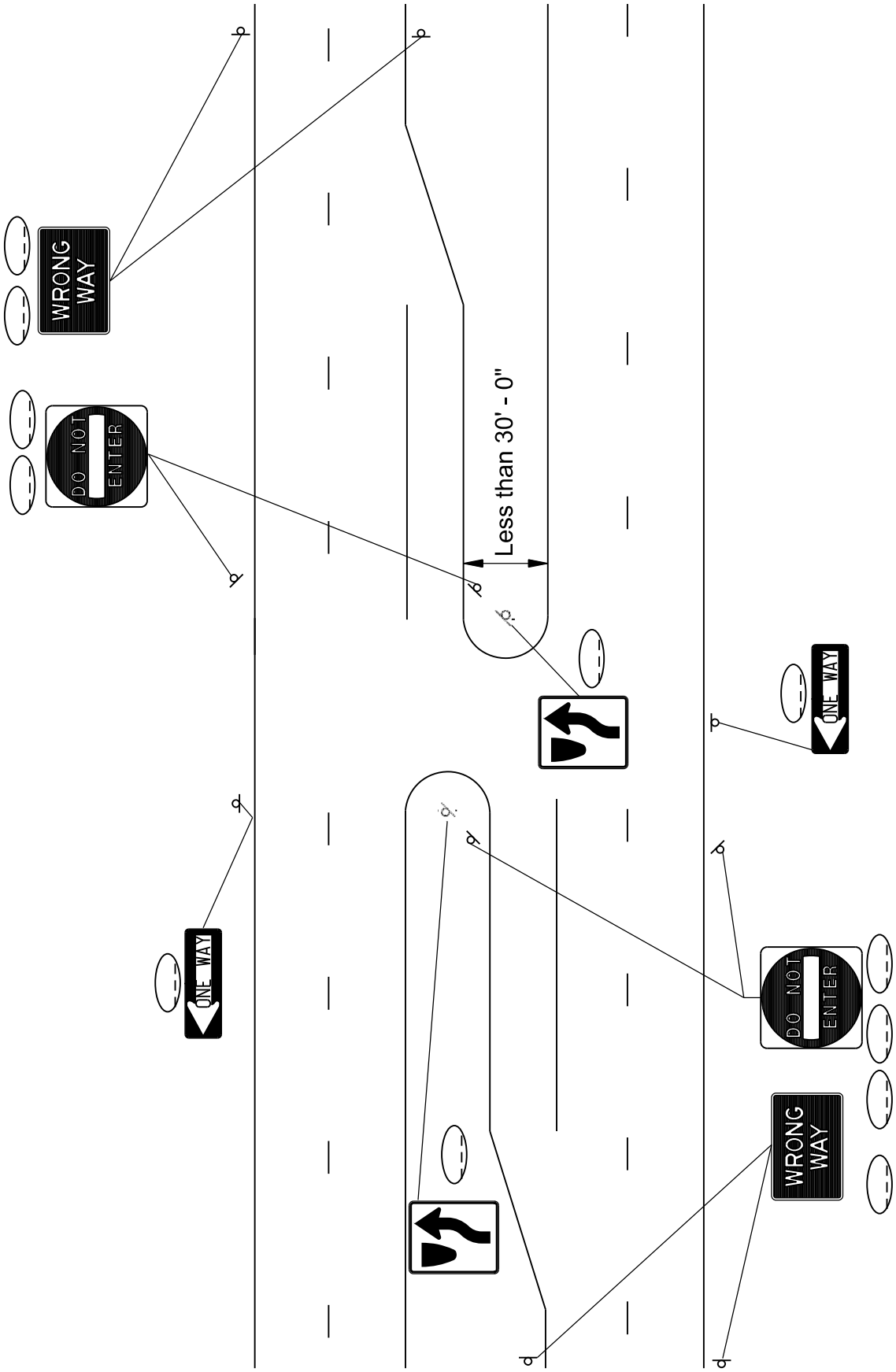


Figure 6.11 — Median Crossover, Medians Less Than 30 feet, One-Way and Wrong-Way Signing

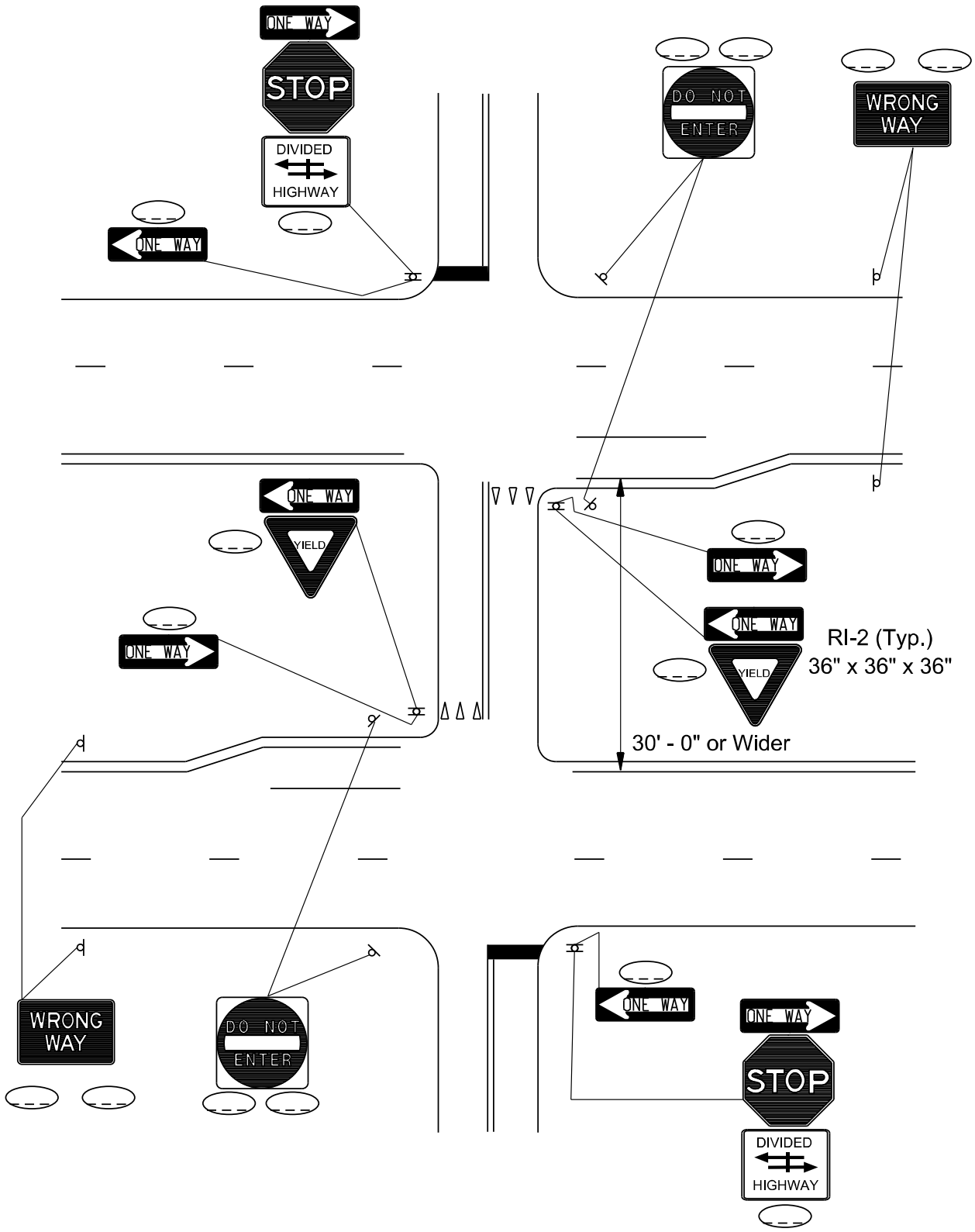


Figure 6.12 — Crossroad Signing, Medians 30 feet or Greater, One-Way and Wrong-Way Signing

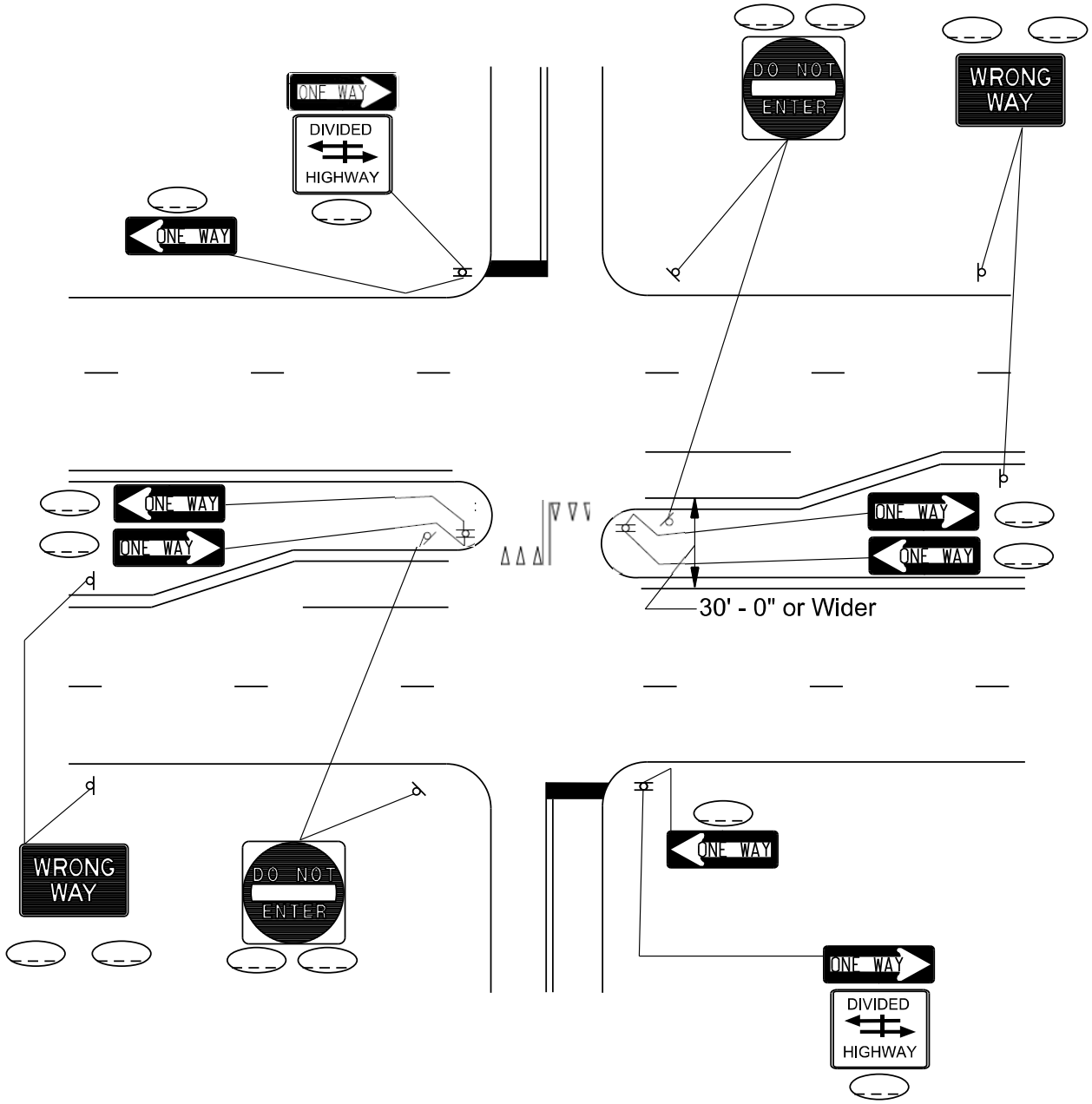


Figure 6.13 — Signalized Intersection, Medians 30 feet or Greater, One-Way and Wrong-Way Signing

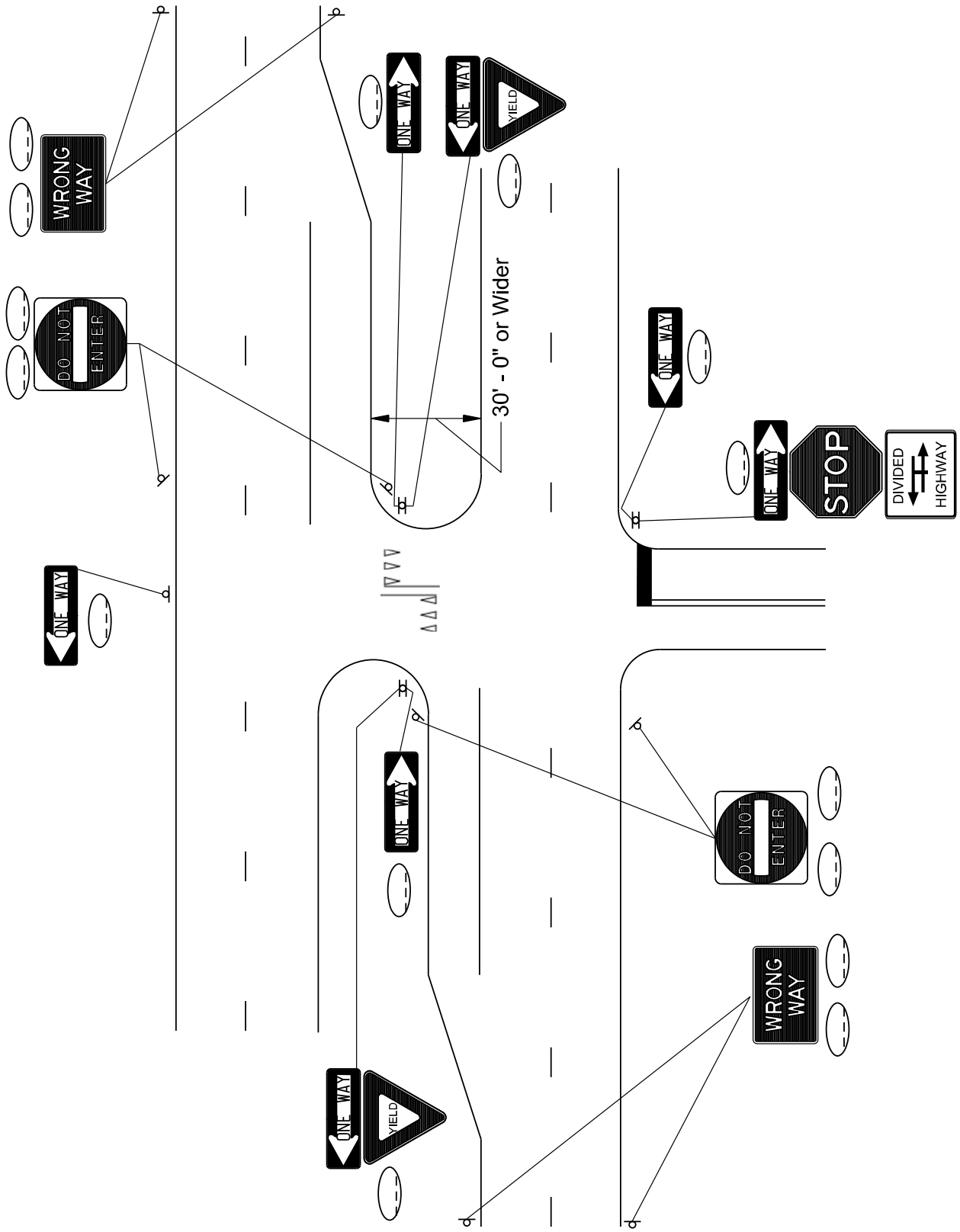


Figure 6.14 — "T" Intersection Right, Medians 30 feet or Greater, One-Way and Wrong-Way Signing

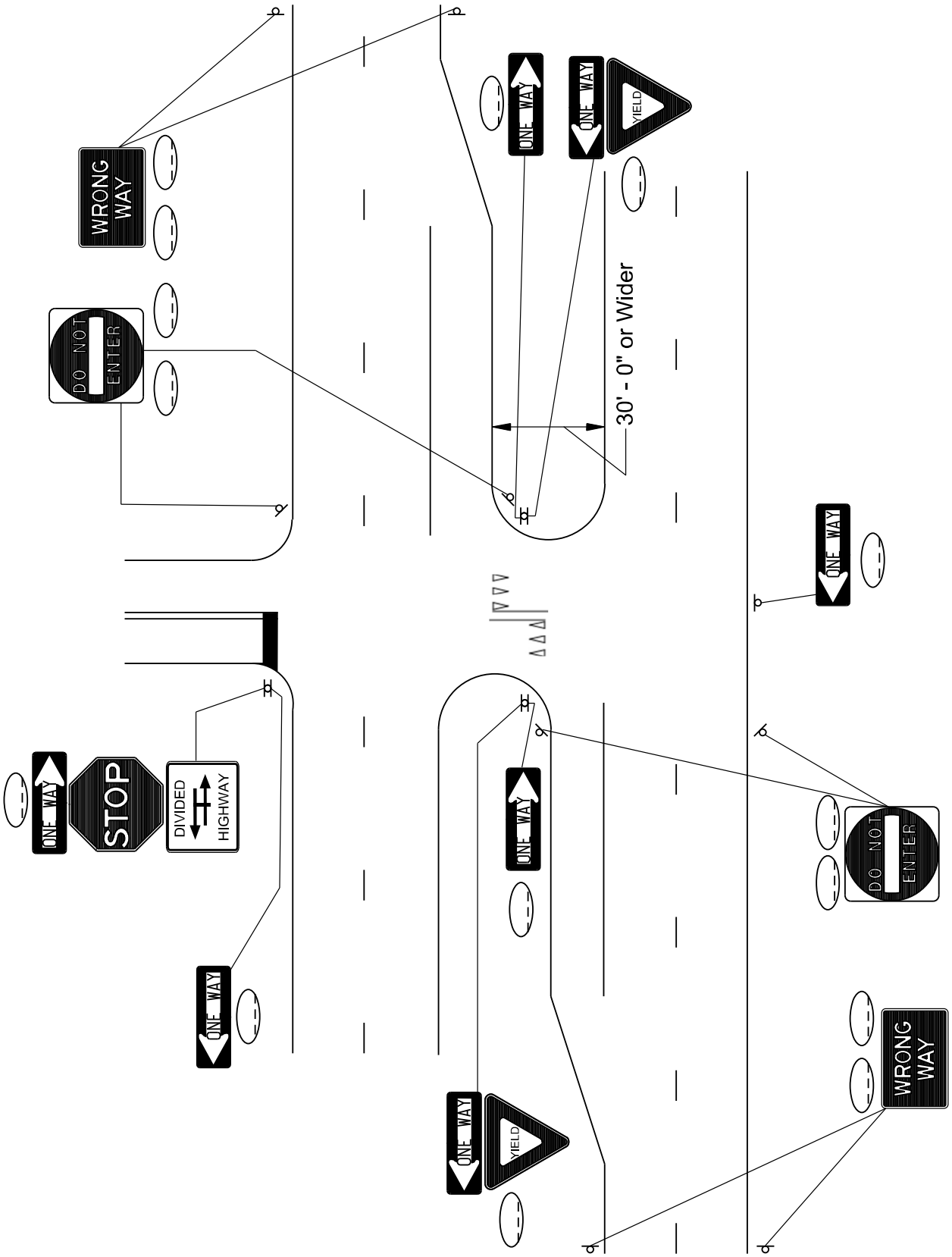


Figure 6.15 — "T" Intersection Left, Medians 30 feet or Greater, One-Way and Wrong-Way Signing

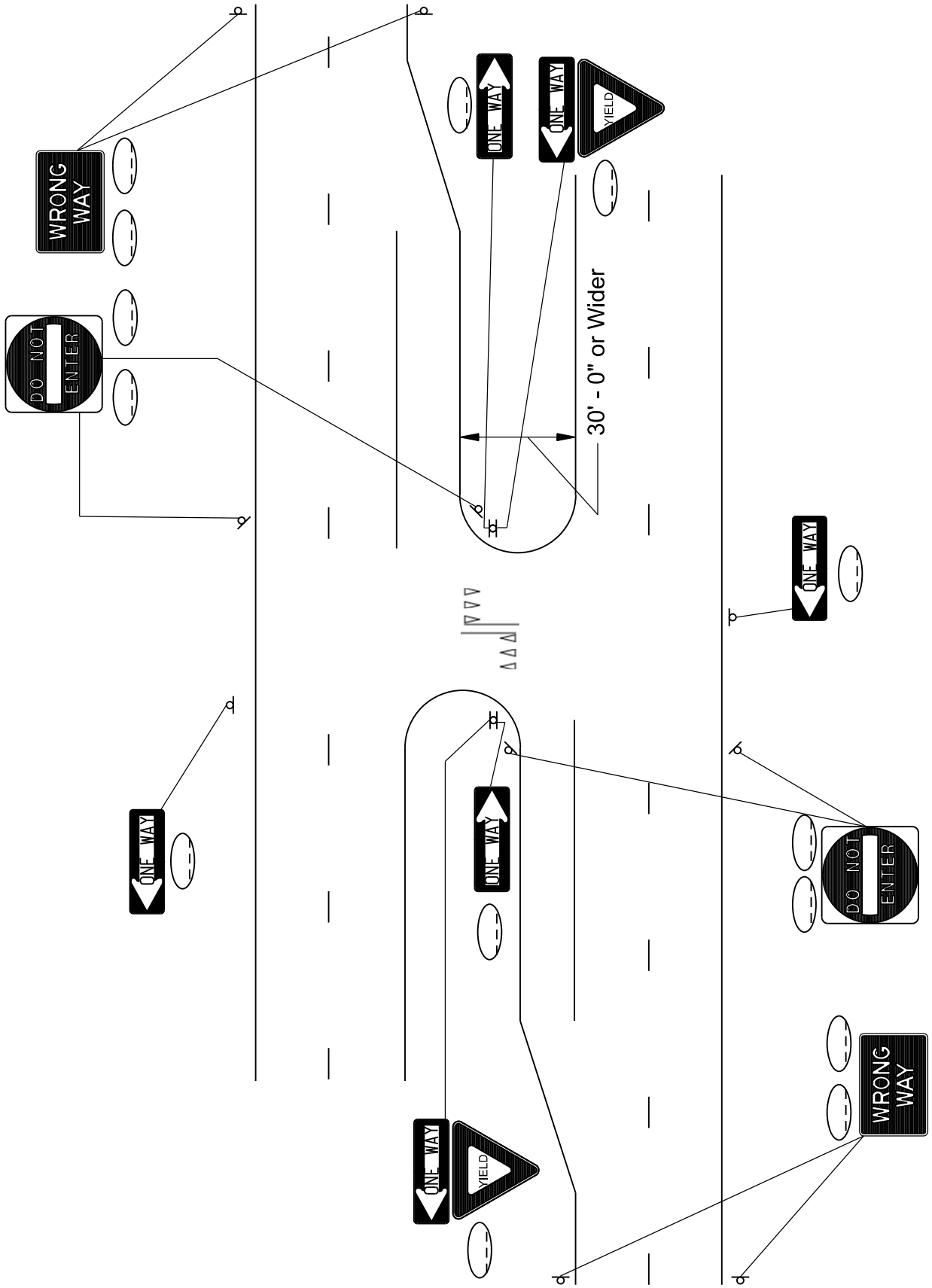


Figure 6.16 — Median Crossover, Medians 30 feet or Greater, One-Way and Wrong-Way Signing

6.1.4.3 Roadside Sign Supports

For roadside signs on two-lane, four-lane, and five-lane, non-access controlled, conventional highways, U-posts and P-posts sign supports are most commonly used. Table 6.1 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 6.17 illustrates how to estimate the length of the sign supports for rural and urban roadside signs. Note the support lengths shown in Table 6.1 do not include the stub length in the ground. For P-posts, add 3 feet for the stub. For U-Posts, add 3.5 feet for the stub. For guidance on larger sign supports, including breakaway supports, see Section 6.1.5.3.

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 6.2 provides the nominal weight per foot for the U-post and P-posts supports used by TDOT.

6.1.4.4 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 6.18 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 Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.

Table 6.1 — Post Selection for Various Sign Assemblies

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
1 21"X15" 24"X24"	9'-11' P2 12'-13' P3/P8	9'-10' U3 11'-13' U6	9'-10' MU3 11'-12' MU5 13' Not Applicable	9'-13' R2	9'-11' A1 12'-13' A2
2 21"X15" 30"X24"	9'-10' P2 11'-13' P3/P8	9'-12' U6 13' Not Applicable	9'-11' MU5 12' Not Applicable	9'-13' R2	9'-13' A2
3 21"X15" 24"X24" 24"X24"	11' P3/P8 12'-15' P5	Not Applicable	Not Applicable	Not Applicable	11'-12' A2 13' Not Applicable
4 21"X15" 30"X24" 24"X24"	11' P3/P8 12'-15' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
5 21"X15" 30"X24" 30"X24"	11' P3/P8 12'-15' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
6 24"X12" 24"X24"	9'-11' P2 12'-13' P3/P8	9'-10' U3 11'-13' U6	9'-10' MU3 11'-12' MU5	9'-13' R2	9'-11' A1 12'-13' A2

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
7 24"X12" 30"X24"	9'-11' P2 12'-13' P3/P8	9'-12' U6 13' Not Applicable	9'-11' MU5 12' Not Applicable	9'-13' R2	9'-13' A2
8 24"X12" 24"X24" 24"X24"	11' P3/P8 12'-15' P5	Not Applicable	Not Applicable	Not Applicable	11'-12' A2 13' Not Applicable
9 24"X12" 24"X24" 30"X24"	11'-15' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
10 24"X12" 30"X24" 30"X24"	11'-15' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
11 24"X12" 24"X24" 24"X12" 24"X24"	12'-15' P5 16' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
12 24"X12" 24"X24" 24"X12" 30"X24"	12'-14' P5 15'-16' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable
13 24"X12" 24"X24" 24"X12" 30"X24"	12'-14' P5 15'-16' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable
14 24"X12" 24"X24" 21"X15"	10'-12' P3/P8 13'-14' P5	10'-11' U6 12' Not Applicable	10'-11' MU5 12' Not Applicable	10'-12' R2 13' Not Applicable	10'-14' A2
15 24"X12" 30"X24" 21"X15"	10'-12' P3/P8 13'-14' P5	Not Applicable	Not Applicable	10'-11' R2 12' Not Applicable	10'-13' A2 14' Not Applicable

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
16 24"X12" 24"X24" 24"X24" 21"X15"	12'-15' P5 16' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable
17 24"X12" 24"X24" 30"X24" 21"X15"	12'-13' P5 14'-16' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable
18 24"X12" 30"X24" 30"X24" 21"X15"	12'-13' P5 14'-16' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable
19 24"X12" 24"X24" 24"X12" 24"X24" 21"X15"	13'-14' P5 15'-17' P6	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
20 24"X12" 24"X24" 24"X12" 30"X24" 21"X15"	13'-14' P5 15'-16' P6 17' Not Applicable	Not Applicable	Not Applicable	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	Not Applicable	Not Applicable	Not Applicable
22 24"X12" 24"X24" 24"X24" 24"X12" 24"X24" 21"X15"	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
23 24"X12" 30"X24" 24"X24" 24"X12" 24"X24" 21"X15"	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
24 24"X12" 30"X24" 24"X24" 24"X12" 30"X24" 21"X15"	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
25 24"X12" 24"X12" 24"X24"	10'-13' P3/P8 14' P5	10'-11' U6 12' Not Applicable	10'-11' MU5 12' Not Applicable	10'-13' R2 14' Not Applicable	10'-14' A2
26 24"X12" 24"X12" 30"X24"	10'-12' P3/P8 13'-14' P5	10' U6 11' Not Applicable	10' MU5 11' Not Applicable	10'-11' R2 12' Not Applicable	10'-13' A2 14' Not Applicable

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
27 24"X12" 24"X12" 24"X24" 21"X15"	11' P3/P8 12'-15' P5	Not Applicable	Not Applicable	Not Applicable	11'-13' A2
28 24"X12" 24"X12" 30"X24" 21"X15"	11'-15' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
29 30"X30"	8' P1 9'-12' P2	8' U1 9'-11' U3 12' U6	8' MU1 9'-11' MU3 12' MU5	8' R1 9'-12' R2	8'-12' A1
30 36"X36"X36" 30"	8'-11' P1 12' P2	8'-9' U1 10'-12' U3	8'-9' MU1 10'-12' MU3	8'-9' R1 10'-12' R2	8'-12' A1
31 18"X18"	7'-11' P1	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
32 24"X24"	7'-10' P1 11' P2	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
33 24"X30"	8'-9' P1 10'-12' P2	8' U1 9'-12' U3	8' MU1 9'-12' MU3	8'-9' R1 10'-12' R2	8'-12' A1

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
34 24"X48"	9' P2 10'-12' P3/P8 13' P5	9'-11' U6 12' Not Applicable	9'-11' MU5 12' Not Applicable	9'-12' R2 13' Not Applicable	9'-13' A1
35 30"X30"	8'-11' P2 12' P3/P8	8' U3 9'-12' U6	8' MU3 9'-12' MU5	9'-12' R2	8' A1 9'-12' A2
36 36"X12"	6'-10' P1	6'-10' U1	6'-10' MU1	6'-10' R1	6'-10' A1
37 36"X24"	7' P1 8'-11' P2	7' U3 8'-11' U6	7' MU3 8'-11' MU5	7'-11' R2	7'-11' A2
38 36"X48" 2-Post	9'-12' P2 13' P3/P8	9'-10' U1 11'-12' U3 13' U6	9'-10' MU1 11'-12' MU3 13' MU5	9'-10' R1 11'-13' R2	9'-13' A1
39 36"X72" 2-Post	11'-14' P3/P8 15' P5	11'-13' U6 14' Not Applicable	11'-12' MU5 13' Not Applicable	11'-14' R2 15' Not Applicable	11'-12' A1 13'-15' A2
40 48"X24" 2-Post	7'-10' P1 11' P2	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
41 24"X24" 24"X18"	9'-10' P2 11'-13' P3/P8	9'-12' U6 13' Not Applicable	9'-12' MU5 13' Not Applicable	9'-13' R2	9' A1 10'-13' A2

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
42 24"X24" 24"X6" 24"X6"	9'-11' P2 12'-13' P3/P8	9'-10' U3 11'-13' U6	9'-10' MU3 11'-13' MU5	9'-13' R2	9'-11' A1 12'-13' A2
43 24"X8" 24"X30" 24"X10"	10'-13' P3/P8 14' P5	10'-11' U6 12' Not Applicable	10'-11' MU5 12' Not Applicable	10'-12' R2 13' Not Applicable	10'-14' A2
44 30"X30" 21.21"	9'-11' P2 12'-13' P3/P8	9'-11' U6 12' Not Applicable	9'-11' MU5 12' Not Applicable	9'-13' R2	9'-13' A2
45 30"X30" 24"X18"	11' P3/P8 12'-15' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
46 36"X36" 25.46"	10'-11' P3/P8 12'-14' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
47 36"X36" 24"X18"	10'-11' P3/P8 12'-14' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
48 36"D	8'-10' P2 11'-12' P3/P8	8'-11' U6 12' Not Applicable	8'-11' MU5 12' Not Applicable	8'-12' R2	8'-12' A2
49 36"X12" 36"X36"	9' P8 10'-13' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable
50 48"X18" 2-Post	7'-11' P1	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
51 60"X18" 2-Post	7'-10' P1 11' P2	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
52 72"X18" 2-Post	7'-9' P1 10'-11' P2	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
53 84"X18" 3-Post	7'-11' P1	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1
54 96"X18" 3-Post	7'-10' P1 11' P2	7'-11' U1	7'-11' MU1	7'-11' R1	7'-11' A1

Note: Post lengths shown in table do not include the stub length.

Table 6.1 — Post Selection for Various Sign Assemblies *(Continued)*

Sign Face	Perforated Tube	U-Post (Franklin)	U-Post (Missouri)	Ribbed U-Post	Aluminum U-Post
55 48"X30" 2-Post	8'-9' P1 10'-12' P2	8'-11' U1 12' U3	8'-11' MU1 12' MU3	8'-11' R1 12' R2	8'-12' A1
56 60"X30" 2-Post	8'-10' P2 11'-12' P3/P8	8'-9' U1 10'-11' U3 12' U6	8'-9' MU1 10' MU3 11'-12' MU5	8'-9' R1 10'-12' R2	8'-12' A1
57 72"X30" 2-Post	8'-9' P2 10'-12' P3/P8	8' U1 9' U3 10'-12' U6	8' MU1 9' MU3 10'-12' MU5	8' R1 9'-12' R2	8'-12' A1
58 84"X30" 3-Post	8'-11' P2 12' P3/P8	8'-9' U1 10'-11' U3 12' U6	8'-9' MU1 10'-11' MU3 12' MU5	8'-10' R1 11'-12' R2	8'-12' A1
59 96"X30" 3-Post	8'-9' P2 10'-12' P3/P8	8' U1 9'-10' U3 11'-12' U6	8' MU1 9'-10' MU3 11'-12' MU5	8'-9' R1 10'-12' R2	8'-12' A1
60 36"X36"	10'-11' P3/P8 12'-14' P5	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: Post lengths shown in table do not include the stub length.

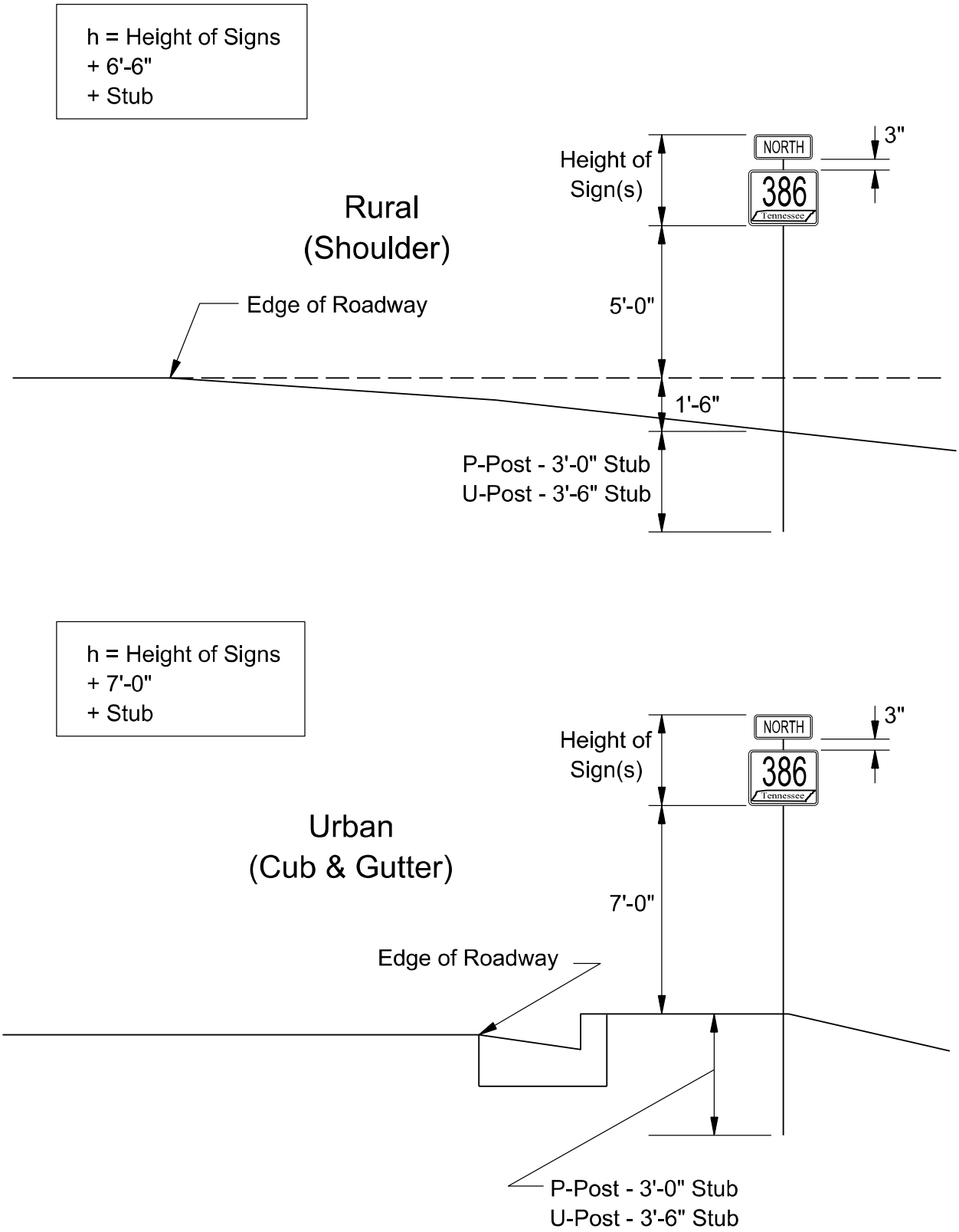


Figure 6.17 — Estimating Length of Support

Table 6.2 — 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/FT)**
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			

(1) 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.
(2) Add the length of stub (3.5 feet) to the post length as determined from Figure 6.17 and multiply the total length by the unit weight shown in the table.

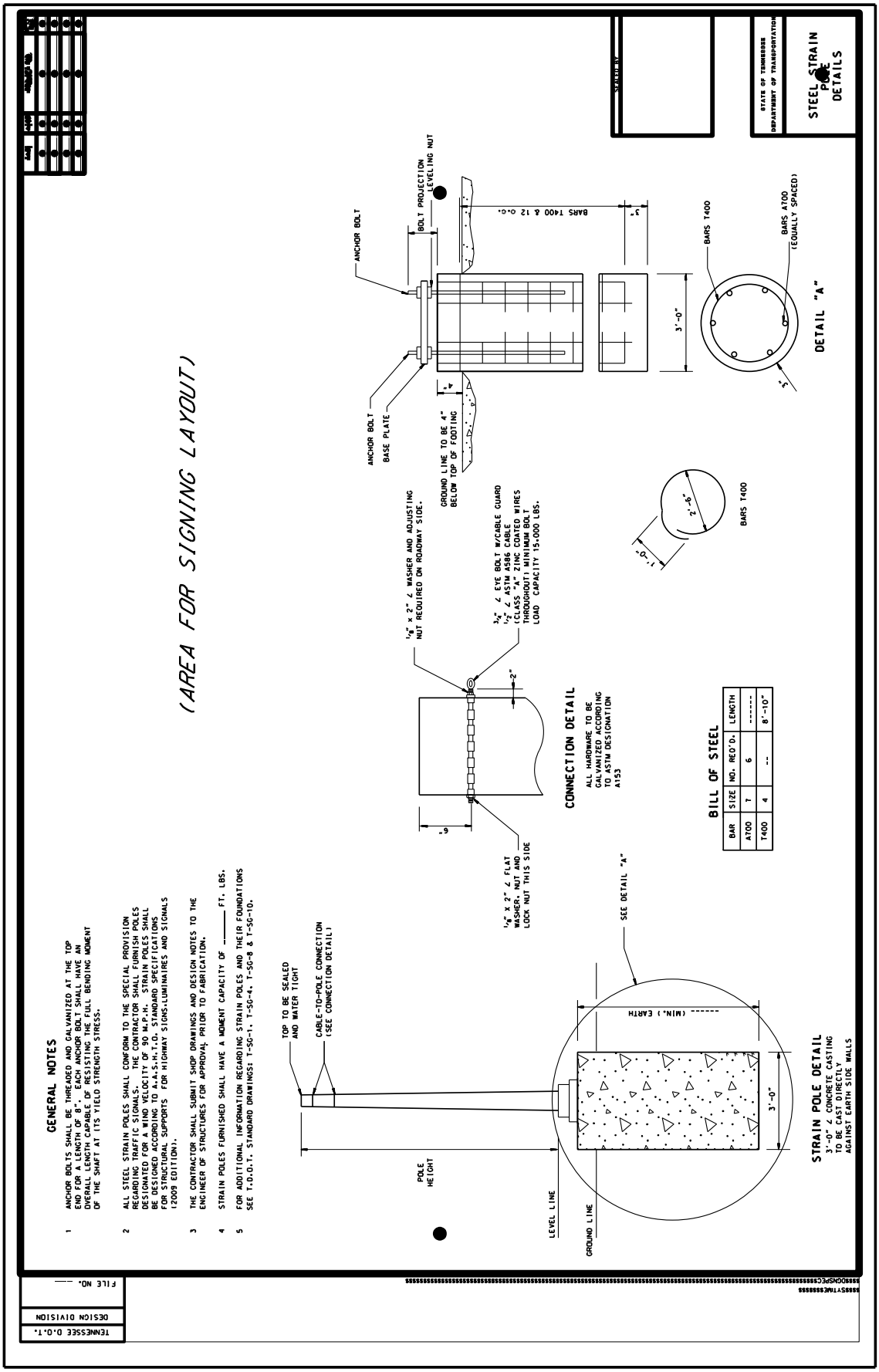


Figure 6.18 — Strain Pole Foundation and Cable Connection Details

6.1.5 Freeway and Expressway (Access Controlled) Signs

6.1.5.1 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, also include 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 Structure Division to obtain the ID number.);
- in the sign design data, the design area of the sign, the minimum wind velocity, and applicable soil data parameters, see Standard Drawing STD-8-4 for guidance; and
- other details notes to the Contractor.

Figure 6.19 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.

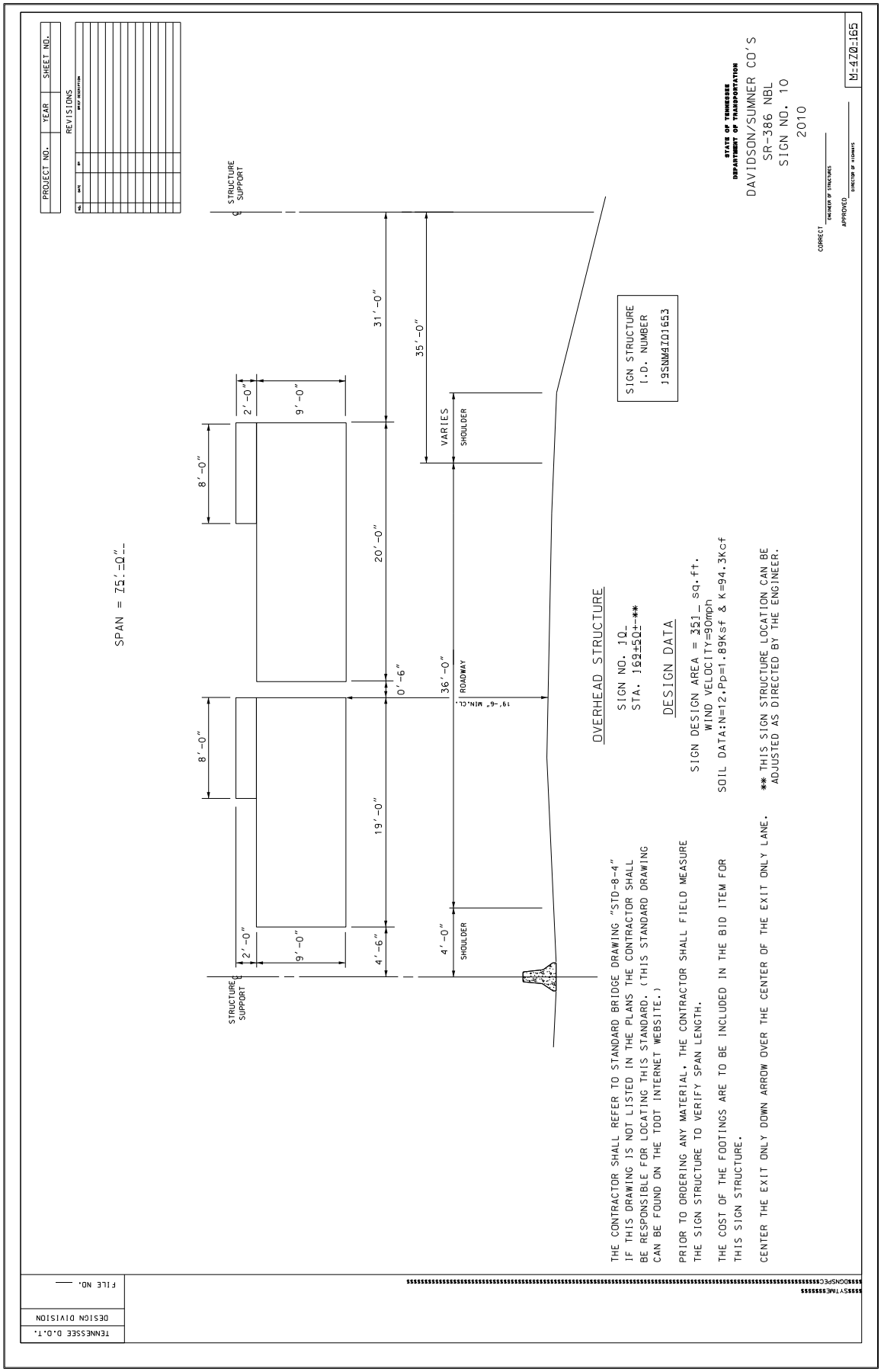


Figure 6.19 — Example of Overhead Sign Detail Sheet

6.1.5.2 Structural Support Foundations

If a sign is mounted on a concrete median barrier (CMB), the designer is responsible for ensuring the applicable Standard Drawings are noted in the contract plans.

6.1.5.3 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,
- S3x5.7 to S7x15.3 steel posts, and
- W6x15 to W10x30 I-beam steel posts.

Table 6.3 provides guidance on the selection of the appropriate post types for typical sign assemblies assuming a 90-mph wind speed.

Table 6.3 — Support Selection for Access-Control Roadside Signs

(Table 6.3 to be prepared at a later date.)

6.1.6 Sign Vertical Clearances[2]

Sign vertical clearances are as follows:

1. Rural. The minimum height, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement, of signs installed at the side of the road in rural areas shall be 5 feet (see Figure 6.20). The height to the bottom of a secondary sign mounted below another sign may be 1 foot less.

2. Urban. The minimum height, measured vertically from the bottom of the sign to the top of the curb, or in the absence of curb, measured vertically from the bottom of the sign to the elevation of the near edge of the traveled way, 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 7 feet (see Figure 6-20).

   The height to the bottom of a secondary sign mounted below another sign may be 1 foot less than the height specified above.

   The minimum height, measured vertically from the bottom of the sign to the sidewalk, of signs installed above sidewalks shall be 7 feet.

   If the bottom of a secondary sign that is mounted below another sign is mounted lower than 7 feet above a pedestrian sidewalk or pathway, the

[2] 2009 MUTCD, FHWA, Section 2A.18 "Mounting Height"

secondary sign shall not project more than 4 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 5 feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement.

3. Freeways and Expressways. Directional signs on freeways and expressways shall be installed with a minimum height of 7 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 7 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 8 feet and the secondary sign shall be installed with a minimum height of 5 feet, measured vertically from the bottom of the sign to the elevation of the near edge of the pavement.

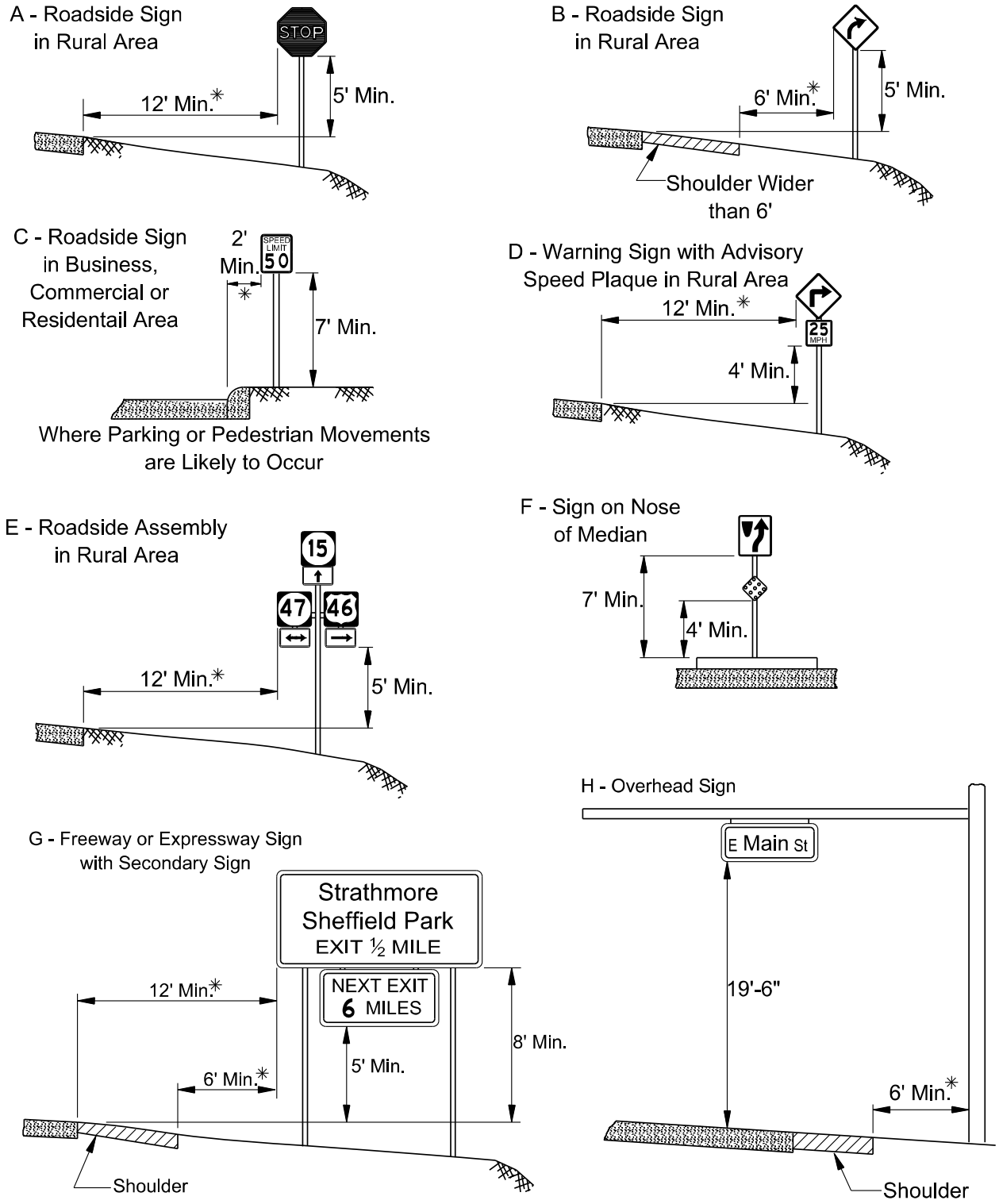
   Where large signs having an area exceeding 50 square feet are installed on multiple breakaway posts, the clearance from the ground to the bottom of the sign shall be at least 7 feet.

4. 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.

5. 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.

6. Overhead Signs/Structures. Overhead signs shall provide a vertical clearance of not less than 19 feet 6 inches 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.



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

Figure 6.20 — Sign Vertical Clearances

6.1.7 Traffic Signal Signs

The following guidance is provided for traffic control signs at or in advance of signalized intersections. Figure 6.21 illustrates some of the traffic signs associated with traffic signals.

6.1.7.1 Span Wire/Mast Arm Mounted

Where overhead signs are provided, the minimum vertical clearance over the entire roadway is 19 feet 6 inches.

6.1.7.1.1 *LEFT TURN SIGNAL Signs (R10-10, R10-12)*

1. LEFT TURN SIGNAL Sign (R10-10). This sign is normally installed with 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.

2. 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).

6.1.7.1.2 *Shared Lanes*

Where two or more movements from a specific lane and where a one of the movement is not normally expected, install an Optional Movement Lane Control Sign (R3-6).

6.1.7.1.3 *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 2009 MUTCD for guidance on post mounted lane use control signs.

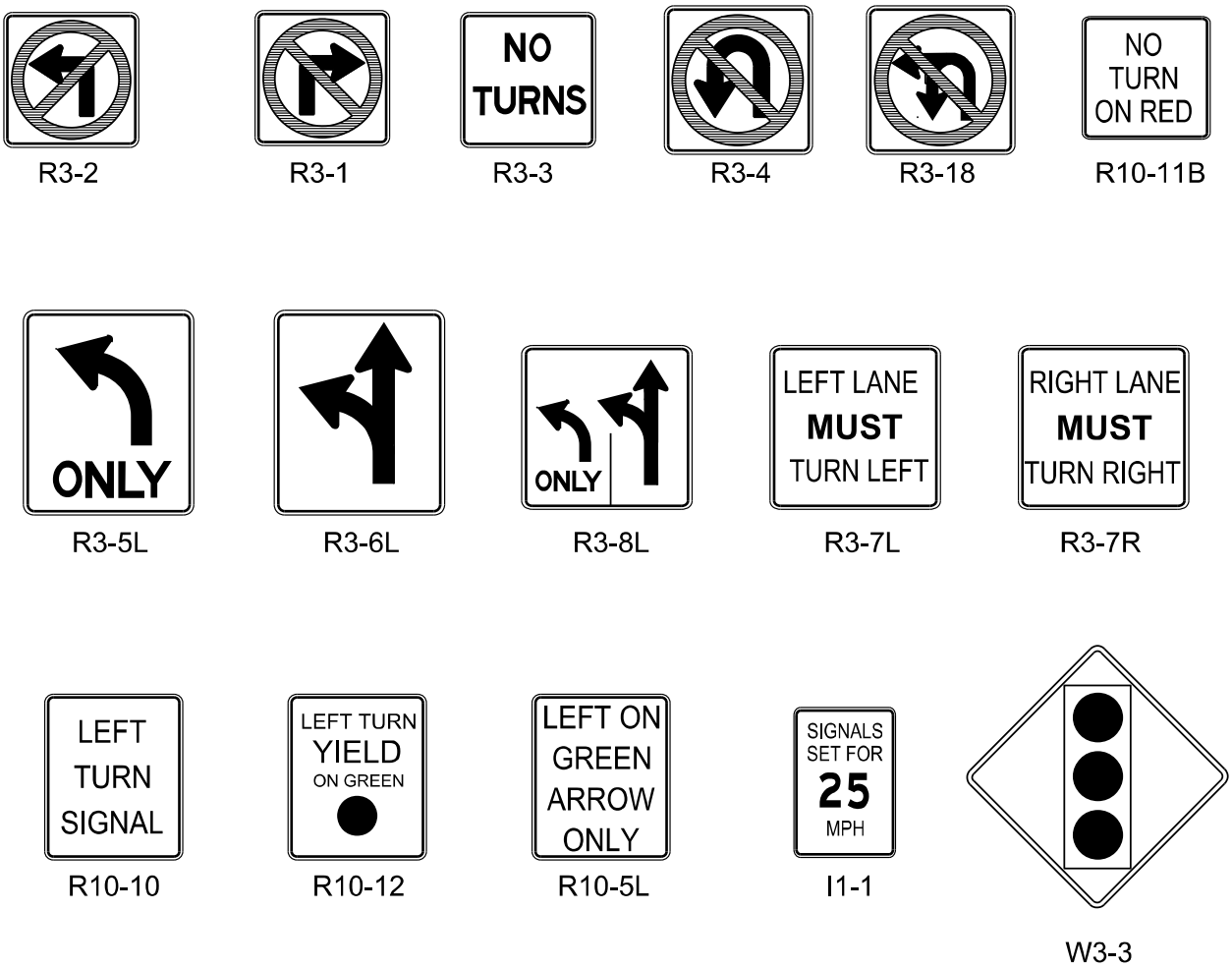


Figure 6.21 — Typical Signal Related Signs

6.1.7.1.4 *Turn Prohibition Signs (Signs R3-1, R3-2, R3-3, R3-4)*

In general, where turns are prohibited, install the appropriate turn prohibitions signs (R3-1 through R3-4), unless one-way signs are used.

1. The NO RIGHT TURN sign (R3-1) may be installed adjacent to the signal face for the right lane.

2. 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.

3. 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.

4. Where ONE WAY signs are used, turn prohibition signs may be omitted.

6.1.7.1.5 *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. Use this sign if a sign is installed for an all arrow turn signal.

6.1.7.1.6 *NO TURN ON RED (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 right-turn-on-red maneuvers, especially involving children, older pedestrians, or persons with disabilities.
- Where there are more than three right-turn-on-red 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 4.8.2 for further guidance.
- For multi-lane applications the use of R10-11c or R10-11d may be used to restrict the right-turns-on-red from a specific lane.

6.1.7.1.7 *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 signal has a railroad preemption sequence and left 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 turn signal if the left turn is prohibited.

6.1.7.1.8 *Street Name Signs (D3-1)*

Street name signs are installed by the local jurisdiction. If mounted overhead, the lettering should be composed of initial upper-case letters at least 12 inches in height and lower-case letters at least 9 inches in height. Ensure the support poles are designed to accommodate loadings for street name signs if they will be installed during or after the project.

6.1.7.2 Ground Mounted Signs

The following discuss ground-mounted signs to be used at or in advance of signalized intersections.

6.1.7.2.1 *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.

6.1.7.2.2 *SIGNAL AHEAD Sign (W3-3)*

The installation of this sign is appropriate under the following conditions:

1. 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.

2. Speed. On high-speed rural approaches, approaching the first signal in an urbanized area, the W3-3 sign may be justified.

3. Engineering Judgment. In other situations where engineering judgment reveals the need for 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 5.2.6).

6.1.7.2.3 *Street Name Signs (D3-1)*

Street name signs are installed only by the local jurisdiction. The minimum lettering heights are 6 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 8 inches for initial upper-case letters and 6 inches for lower-case letters.

6.1.8 Other Traffic Control Signs

6.1.8.1 SPEED LIMIT Signs (R-2 series)

SPEED LIMIT signs shall be posted at the points where the speed limits change. Ensure that both directions are consistent. Additional signs should be installed beyond major intersections to inform traffic of the posted speed limit.

6.1.8.2 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.

6.1.8.3 School Signs

School signs shall have a fluorescent yellow-green background with a black legend and border.

6.2 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.

6.2.1 Stop Lines[3]

6.2.1.1 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 6.22 and 6.23)

6.2.1.2 Placement

When determining the placement of the stop line, consider the following:

1. Sight Distance. Position the stop line to allow the motorist adequate sight distance of the cross street traffic.

2. Staggered. Stop lines may be staggered longitudinally on a lane-by-lane basis; see Figure 6.22. Check turning paths of the design vehicles from the cross street to ensure there are no conflicts. For must intersections, use the turning path of a single-unit (SU) design vehicle to determine the location of the stop line.

3. Crosswalks. Where used, place the stop line a minimum of 4 feet in advance of the nearest crosswalk line at controlled intersections, except at midblock crosswalks (see Figure 6.23).

4. 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 4 feet from the nearest edge of the intersecting traveled way (see Figure 6.23).

5. Mid-block Crossings. Stop lines at midblock signalized locations should be placed at least 40 feet in advance of the nearest signal indication.

6. 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 prohibited in the area between the stop line and the crosswalk.

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[3] 2009 MUTCD, FHWA, Section 3B.16 "Stop and Yield Lines"

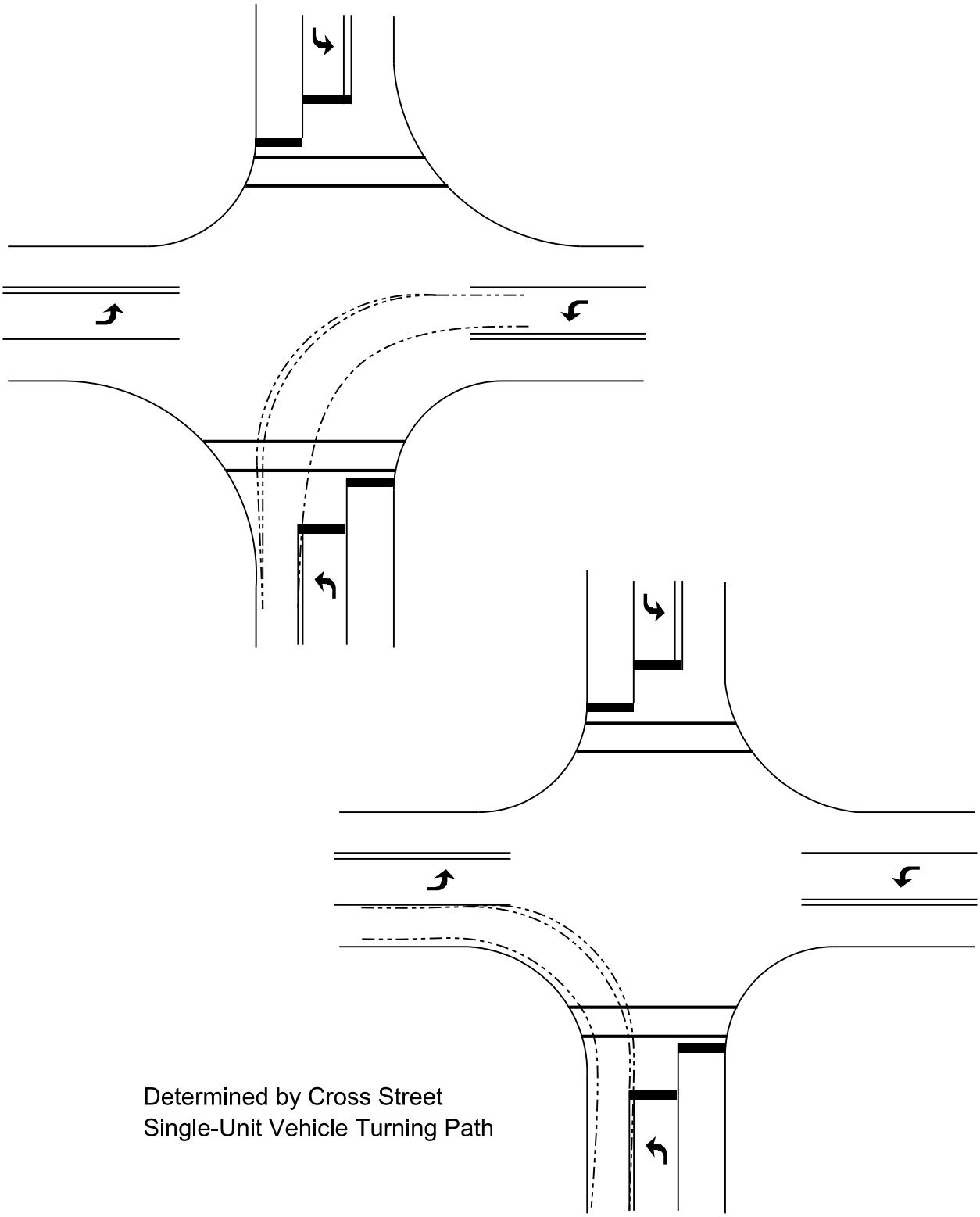
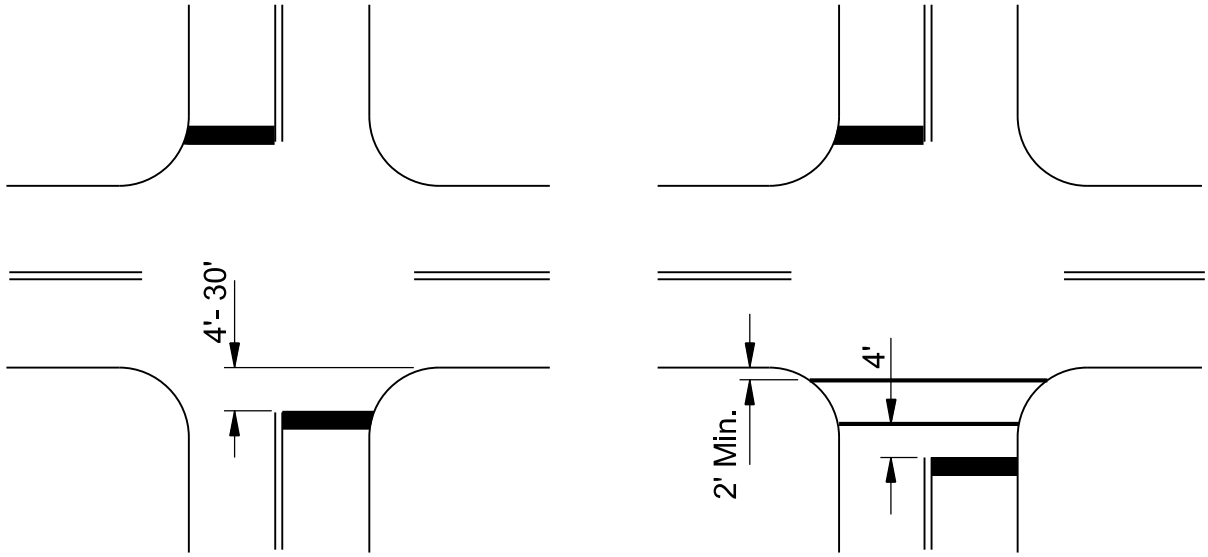
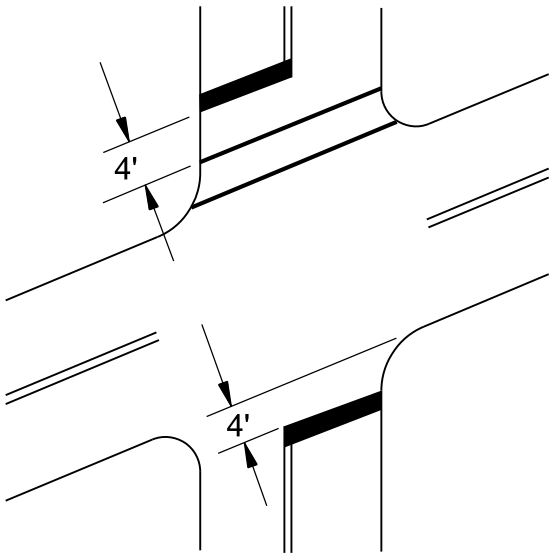


Figure 6.22 — Stop Line Placement



With No Crosswalks

With Crosswalks



Parallel to Cross Street
Curb Line

Figure 6.23 — Stop Line Locations

6.2.2 Yield Lines[4]

6.2.2.1 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 – 12 inches to 24 inches
- Height – 1.5 times the base width
- Color – white
- Orientation – generally parallel to cross street curb line
- Spacing Between Triangles – 3 inches to 12 inches

6.2.2.2 Placement

When determining the placement of the yield line, consider the following:

1. Sight Distance. Position the yield line to allow the motorist adequate sight distance of the cross street traffic.

2. 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.

3. Crosswalks. Where used, place the yield line a minimum of 4 feet in advance of the nearest crosswalk line at controlled intersections or roundabouts, except at midblock crosswalks.

4. 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 4 feet from the nearest edge of the intersecting traveled way.

5. 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 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, Yield Here To (Stop Here For) Pedestrians (R1-5 series) signs shall be used.

6. Roundabouts. A yield line may be used to indicate the point behind which vehicles are required to yield at the entrance to a roundabout.

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[4] Ibid. 3B.16

6.2.3 Crosswalks[5]

6.2.3.1 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 – 8 inches or 12 inches
- Color – white
- Crosswalk Width – 6 feet (min.)

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 or 85th-percentile speed,
- geometry of the location,
- possible consolidation of multiple crossing points,
- availability of street lighting, and
- other appropriate factors.

6.2.3.2 Placement

When determining the placement of crosswalks, consider the following:

1. 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.

2. Type. Normally, transverse lines are used. Where additional crosswalk visibility is required, diagonal or longitudinal lines should be used.

3. Orientation. The crosswalk should be oriented parallel to the cross street.

4. Accessibility.[6] 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

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[5] 2009 MUTCD, FHWA, Section 3B.18 "Crosswalk Markings"
[6] 2011 Public Rights-of-Way Accessibility Guidelines (draft); Section 204.3 "Pedestrian Street Crossings"

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, railings).

5. 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.

6. 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.

6.2.4 Arrows

Pavement marking arrows should be used for specific turn lanes. The turn arrow marking will suffice, 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.

6.2.5 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 7

HIGHWAY LIGHTING

7.0 GENERAL

The primary objective of highway lighting is to enhance highway 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.

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.

7.0.1 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.

7.0.2 Priorities and Funding Guidelines

The Tennessee Department of Transportation (TDOT) recognizes that under certain conditions, the installation of roadway lighting can improve the safety of a road or intersection. Consequently, the Department 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 Design Section, and/or as prescribed either by NCHRP Report No. 152 or An Informational Guide for Roadway Lighting, AASHTO, 2005.

- 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 the Department when the project is programmed.

Non-Interstate Highways

The Department 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:

1. 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 Maintenance Division, Traffic Engineering.

2. Installation or relocation of roadway lighting in a State project occurs only at the local agency's request.

   The Design Division Director must approve the installation or relocation.

   The project must be constructed under specific funding allowing such usage.

3. 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 Department's Utilities Office prepares relocation plans and submits funds to cover relocation costs prior to letting.

4. All requests for roadway lighting installations on non-interstate highways will be reviewed and approved by the Headquarters 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, the Department will replace the lighting in-kind.

7.1 ANALYZING HIGHWAY LIGHTING NEEDS

Driver visibility should be considered when analyzing highway 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

7.1.1 Freeways

Use the criteria presented in the following sections when analyzing the lighting needs for freeway facilities.

7.1.1.a Continuous Freeway Lighting

Continuous freeway lighting (CFL) should be considered under the following conditions:

1. Freeway Volume. On those freeway sections in and near cities where the current ADT is 30,000 or more, CFL should be considered.

2. Interchange Spacing. CLF should be considered where three or more successive interchanges are located with and average spacing of 1.5 miles or less, and adjacent areas outside the right-of-way are substantially urban in character.

3. Land Development/Lighting Conditions. Consider providing CFL where, for a length of 2 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.

4. 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.

5. 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.

7.1.1.b Complete Interchange Lighting

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.

Complete interchange lighting should be considered under the following conditions:

1. 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.

2. Crossroad Volume. Consider providing CIL where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

3. Land Development/Lighting Conditions. Consider providing CIL 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.

4. 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.

5. Local Agency Needs. CIL 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.

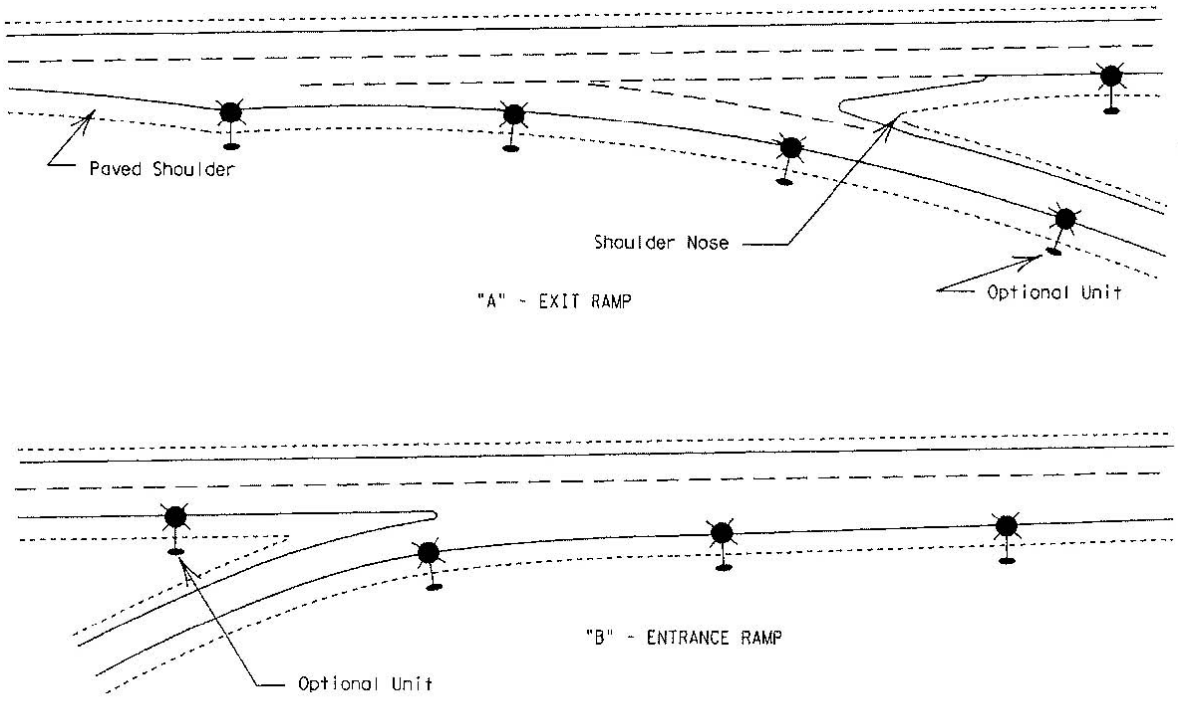
6. Continuous freeway Lighting. Provide CIL at interchanges where continuous freeway lighting is provided.

7.1.1.c Partial Interchange Lighting

Partial interchange lighting (PIL) is defined as a lighting system that provides illumination only of decision making areas of roadways including:

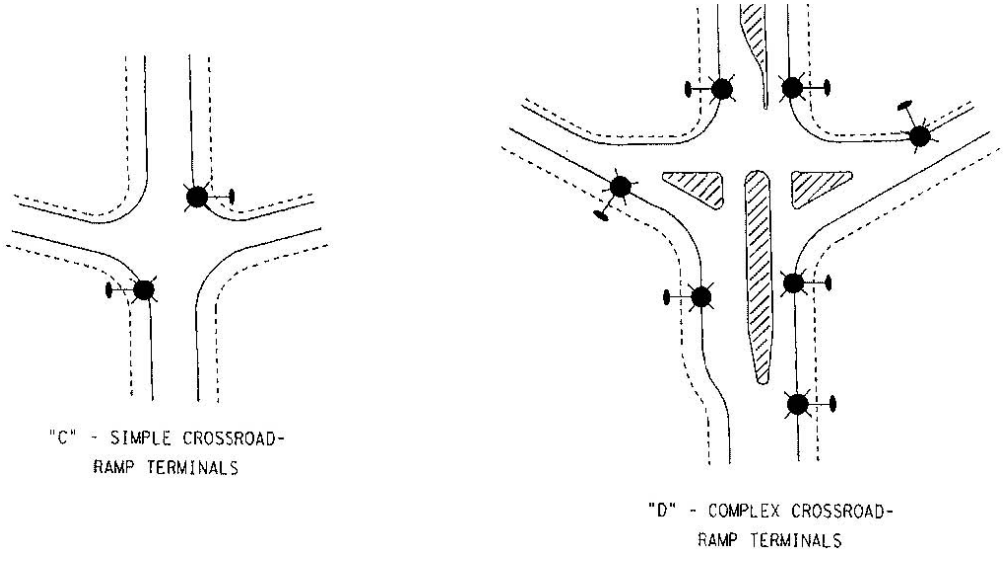
- Acceleration and deceleration lanes
- Ramp terminals
- Crossroads at frontage road or ramp intersections
- Other areas of nighttime hazard.

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 7-1 shows examples of partial interchange lighting with separate illustrations for different ramp conditions. 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.



PARTIAL INTERCHANGE LIGHTING
Figure 7-1

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 7-2 below.



PARTIAL INTERCHANGE LIGHTING
Figure 7-2

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 provided at interchanges under the following conditions:

1. Ramp Volume. Consider providing PIL 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.

2. Freeway Volume. Consider providing PIL 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.

3. 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.

4. Local Agency Needs. PIL 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.

5. Continuous Freeway Lighting. Consider providing PIL 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.

6. Complete Interchange Lighting. 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.

7.1.1.d Crossroad Ramp Terminal Lighting

Where the crossroad ramp terminal of freeway interchanges incorporates raised channelizing or divisional islands or where there is poor sight distance, lighting of the crossroad ramp terminal should be considered regardless of traffic volume.

7.1.2 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.

7.1.2.a 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):

1. Facilities with Raised Medians. Consider highway lighting along facilities that have raised medians.

2. Major Urban Arterials. Consider highway lighting along major arterials that are located in urban areas.

3. 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.

4. 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.

5. 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.

6. 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.

7. 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.

8. 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.

7.1.2.b TDOT Requirements

Lighting on Streets and Highways Other Than Interstates

While TDOT provides lighting for interstate highways and bridges as previously indicated, roadway lighting on other state roads may be installed under the conditions stated in Section 7.0.2 Priorities and Funding Guidelines.

The Tennessee Department of Transportation through the Utility and Maintenance Office has developed these guidelines in an effort to ensure a safe, effective and economical lighting system. 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:

1. Providing adequate levels of illumination.
2. Minimizing the amount of glare.
3. Reducing the number of poles required.

Submittal of Street Lighting Designs

Street lighting plans submitted to the Department of Transportation Maintenance Division 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 Commissioner of the Department of Transportation, or the Commissioner's designee, will make the final administrative and engineering determinations.

General Design Considerations

1. Recommended Mounting Height – 45 ft. 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 National Electric Safety Code.

2. 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 2 feet from the face of the curb.

3. 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 2 feet from the face of the curb.

4. 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.

5. Mast arm length shall be no greater than 6 feet, except as approved for the lighting design.

6. Footcandle levels shall be used as recommended in Tables 7.3 and 7.4 on pages 7-39 and 7-40.

7. Concrete pole bases should be flush but shall not extend over 4 inches above ground level.

8. 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 used in the installation.

All poles must be installed a minimum of 4 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.

9. 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.

10. 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.

11. Rapid changes in levels of illumination may be compensated by using transition lighting or adaptation techniques. When transition lighting 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. A practical formula for calculating the required roadway length for transition lighting is as follows:

$$L = (S)(C)(T)$$

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 Sec. (Recommended exposure time to allow motorist's eyes to adjust to different level of illumination).

For more information on transition lighting, refer to page 7-23.

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/IESNA RP-8 and AASHTO requirements. At the request of a Local Agency, ornamental lighting may be permitted by the Department on a State facility if the Department'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 the Department's street lighting policies.

Light standards may be installed in depressed medians that have a minimum width of forty-eight 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.

For more information refer to the sections on transitional lighting in number 11 of this section and number 4, of section 7.2.4d on page 7-23.

Roadway Lighting Plans Exceptions

If questions arise in the interpretations of the rules and regulations regarding roadway lighting, the Commissioner of TDOT or the Commissioner's designee will make the final administrative and engineering determinations. Requests for street lighting that is to be installed with State Funding should be submitted to the TDOT Commissioner's Office.

Authority: T.C.A. §4-3-2302 (2). Administrative History: Original rule filed August 8, 1983; effective September 7, 1983. Amendment filed July 20, 1984. Amendment filed February1, 1989: effective March 18, 1989.

7.1.3 Other Locations

The following categories are areas where TDOT may install lighting on a limited and case-by-case basis.

7.1.3.a Highway Sign Illumination

TDOT does not generally light highway signs.

7.1.3.b 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.

7.1.3.c Weigh stations

For lighting at weigh stations, there is typically no involvement by TDOT in the design, installation or maintenance. The following general guidelines are noted.

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.

7.1.3.d 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*.

7.1.3.e 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.

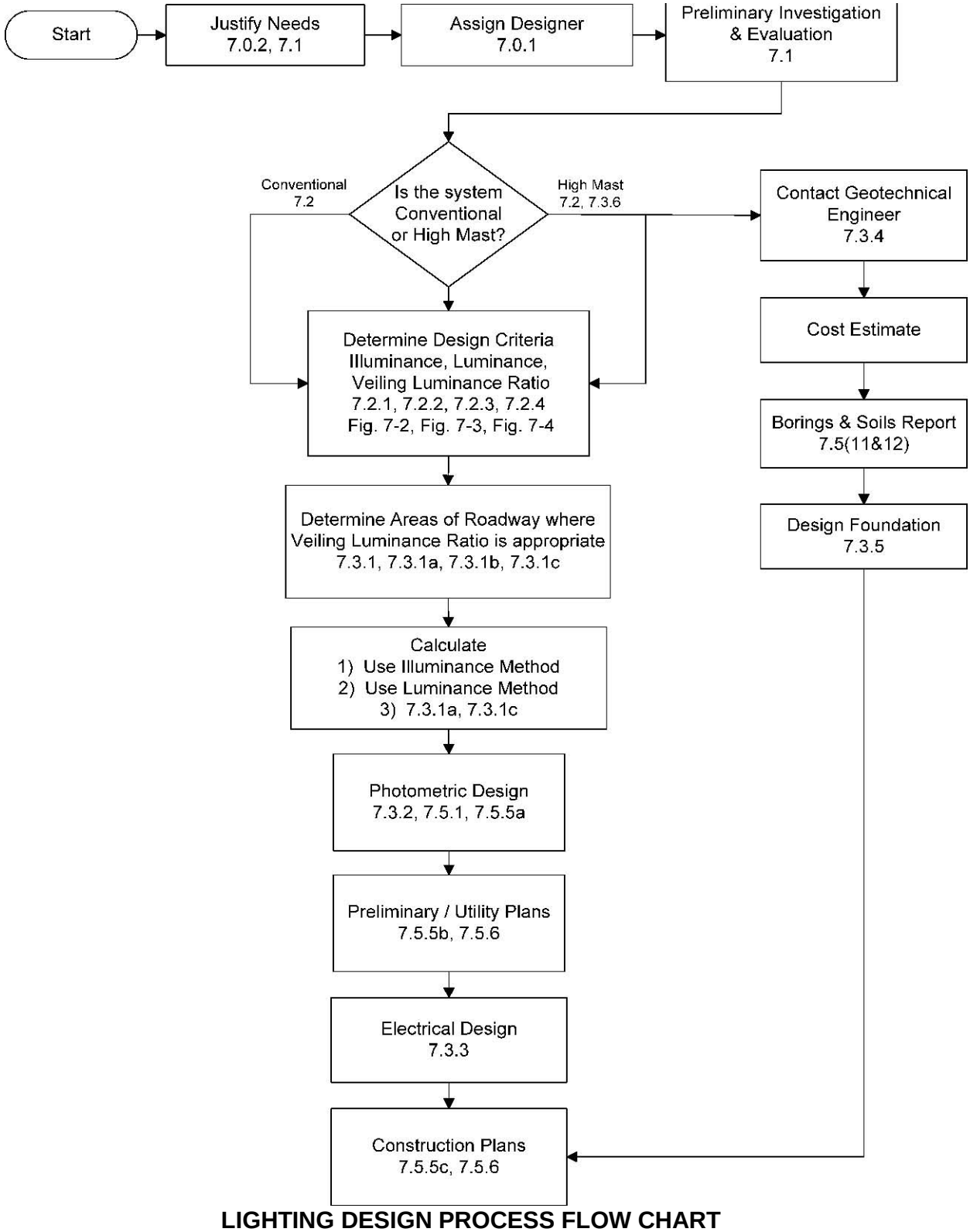
Any need for aviation obstruction warning luminaires on highway structures will be coordinated with the Federal Aviation Administration by the Traffic Design Office. For information on navigable airspace obstructions, consult the FAA Advisory Circular AC 70/7460-2J *Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace*.

7.1.3.f 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.

7.2 LIGHTING PROJECTS NEW

7.2.1 Lighting Design Process Flow Chart



LIGHTING DESIGN PROCESS FLOW CHART
Figure 7-3

7.2.2 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 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 Traffic Design 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. For manual calculations, Equation 7-2.2A should used the equation below. Footcandle (fc) and lux (lx) are units of illuminance expressed in lumens (lm) per square foot (ft2) and lumens per square meter (m2), respectively. Therefore, the average horizontal footcandle (lux) 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(s) as shown below.

EQUATION 7-2.2A

$$S = \frac{LL \bullet CU \bullet MF}{E_h \bullet W}$$

Where:

S	=	luminaire spacing - ft (m)
LL	=	initial lamp lumens - lm
CU	=	coefficient of utilization
MF	=	maintenance factor (i.e., LLD • LDD)
Eh	=	average maintained horizontal illumination - fc (lx)
W	=	width of lighted roadway - ft (m)

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 the equation below to determine the uniformity ratio.

EQUATION 7-2.2B

$$UR = \frac{E_h}{E_{\min}}$$

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/IESNA RP-8

7.2.3 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.

7.2.4 Determine Classifications

Determine the roadway classification, area classification, pavement classification, and environmental conditions. Verify with the Traffic Design Office the classification of any interchange or freeways as urban, suburban, or rural.

7.2.4.a Roadway Classification

Use the following definitions to classify roadway facilities for TDOT highway lighting projects:

1. 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

2. 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.

3. 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.

4. 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.

5. 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.

6. 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.

7. Isolated Intersection: The general area where two or more noncontinuously 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.

8. 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

1. Alley. A narrow public way within a block, generally used for vehicular access to the rear of abutting properties.

2. Sidewalk. Paved or otherwise improved areas for pedestrian use, located within public street right-of-way which also contains roadways for vehicular traffic.

3. Pedestrian Way. Public sidewalks for pedestrian traffic generally not within right-ofway 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.

4. 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 4.2 m (13.8 ft.).

- 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.)

5. Median: The portion of a divided roadway physically separating the traveled ways for traffic in opposite directions. The Department discourages lighting poles mounted in the median or on median barrier walls.

7.2.4.b Area Classification

For TDOT lighting projects, use the following definitions to classify the area in which the roadway traverses:

1. 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.

2. 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.

3. 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.

7.2.4.c Pavement Classification

Use the following definitions to classify the pavement type of the roadway facility:

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 1 cm (0.4 in.)] 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 Q_o values given for computer design calculations.

PAVEMENT CLASSIFICATION
Table 7.1

7.2.4.d Lighting Design Levels

1. 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.

2. 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.

3. 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.

4. 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 ft beyond the last luminaire for traffic lanes emerging from a lighted area (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 number 11 on page 7-12 and the section on Lighting at Isolated Intersections on page 7-13.

5. 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.

6. 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.

7.2.4.e Luminaire Considerations

The following sections discuss design issues related to luminaires.

7.2.4.e1 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:

1. 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:

    a. Short Distribution (S). The maximum candlepower strikes the roadway surface between 1 and 2.25 mounting heights from the luminaire. The theoretical maximum luminaire spacing, using the short distribution, is 4.5 mounting heights.

    b. Medium Distribution (M). 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.

    c. Long Distribution (L). 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.

2. Lateral Light Distribution. IES has developed seven classifications for lateral light distribution. The following provides application guidelines for each luminaire type:

    a. 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.

    b. 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.

c. 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.

d. 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.

e. 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.

f. 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.

g. 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.

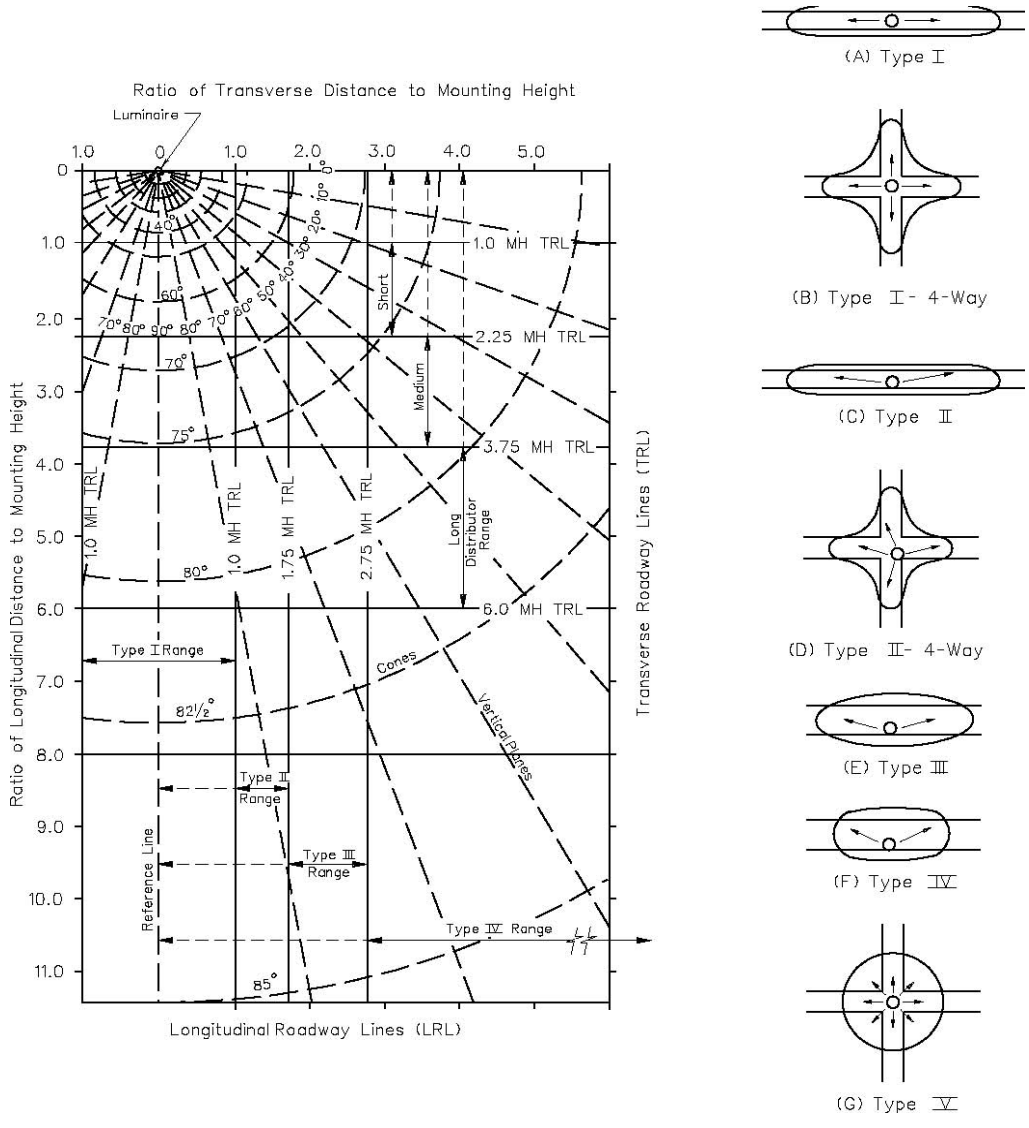
3. Control of Distribution. As the vertical light angle increases, disability and discomfort glare also increase. To distinguish the glare effects on the driver created by the light source, IES has defined the vertical control of light distribution as follows:

a. Cutoff (C). A luminaire light distribution is designated as cutoff (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.

b. Semi-Cutoff (SC). A luminaire light distribution is designated as semi-cutoff (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.

c. Non-Cutoff (N). This classification is 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 7-4.



PLAN VIEW OF ROADWAY COVERAGE FROM IES LUMINAIRES
Figure 7-4

7.2.4.e2 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 the Department for conventional highway lighting purposes range from 35 ft to 55 ft (10.7 m to 16.8 m). Mounting heights for light towers typically are greater than 80 ft (24 m).

7.2.4.e3 Coefficient of Utilization

A utilization curve is used to obtain a luminaire's coefficient of utilization (CU). Manufacturers typically provide utilization curves and isolux diagrams with each of their respective luminaire products. Figure 7-5 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 ouput reaches the area being lighted.

7.2.4.e4 Light Loss Factors

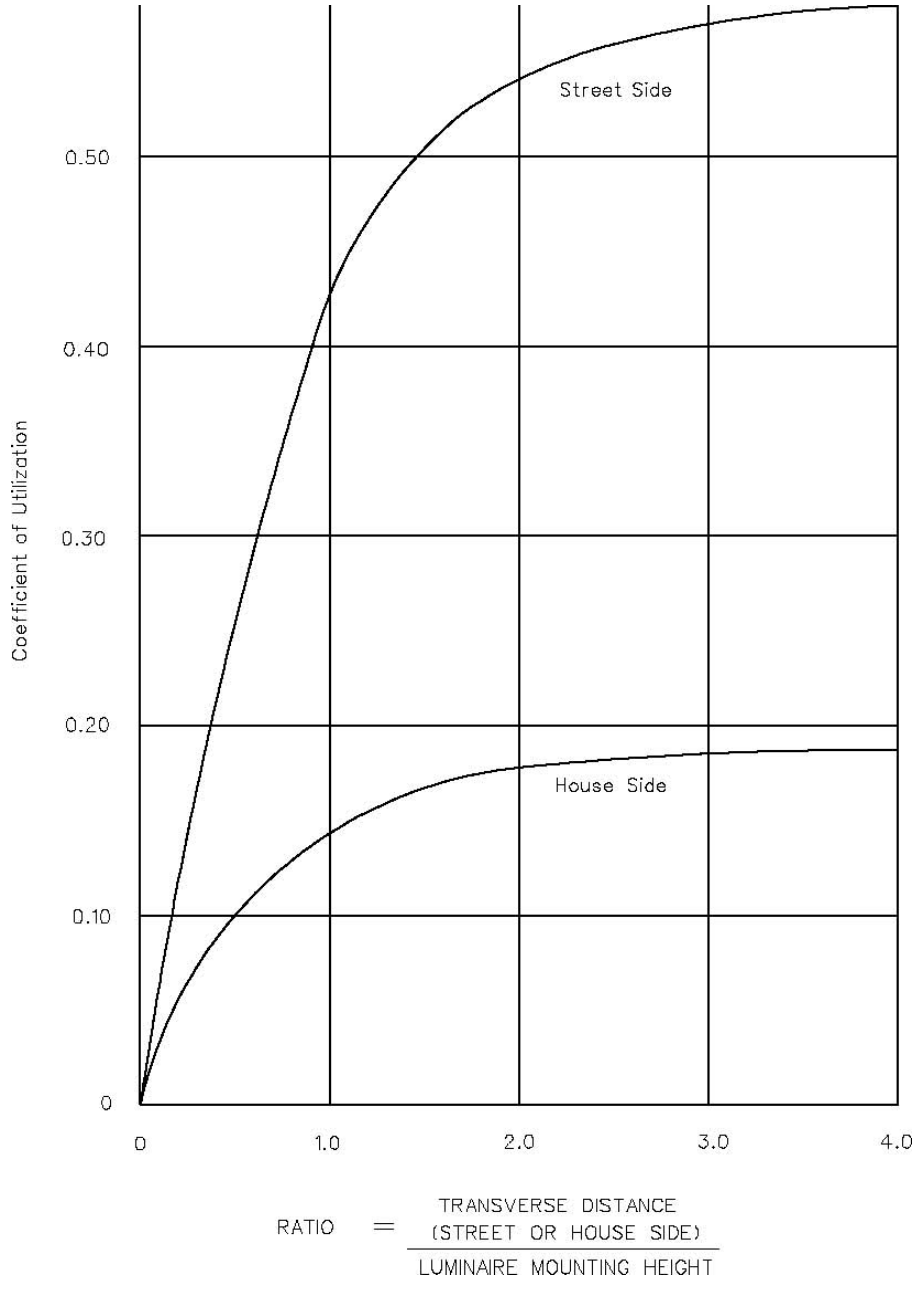
The efficiency of a luminaire depreciates over time. The designer must estimate this depreciation to properly estimate the light available at the end of the lamp's serviceable life. The following briefly discusses these factors:

1. Lamp Lumen Depreciation Factor (LLD). 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.

2. Luminaire Dirt Depreciation Factor (LDD). 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 7-6.

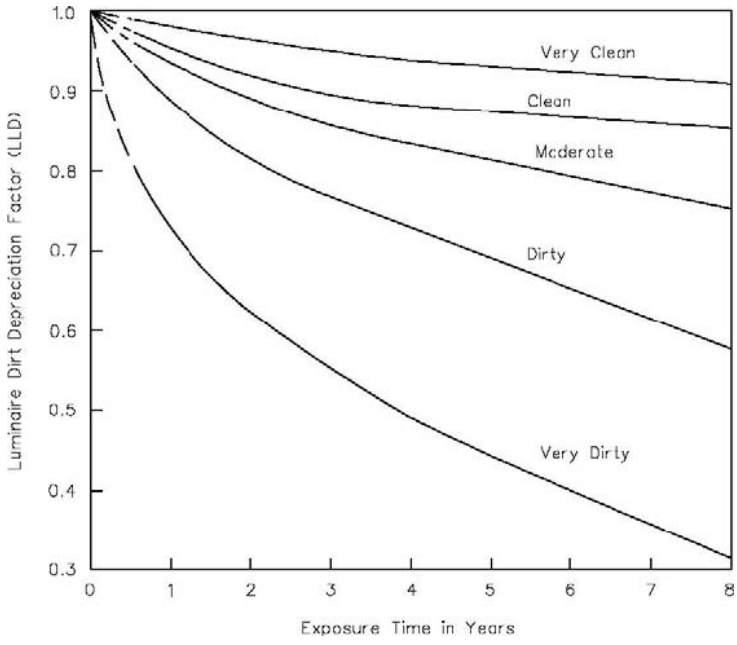
3. Equipment Factor (EF). Equipment factor is a general factor encompassing luminaire losses due to all other factors such as ballast factor, manufacturing tolerances, voltage drop, lamp position, ambient temperature, and luminaire component depreciation.

4. Light Loss Factor (LLF). The reduction factor, referred to as the total LLF (Light Loss Factor is a combination of LDD (Luminaire Dirt Depreciation), LLD (Lamp Lumen Depreciation), and EF (Equipment Factor, 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 Metal Halide) 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.



Note: The utilization curve will vary with each manufacturer and luminaire type.

SAMPLE UTILIZATION CURVE
Figure 7-5



Notes:

1. *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.*

2. *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.*

3. *MODERATE - Moderate smoke or dust-generating activities nearby. The ambient particulate level is not more than 600 micrograms per cubic meter.*

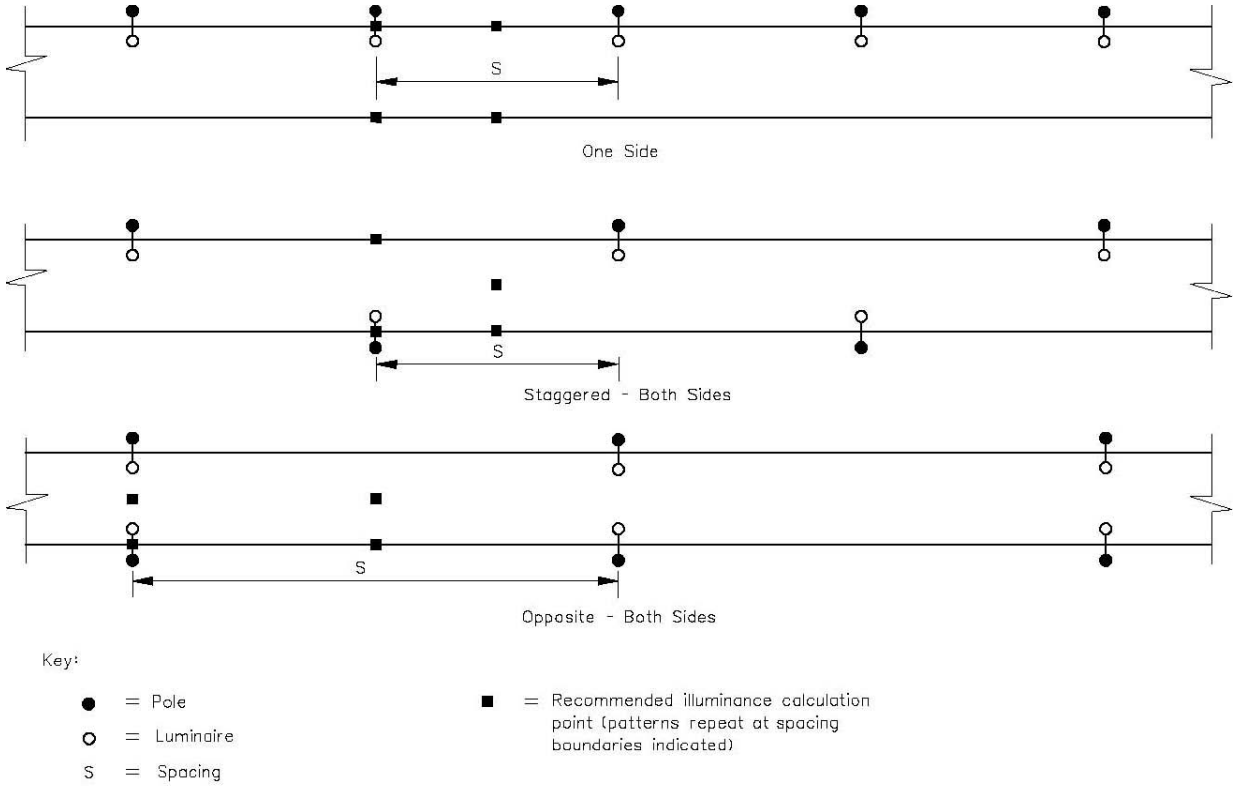
4. *DIRTY - Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.*

5. *VERY DIRTY - As above, but the luminaires are commonly enveloped by smoke or dust plumes.*

ROADWAY LUMINAIRE DIRT DEPRECIATION CURVE
Figure 7-6

7.2.4.e5 Luminaire Arrangement

Figure 7-7 illustrates typical luminaire arrangements for conventional highway lighting designs. Figure 7-7 also illustrates the recommended illuminance calculation points for the various arrangements.



TYPICAL LUMINAIRE ARRANGEMENTS FOR CONVENTIONAL HIGHWAY LIGHTING DESIGN
Figure 7-7

7.2.5 Other Design Considerations

In addition to the items discussed in the previous sections, consider the following when designing the highway lighting system:

1. 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.

2. Structures. Place light poles sufficiently away from overhead bridges and sign structures to minimize glare and distracting shadows on the roadway surface.

3. 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.

4. Location. Typically, lighting standards should be placed a minimum of 50 ft from overhead sign structures, and a minimum of 50 ft from overhead bridges.

7.2.6 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:

1. Clear Zone. Where practical, place light poles outside the roadside clear zone. See 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.

2. 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 will 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:

a. 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 (50 km/h) 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.

b. Breakaway Bases. All breakaway devices will comply with the applicable AASHTO requirements for breakaway structural supports.

c. 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 4 in (100 mm) above the finished grade within a 5 ft (1.5 m) chord above the foundation in accordance with AASHTO criteria.

d. Wiring. All light poles that require breakaway supports will be served by underground wiring and designed with quick disconnect splices.

e. 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.

f. Bridge Parapets and Concrete Barriers. Where poles are mounted atop bridge parapets and concrete barriers, they will be mounted on non-breakaway supports.

3. 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.

4. 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.

5. Maintenance. When determining pole locations, consider the hazards which will be encountered while performing maintenance on the lighting equipment.

6. 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:

   a. Placement. Where a roadside barrier is provided, place all light poles behind the barrier.

   b. 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.

   c. Concrete Barriers. Light poles that are shielded by a rigid or non-yielding barrier do not require a breakaway support.

   d. 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.

7. Protection Features. Do not use protection features, such as barriers, for the primary purpose of protecting a light pole.

8. Longitudinal Adjustments. Locate light poles to balance both safety and lighting needs. Adjustments on the order of 5 ft 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.

9. ADA Requirements. Contact the local agency for their specific ADA requirements.

7.3 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 7.2 presents typical highway lighting design parameters used by the Department.

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 ft Height 250 W or 400 W HPS Multi-Mount Luminaire Breakaway Base where Justified
Typical Parameters for Conventional Lighting (Interstate — Urban)	Aluminum Pole Off-set or Mast-Arm Mounting 45 ft Mounting Height, 250 W or 400 W HPS Horizontal-Mount Luminaire IES Classification: Cut-Off 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) Cut-Off (C) or Semi-Cutoff (SC)
Typical Luminaire Pole Arrangement	Staggered, Opposite, or Same Side

TYPICAL TDOT HIGHWAY LIGHTING DESIGN PARAMETERS
Table 7.2

Note:

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.)*

7.3.1 Methodologies

There are three lighting design methodologies available for use in highway lighting design, Illuminance, Luminance, And Small-Target-Visibility. The Illuminating Engineering Society (IES) of North America has been a leader in developing these methodologies (see the publication *American National Standard Practice for Roadway Lighting*, ANSI/IESNA RP-8). 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
7.3 and 7.4 on pages 7-39 and 7-40. The following sections briefly describe each of the available design methodologies.

7.3.1.a 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 (may move this). 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).

7.3.1.b 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).

7.3.1.c 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 (83 m) from the observer, summing the luminance from each luminaire.

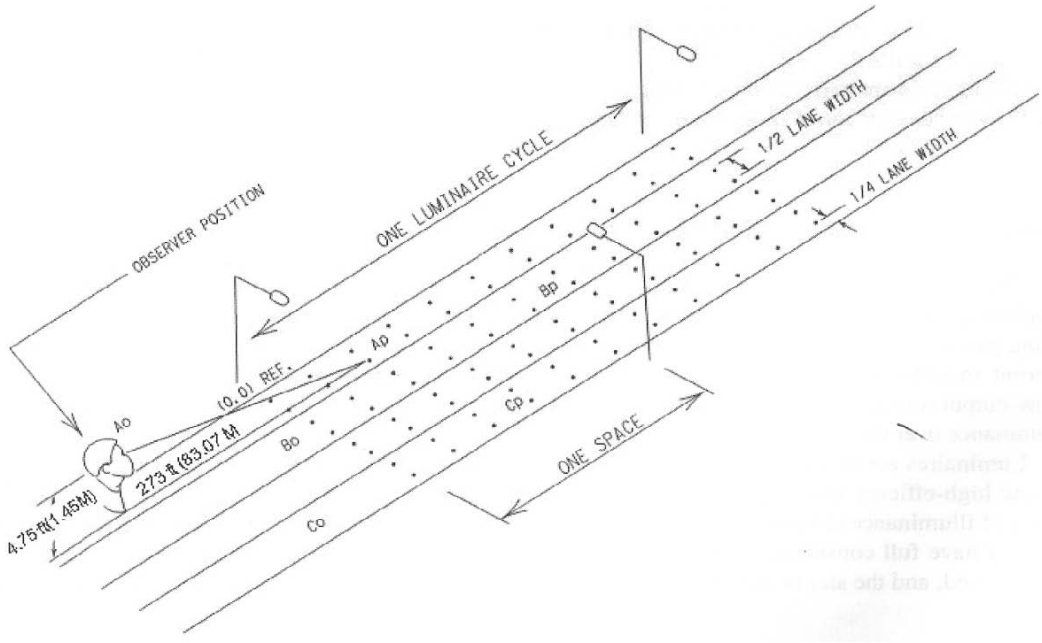
The distance between points should not exceed 15 feet (5 m). Calculations should include a minimum of three luminaire cycles downstream and one luminaire cycle upstream from reference (0.0) REF.

Luminance calculations place the observer's (motorist's) eye height at 4.8 ft. (1.45 m) above grade. The 4.8 ft. (1.45 m) is a design figure used internationally and does not affect the driver eye height of 3.5 ft. (1.07 m). 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 land width from the edge of each lane. The observer is positioned at a point 272 ft. (83.07 m) before the first point in the cycle to be evaluated (See Figure 78).

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.



CALCULATION POINTS FOR LUMINANCE AND ILLUMINANCE DESIGN METHODS
Figure 7-8

Criteria for veiling luminance ratio can be obtained from Table 7.3 and 7.4 on pages 739 and 7-40.

7.3.1.d Small-Target-Visibility (STV)

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 7 inch (180 mm), 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.

7.3.1.e TDOT Recommended Design Methodology

Both the Illuminance and the Luminance methodologies 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.

Roadway Facility Classification	Area Classification (Pedestrian Conflict Areas) (2)	AVERAGE MAINTAINED HORIZONTAL ILLUMINANCE (E_h) footcandle (lux) (4)			UNIFROMITY RATIO (Ave./Min.) Max (6)	VEILING LUMINANCE RATIO L_{Vmax}/L_{avg} (3)
		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	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	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 & Interior Roadways	All	0.4 (4)	0.6 (6)	-	3:1 to 4:1	0.4
Parking & Major Activity Areas	All	0.8 (8)	1.1 (11)	-		
Minor Activity Areas	All	0.4 (4)	0.5 (5)	-	6:1	

Note: Minimum Illuminance for Freeways and Expressways is 0.20 fc.

TDOT ILLUMINANCE DESIGN CRITERIA
Table 7.3

Road and Pedestrian Conflict Area		Average Luminance Lave (cd/m2) (Min)	Uniformity Ratio Lavg/Lmin (Maximum Allowed) (Max)	Uniformity Ratio Lmax/Lmin (Maximum Allowed) (Max)	Veiling Luminance Ratio LVmax/Lmin (Maximum Allowed) (Max) (3)
Road	**Pedestrian Conflict Area (2)**				
Freeway Class A	N/A	0.6	3.5	6.0	0.3
Freeway Class B	N/A	0.4	3.5	6.0	
Expressway	Low	0.6	3.5	6.0	
	Medium	0.8	3.5	6.0	
	High	1.0	3.5	6.0	
Major	Low	0.6	3.5	6.0	
	Medium	0.9	3.0	5.0	
	High	1.2	3.0	5.0	
Minor	Low	0.6	3.5	6.0	
	Medium	0.9	3.0	5.0	
	High	1.2	3.0	5.0	
Collector	Low	0.4	4.0	8.0	0.4
	Medium	0.6	3.5	6.0	
	High	0.8	3.0	5.0	
Local	Low	0.3	6.0	10.0	
	Medium	0.5	6.0	10.0	
	High	0.6	6.0	10.0	

Note: Use Illuminance requirements for sidewalks, walkways and bikeways.

TDOT LUMINANCE DESIGN CRITERIA
Table 7.4

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. *L_v(max) refers to the maximum point along the pavement, not the maximum in lamp life. The Maintenance Factor applies to both the L_v term and the L_{ave} 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..*

7.3.2 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.

7.3.3 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 places 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 7.3.1. Upon completion of the photometric design, the electrical design can be initiated. The following lists items that support a sound electrical design:

1. <u>Determine the service voltage provided for the lighting design</u>. It is the responsibility of the lighting designer to verify, with the Utility Owner/Maintaining Agency (See Section 7.2.2), 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:

A. Determine the service voltage (*VL)* provided by the electrical company.

B. Determine the lamp amperes *(I)* from Figure 7-5 based on the lamp wattage and service voltage.

C. Determine the resistance *(R)* of the wire size to be used from Figure 7-6.

D. Determine the distances *(L)* from each luminaire to the circuit breaker.

E. Use the equations below in determining the percentage voltage drop for a luminaire in a Two-wire single phase circuit,

F. Or, use the equations below in determining the percentage voltage drop between outside conductors and neutral in Three-wire single phase circuits. (See Note 3 below).

EQUATION 7-3.3A

$$V_d = (2 \cdot L \cdot I \cdot R) / V_L$$

Where:

V_d	=	*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 and Figure 7-5*
R	=	*resistance per ft of conductor (ohms/ft), see Note 2 and Figure 7-6*
V_L	=	*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 (75°C) operating temperature with an insulated covering and located in conduit. (resistance in ohms/ft or ohms/m)*

3. *Voltage drop between one outside conductor and neutral equals one-half of voltage drop calculated by formula above for 2-wire circuits.*

G. Use the following equation to determine the voltage drop for all of the luminaires being connected to the branch circuit breaker.

EQUATION 7-3.3B

$$\textbf{Total } V_d = \Sigma\, V_d \qquad \textit{(Voltage Drop for each luminaire)}$$

Note:

Total V_d = total voltage drop in one branch circuit (%)

H. Voltage drop should not exceed 3% as defined in this section and in Figure 7-2.

I. Calculating voltage drop, will determine the total number of luminaires that may be connected to each branch circuit breaker (See Circuit Breaker Size Determination below).

WATTS	Lamp Amperes (I) 120 VOLTS	Lamp Amperes (I) 240 VOLTS	Lamp Amperes (I) 480 VOLTS
150 WATTS	1.7	1.0	0.6
250 WATTS	2.7	1.4	0.8
400 WATTS	3.9	2.1	1.1
1000 WATTS	9.1	4.6	2.3

LAMP AMPERES (HPS MAG REG BALLAST)
Table 7.5

Information in the table shown below is based on extractions from the National Electric Code and may be used in TDOT lighting designs for circuit resistance in the voltage drop calculation.

Wire Size AWG	Circuit Resistance (R) Ohms/ft (ohms/m)	Wire Size AWG	Circuit Resistance (R) Ohms/ft (ohms/m)
14	0.0032614 (1.0700)	2	0.0002009 (0.0659)
12	0.0020498 (0.6725)	1	0.0001600 (0.0525)
10	0.0012899 (0.4232)	1/0	0.0001271 (0.0417)
8	0.0008089 (0.2654)	2/0	0.0001009 (0.0331)
6	0.0005099 (0.1673)	3/0	0.0000796 (0.0261)
4	0.0003210 (0.1053)	4/0	0.0000625 (0.0205)

CONDUCTOR PROPERTIES
Table 7.6

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:

A. Determine the total number of luminaires that can be supported on one branch circuit breaker.

B. Use the following equation to determine the size for a branch circuit breaker:

EQUATION 7-3.3C

$$BCB = (\text{Total No. of Luminaires} \times I) / 80\%$$

Where:

BCB = branch circuit breaker

I = current in conductor (lamp amperes), see Figure 7-5

C. 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 4 branch circuit breakers and 1 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.

D. The main circuit breaker size is determined from the following equation:

EQUATION 7-3.3D

$$MCB = (\Sigma BCB) / 80\%$$

Where:

MCB = main circuit breaker

BCB = branch circuit breaker

E. 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.

7.3.4 Foundation, Pole Mounting, and Structural Considerations

The TDOT *Standard Specifications for Road and Bridge Construction 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:

1. 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 4 in (100 mm) above the finished grade within a 5 ft (1.5 m) chord.

2. Steel Foundations. The steel (i.e., helix screw-in type) foundation is one that is commonly used by the Department 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 8 in to 10 in (200 mm to 250 mm) and is typically 6 ft (1.8 m) long. Shorter lengths may be appropriate for foundations in areas with shallow bedrock. The steel foundation will accommodate poles with 11.5 in and 15 in 56-5(21) (292 mm and 381 mm) bolt circles for luminaire mounting heights ranging from 40 ft to 50 ft (12 m to 16 m).

3. 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 ft (1.7 m), for 30 ft (9 m) poles, to 12 ft (3.6 m), for 65 ft (19.8 m) poles. The use of butt base anchors also may be considered.

4. 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.

5. 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.

6. Structural Design. Poles will be designed and fabricated to meet or exceed AASHTO requirements as documented in *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).

7. 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 ft (1.2 m) diameter reinforced concrete foundation, to a depth as required by the soils analysis, usually is adequate for towers accommodating 80 ft (24.4 m) luminaire mounting heights.

7.3.5 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 standard drawing T-L-1 plus ten (10) feet or to solid rock, which ever 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 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, 4th Edition, 2001, or latest revised edition thereof. As a secondary check, the following equation, presented in the Civil Engineering magazine, May 1969, may also be used:

EQUATION 7-3.5A

$$L = \frac{2.13F}{2PpD} \left\{ \left(\frac{2.13F}{2PpD}\right)^2 + \frac{3.2M}{PpD} \right\}^{0.5}$$

EQUATION 7-3.5B

$$\Delta = \frac{2.16F}{KDL^2} \left\{ 1.33 \left(\frac{H}{L}\right) + 1 \right\}$$

Where:

Pp	=	*passive pressure, ksf*
D	=	*diameter of foundation, ft (typically four feet)*
L	=	*length of foundation, ft*
F	=	*resultant of all horizontal external loads, kips*
M	=	*moment at ground line or top of footing, = FxH, ft-kips*
H	=	*distance from ground line to resultant of horizontal loads, ft*
Δ	=	*lateral movement of foundation at ground line, in*
K	=	*coefficient of passive subgrade reaction, kcf*

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 Geotechnical Engineering Office. Manday proposals and costs for the structural design of high

mast foundations will be reviewed and approved by the Structures Division. Final foundation designs will be reviewed by the Structures Division. These reviews and approvals will be coordinated by the Traffic Design Office.

7.3.6 HIGH-MAST LIGHTING DESIGN

In general, the design of high-mast lighting systems follows the same design procedures as discussed in Section 7.2 and 7.3. In addition, consider the following:

1. 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.

2. Light Source. Generally, either 400 W or 1000 W HPS lamps should be used. 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 (30 m) 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 (45 m). The number of luminaires per pole typically ranges from 4 to 6 luminaires.

   Luminaires are typically installed in multiples of two in order to balance the lowering device ring.

3. 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:

   a. 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).

   b. 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.

   c. Signs. Locate light towers so that they are not within the driver's direct line of sight to highway signs.

d. Special attention should be made to avoid underground utilities, drainage structures, overhead utility lines, and clusters of trees.

4. Design. There are generally two methodologies for checking the adequacy of light uniformity — the point-by-point method and the template method. The point-bypoint 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.

5. 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. Coordinate this effort with the Traffic Design Office.

7.3.7 Underpass Lighting

Because of their typical configuration and length-to-he ight 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.

7.3.8 TDOT Bridge Lighting Plan

Luminaires mounted on the bridge supports and bridge piers shall be approved by the Department's 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 rations 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.

<u>Bridge Lighting for Structures Submittal</u>

For overpass and underpass bridge lighting, the lighting designer shall submit the following to structures for inclusion in the bridge plans:

- Bridge Name, Site Location and L.M.
- Structural lighting quantities for each bridge
- Locations of all conduit, junction boxes, footings, etc.
- see Figure 7-9 and Figure 7-10 for details.

Bridge Lighting for Lighting Plans

For overpass and underpass bridge lighting, bridge lighting detail sheets shall be included in the lighting plans.

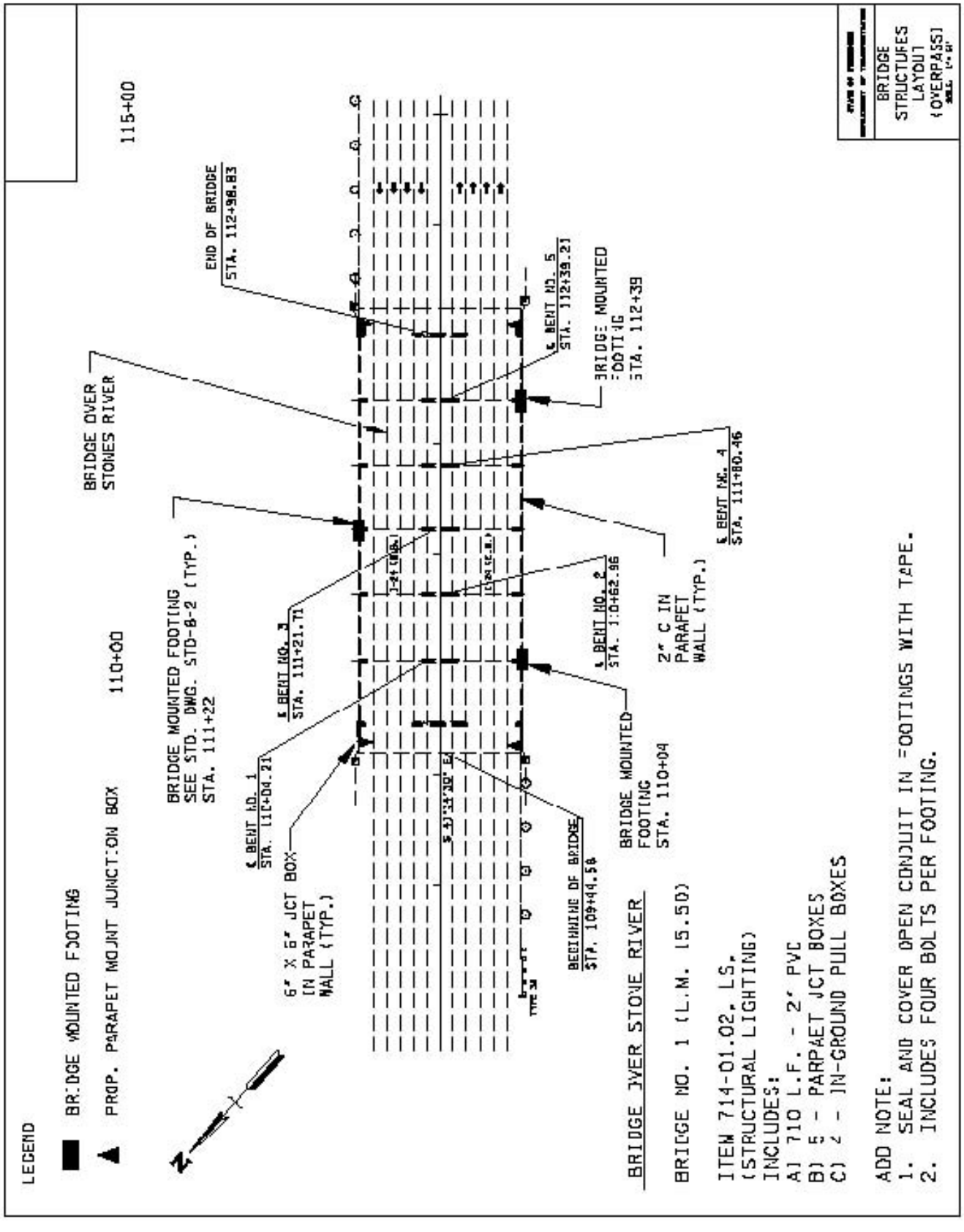
Overpass and underpass lighting is detailed in separate formats as described below.

1. Overpass Lighting. For overpass lighting, the lighting plans shall include the following in the "lighting layout":

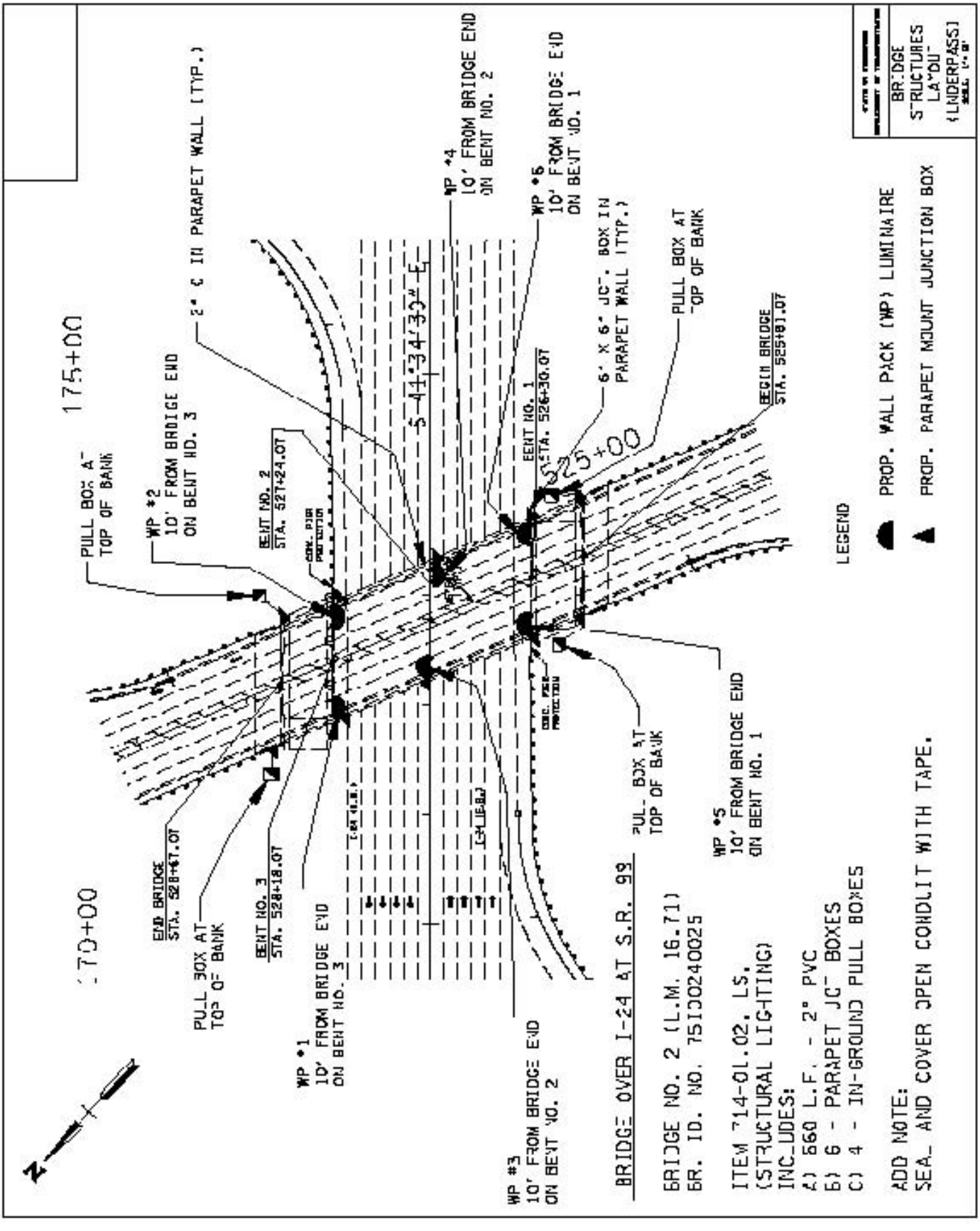
    - pole number and light pole location
    - junction box location in parapet wall
    - conduit location in parapet wall
    - see Figure 7-11 for details

2. 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:

    - 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
    - See Figure 7-12 for details.

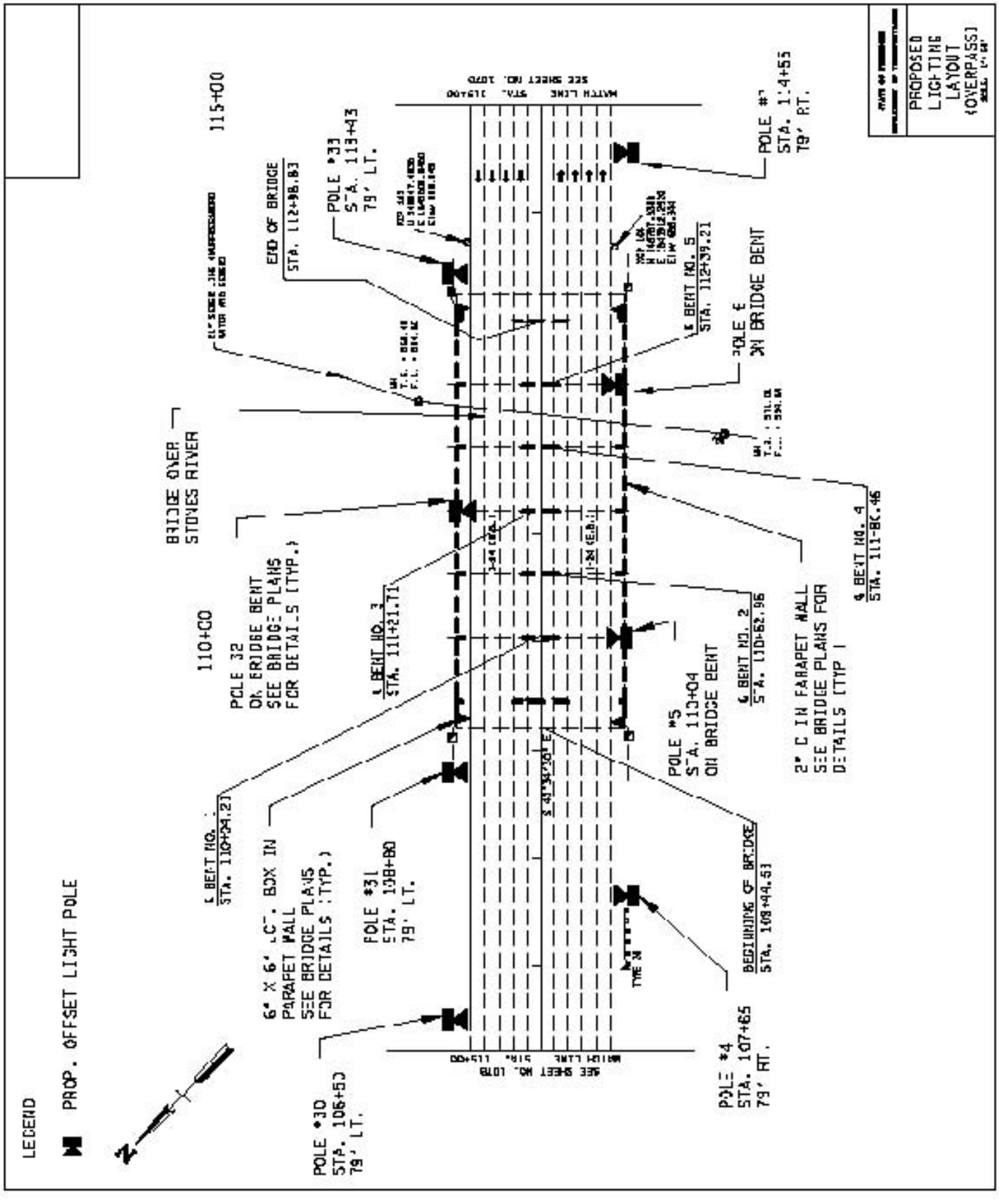


DETAIL OF OVERPASS BRIDGE LIGHTING FOR SUBMITTAL TO STRUCTURES
Figure 7-9

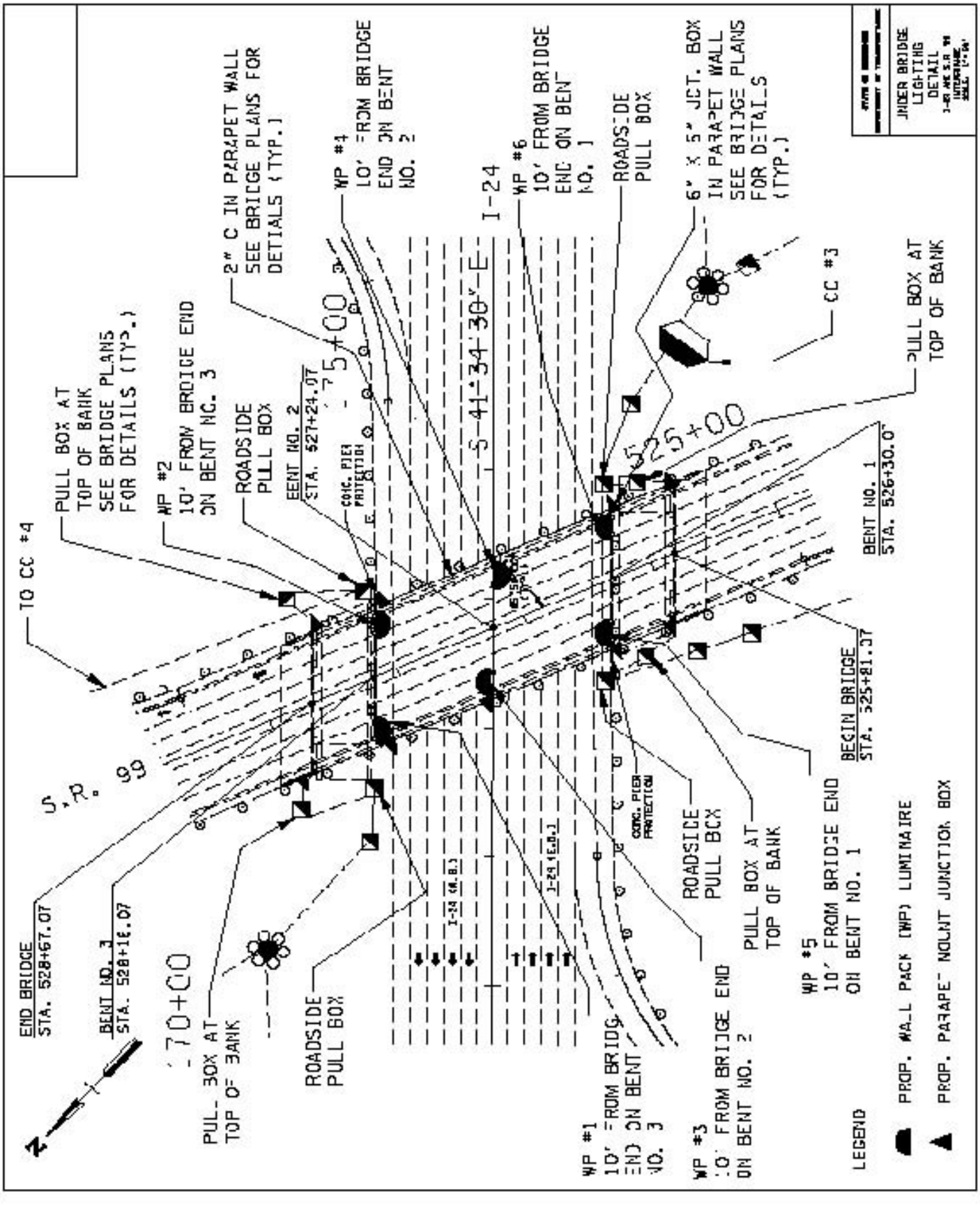


DETAIL OF UNDERPASS BRIDGE LIGHTING FOR SUBMITTAL TO STRUCTURE

Figure 7-10



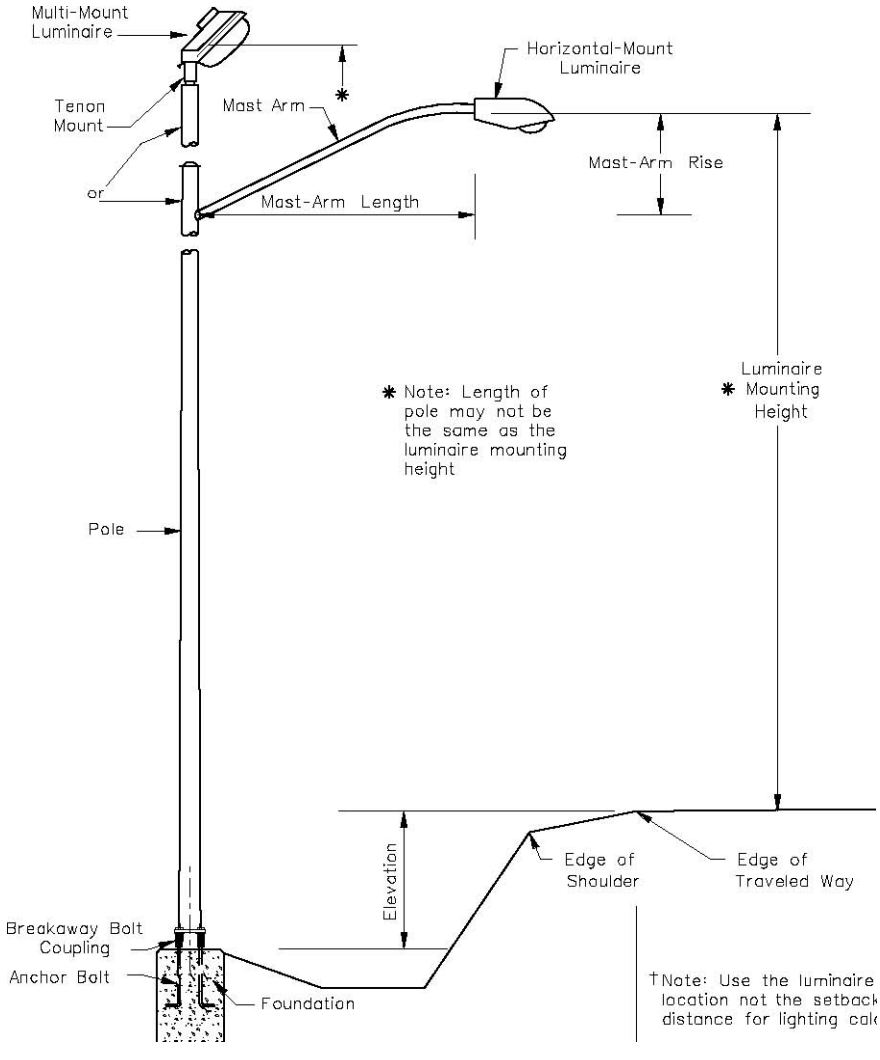
DETAIL OF PROPOSED LIGHTING LAYOUT AT BRIDGE OVERPASS (NTS)
Figure 7-11



DETAIL OF PROPOSED LIGHTING LAYOUT AT BRIDGE UNDERPASS (NTS)
Figure 7-12

7.4 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. Section 7.4 provides specific design guidance for luminaires, electrical devices, and support structures used by TDOT. Figure 7-13 illustrates the various components of a 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

TYPICAL HIGHWAY LIGHTING STRUCTURE
Figure 7-13

7.4.1 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.

7.4.2 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. Section 7.2.6 provides design guidance on this issue. The following briefly describes the pole bases used by the Department:

1. 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.

2. 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.

3. 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.

7.4.3 Poles

Light poles for conventional highway lighting applications support luminaire mounting heights ranging from approximately 30 ft to 65 ft (9 m to 19.8 m). 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 ft to 160 ft (24 m to 49 m) and are designed in multiple sections.

7.4.4 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.

7.4.4.a 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. It is rare that a light source other than the high-intensity discharge type is 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:

1. High Pressure Sodium (HPS). 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.

2. Low Pressure Sodium (LPS). 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.

3. Mercury Vapor (MV). Prior to the introduction of HPS lamps, MV was the most commonly used light source in highway applications. The MV lamp produces a bluish-white light and is not as efficient as the HPS lamp.

4. Metal Halide (MH). 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.

7.4.4.b 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:

1. Light Source. See Section 7.4.4.a for information on the high-intensity discharge lamps used in highway applications.

2. 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.

3. 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.

7.4.4.c Ballasts

All 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.

7.4.4.d 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).

7.4.5 Other Materials and Equipment

There are numerous other materials and equipment that are used in a highway lighting system such as quick disconnect fuseholders, controllers, photocells, surge arresters, raceways, ground rods, cabling, transformers, conduit, handholes, and pullboxes. 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.

7.5 TDOT LIGHTING PLANS LAYOUTS

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 Traffic Design 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:

1. 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.

2. 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 stand alone lighting projects, the standard drawings, tabulated quantities, and notes shall be prepared on separate sheets (Index of Standard Drawing Sheet, Estimated Roadway Quantities Sheet, General Notes Sheet).

3. 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.

4. Control Center Details. This sheet shall include details for the wiring schematic, notes, and control center mounting detail (pad or pole mounted).

5. 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.

6. Special Lighting Details. This sheet shall include details of special fixtures or other non-standard TDOT items clearly identified and detailed.

7. 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.

8. Proposed Lighting Layout Sheets. These sheets should be developed as follows:

   a. The plans should be designed for 1 in. = 50 ft. scale for straight and curved roadway lengths and 1 in. = 100 ft. scale for interchanges.

   b. The location of lighting standards in relation to the proposed roadway should be shown. Each standard shall be flagged to note the pole number, station, coordinates, offset, and pole height if it varies.

   c. 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.

   d. All Control Centers shall be located and numbered, and the power source location shall be identified.

   e. 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.

   f. North arrow, legend and road names shall be on all layout sheets.

9. 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 7-12 for under bridge lighting details.

10. 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 Structures Division as

depicted in Figure 7-9 and Figure 7-10. The Bridge Layout Sheets shall be signed and sealed exclusively by the structural designer

11. 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.

12. 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.

13. 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.

7.5.1 Photometric/Preliminary Plans Preparation

The Designer shall prepare all components necessary for photometric/preliminary plan submittal. The Designer shall submit to the TDOT Supervisor/Manager 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 ft (4.5 m), 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 10 to 20 ft. along the roadway length (e.g. for a 12 foot lane, the grid size should be 6ft. X 10ft.).
- For high mast lighting, the point-by-point grid size should be a maximum of the lane width by 20 ft along the roadway length (e.g. for a 12 foot lane, the grid size should be 12ft. X 20ft.).

- The Photometric/Preliminary Plans shall be designed to Survey and Design Computer-Aided Drafting Standards. Section 7.5.3 describes additional drafting standards.
- Plan preparation checklists are listed in Section 7.5.5.
- Plans and Work File submittals are discussed in Section 7.5.6.

7.5.2 Photometric/Preliminary Plan Review

Upon receipt of the Photometric/Preliminary Plans, the TDOT Supervisor/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 Supervisor/Manager shall approve the Photometric/Preliminary Plans.

The TDOT Supervisor/Manager shall have up to one (1) 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.

7.5.3 Lighting CADD Standards

Lighting plans shall follow the Survey and Design Computer-Aided Drafting Standards. The following details additional lighting design criteria that will aid to maintain uniformity in all lighting plans submitted to the Department:

- Lighting Plans Layout Sheets shall be scaled to 1 in. = 50 ft. for straight and curved roadway lengths and 1 in. = 100 ft. for Interchanges.
- Conventional light poles shall be numbered as 1, 2, etc.
- High Mast poles (Tower poles) shall be numbered as HM 1, HM 2, etc.
- Control Centers shall be numbered as CC 1, CC 2, etc.

7.5.4 Site Visits and Field Review

1. Site Visits. A very necessary, but sometimes overlooked, part of a complete lighting design is the need for site visits. The number of site visits will be dependant on the complexity of the project. It is prudent that the lighting designer have at least one site visit. The following benefits may be obtained through site visits:

   - Site visits 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 visits can provide a better understanding of the neighborhood and other environmental issues that may factor into pole/fixture selection and placement.

   - Site visits clearly show the roadway configuration. This will enable the designer to determine the lighting design criteria specific to the roadway configuration.

   - Site visits will enable the lighting designer to select potential service point locations by identifying power sources throughout the immediate project area.

   - Site visits 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.

2. 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.

3. 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.

7.5.5 Lighting Design Checklist

In order to reduce plan revisions, errors, and standardize the preparation, format and content of plans, the following Lighting Design Checklists shall be used by all Designers, Consultants, Supervisors, 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. NA (not applicable) 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.

LIGHTING DESIGN CHECKLIST

COUNTY: _____

F.A. PROJECT NO.: _____

P.E. NO.: _____

DESCRIPTION: _____

DESIGNER: _____

TDOT SUPERVISOR: _____

PROJECTED ROW AUTHORIZATION DATE: _____

PROJECTED LETTING DATE: _____

7.5.5.a PHOTOMETRIC/PRELIMINARY LIGHTING PLANS CHECK LIST

PROJECT NO.: _____ 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

7.5.5.b UTILITY/R.O.W. LIGHTING PLANS CHECK LIST

PROJECT NO.: _____ 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)
____ Supervisor 2 or 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/R.O.W. LIGHTING PLANS CHECK LIST

PROJECT NO.: _____ 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

7.5.5.c CONSTRUCTION LIGHTING PLANS CHECK LIST

PROJECT NO.: _____ 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
____ Supervisor 2 or 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 CHECK LIST

PROJECT NO.: _____ 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 CHECK LIST

PROJECT NO.: _____ 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 CHECK LIST

PROJECT NO.: _____ 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

7.5.6 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 to the Traffic Design 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. The following lists items that shall be submitted with the photometric plans:

1. Photometric Plan. The following shall be submitted as specified by TDOT Project Manager:

   - Send by disks or email - Centerline File, Survey File, Work File, Sheet Files, and the GPK and TIN files in MicroStation V8 format and Photometric Design Input and Output Files, or

   - PDF files showing the required design information, or

   - One set of 24” X 36” prints showing the required design information.

DESIGN REFERENCES

The designer responsible for a highway lighting project should be aware that the design must comply with various standards. The criteria derived in this standard were extracted from various other federal local and national standards. For information applicable to TDOT highway lighting design projects, following publications were consulted:

1. *2006 Lighting Software Directory,* IESNA Computer Committee;

2. *A Guide to Standardized Highway Lighting Pole Hardware,* American Association of State Highway and Transportation Officials;

3. *American National Standard Practice for Roadway Lighting ANSI/IESNA RP-8*, American National Standards Institute/Illuminating Engineering Society of North America;

4. *Highway Lighting,* Chapter 56, Illinois Department of Transportation;

5. *Highway Lighting Systems*, Section 11, New Jersey Department of Transportation;

6. *Manual on Uniform Traffic Control Devices (MUTCD*), U.S. Department of Transportation, Federal Highway Administration;

7. *Nashville Downtown Streetscape Elements Design Guidelines*, Metropolitan Developmemt and Housing Agency (MDHA);

8. *National Electrical Code*, National Electrical Code Committee of the American National Standards Institute (ANSI), sponsored by the National Fire Protection Association (NFPA);

9. *National Electrical Safety Code*, American National Standards Institute/Institute of Electrical and Electronics Engineers;

10. *Partial Lighting of Interchanges,* National Cooperative Highway Research Program Report No. 256, Transportation Research Board;

11. *Roadside Design Guide*, American Association of State Highway and Transportation Officials;

12. *Roadway and Structure Lighting Specifications,* Section 714, Tennessee Department of Transportation;

13. *Roadway Lighting Design Guide,* American Association of State Highway and Transportation Officials;

14. *Roadway Lighting Handbook*, U.S. Department of Transportation, Federal Highway Administration, Offices of Research and Development, Office of Traffic Operations;

15. *Rules and Regulations for Accommodating Utilities within Highway Rights-of-Way,* Chapter 1680-06-01, Tennessee Department of Transportation;

16. *Standard English Drawings,* Tennessee Department of Transportation;

17. *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, American Association of State Highway and Transportation Officials;

18. *Street Light Design Manual*, Nashville Electric Service (NES);

19. *Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, National Cooperative Highway Research Program Report No. 411, Transportation Research Board

20. *Warrants for Highway Lighting*, National Cooperative Highway Research Program Report No. 152, Transportation Research Board

21. *Traffic Engineering Design Manual 2006, Section V, Chapter 2 Engineering Concepts/Guidance, Virginia Department of Transportation*

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CHAPTER 8

INTELLIGENT TRANSPORTATION SYSTEMS

8.0 INTRODUCTION

This Chapter of the Tennessee Department of Transportation Traffic Design Manual will be used to address policies, guidelines, standard procedures, etc. related to Intelligent Transportation Systems (ITS) and the Systems Engineering Analysis (SEA) documentation.

TDOT's Intelligent Transportation System is referred to as the TDOT SmartWay. It is designed to reduce traffic congestion by decreasing incident clearance time, increase safety by decreasing the number of secondary accidents, and, working alongside our incident management program (HELP), improving emergency response to traffic situations. TDOT SmartWay uses cameras to monitor the highways from Traffic Management Centers, sensors to gauge traffic flow, large electronic message signs to send urgent traffic notices to drivers along the highways and the Highway Advisory Radio system to alert motorists of important information. Nashville, Knoxville, Memphis, and Chattanooga have fully integrated TDOT SmartWay systems.

TDOT SmartWay advanced information technologies take many forms such as:

Roadway Traffic Sensors to report traffic counts, speed and travel time;

Camera Video Surveillance to monitor freeway traffic flows and provide improved incident management capabilities;

Dynamic Message Signs to provide real-time traffic, construction, and weather information to motorists, as well as provide information on Amber Alerts;

Highway Advisory Radio to provide urgent real-time traffic, construction, and weather information to motorists via AM radio, as well as provide information on Amber Alerts;

HELP Freeway Service Patrols to reduce congestion by removing minor incidents in a timely fashion;

Transportation Management Centers (TMC) serve as a central location for traffic management operations and communications in their respective Regions;

Incident Management to detect, verify, and respond to incidents in an efficient manner and manage traffic conditions around the incident site;

Construction Information is provided to advise motorists traveling through construction sites;

TDOT SmartWay Information System (TSIS) is a system communicating data from TDOT SmartWay devices to a central location and distributing that transportation information to motorists and other interested parties before and while making trips. Information is distributed via TDOT's Web site and through the media. TDOT also provides motorist information on Tennessee 511, a component of TDOT SmartWay.

Information on Weather-Related Road Conditions informs travelers where problems may exist on any state road due to severe weather conditions.

While the potential of ITS is significant, deployment and operation of these systems requires specialized coordination, design, device specifications, procurement / construction, operations management, and maintenance. The TDOT Design Division shall provide implementation plans for ITS and policies for ITS operation.

8.1 23 CFR 940 COMPLIANCE

8.1.1 INTRODUCTION AND SCOPE

These requirements apply to Federal Aid projects, as required by Federal Highway Administration, Department of Transportation 23 CFR Part 940. State-funded projects will follow the same process for consistency.

In accordance with 23 CFR 940, ITS projects funded through the highway trust fund shall conform to the National ITS Architecture and applicable standards. 23 CFR 940 also stipulates that "conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a Regional ITS Architecture, as applicable, and the subsequent adherence of all ITS projects to that Regional ITS Architecture." This chapter outlines the TDOT procedures for implementing these requirements. The level of documentation should be commensurate with the project scope.

8.1.2 GENERAL CRITERIA

In accordance with 23 CFR 940.3, an ITS project is "any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture". Any reference to the ITS Architecture in this document refers to Statewide and Regional Architectures. Documentation for ITS Projects classified as High Risk, as defined in section 8.1.3, should be completed by staff with qualified ITS experience.

In Tennessee, a project would be considered to be an ITS project if it meets any of the following:

- It requires the integration of multiple separate systems;
- It is a project that has significant potential to involve the integration of technologies on a multi-jurisdictional level;

- It replaces existing or installs new centrally controlled software.

ITS Projects may be either High Risk, Low Risk, or Exempt ITS Projects. The SEA development process is different for each category.

The following describes the categories of ITS projects in Tennessee: **High Risk, Low Risk,** and **Exempt**. The decisive factor in this determination is the scale and complexity of the project. Traffic Signal projects are the most common scale sensitive projects. The nature of the engineering development for ITS projects implies a greater risk and uncertainties to successful completion. Project risk may be defined in terms of schedule, cost, quality, and requirements. These risks can increase or decrease significantly based on several identified factors associated with ITS projects.

The factors are:

- Number of jurisdictions and modes;
- Extent of software creation;
- Extent of proven hardware and communications technology used;
- Number and complexity of new interfaces to other systems;
- Level of detail in requirements and documentation;
- Level of detail in operating procedures and documentation;
- Service life of technology applied to equipment and software.

Generic criteria for the determination of risk are shown in the list below.

- Technology: functions are not fully identified, user interface not right, unrealistic technical requirements, component shortcomings;
- People: personnel shortfalls;
- Physical Environment: external dependencies, device placement;
- Political Environment: adding requirements that are not tied to a need, do you have a champion;
- Contract Issues: unrealistic schedules and budgets, requirements change;
- Additional Risk Factors are shown in Table 8.1.

8.1.3 HIGH RISK ITS PROJECTS

A High Risk ITS project is an ITS project that implements part of a regional ITS initiative that is multijurisdictional, multi-modal, or otherwise affects regional integration of ITS. Multi-jurisdictional does not necessarily mean that a project with termini in more than one city is High Risk ITS. The key criteria is “Regional ITS initiative.”

High Risk ITS projects have ***one* (or more)** of the following characteristics:

- Multi-Jurisdictional or Multi-modal;
- Custom software is required;
- Hardware and Communications are “cutting-edge” or not in common use;

- New interfaces to other systems are required;
- System requirements not detailed or not fully documented;
- Operating procedures not detailed or not fully documented;
- Technology service life shortens project life-cycle.

The following are examples of High Risk ITS projects:

- TDOT SmartWay (if additional functionality is to be added);
- Traffic Signal systems scoped to be centrally controlled (Closed loop systems are NOT central control systems);
- Traffic signal projects that require the integration of signal systems with TDOT SmartWay, an Arterial Management System, or RWIS systems;
- An ITS system that involves multiple political jurisdictions;
- Regional Transit Systems;
- Transit Signal Priority Systems.

8.1.4 LOW RISK ITS PROJECTS

Low-Risk ITS projects are often referred to as ITS infrastructure expansion projects.

Low Risk ITS projects will have ***all*** of the following characteristics:

- Single jurisdiction and single transportation mode (highway, transit, or rail);
- No software creation – commercial-off-the-shelf (COTS) or proven software;
- Proven COTS hardware & communications technology;
- No new interfaces;
- System requirements fully detailed in writing;
- Operating procedures fully detailed in writing;
- Project life-cycle not shortened by technology service life.

The following are examples of Low Risk ITS projects:

- Traffic signals with emergency vehicle preemption;
- Roadway Weather Information System (RWIS);
- Parking Management Systems;
- Various surveillance or control systems that could functionally be integrated into a Freeway Management System;
- Expanding existing communications systems – this consists of extending existing fiber-optic or wireless communications systems, using the same technology and specifications as the preexisting system;
- Leasing turnkey services only (e.g., website-based information service) – with no hardware or software purchases.

8.1.5 EXEMPT ITS PROJECTS

Exempt ITS projects do not require a Systems Engineering Analysis (SEA). All activities of the traditional roadway project development life-cycle process will be followed. No further ITS-specific action is necessary.

Exempt ITS projects can be classified into two categories:

- An exempt ITS project is one that does not use federal funding;
- ITS System expansions that do not add new functionality. In other words, a project that by itself may have been considered high or low risk, but if the scope of the project simply expands this system it can be considered Exempt.

The following are examples of Exempt ITS projects:

- Upgrades to an existing traffic signal – This may include, for example, adding or revising left turn phasing or other phasing, adding pedestrian-crossing displays;
- Installing an "isolated" traffic signal – This is a signal not connected to any type of external signal-control system, nor likely to be in the future because of its isolation;
- The project adding new intersections could be considered Exempt because it is an expansion of an existing system within the same jurisdiction with no new functionality.
- A signal interconnect project that uses existing software and is on an isolated corridor connecting multiple signals;
- Traffic signal timing projects – This includes all "studies" whose purpose is to change the coordination parameters for controlling a group of signals – but with ***no*** installation of new hardware or software;
- A project to add DMS devices to SmartWay with existing DMS devices could be considered an Exempt project;
- Studies, Plans, Analyses – This includes ITS Master Plans, Deployment Plans, Technology Studies, etc. whose product is only a document, with no new hardware of software installed;
- Routine Operations – This includes operating and maintaining any ITS elements or systems – again with no new hardware or software installed.

	Low-Risk Project Attributes	High-Risk Project Attributes	Risk Factors
1	Single jurisdiction and single transportation mode (highway, transit or rail)	Multi-Jurisdictional or Multimodal	With multiple agencies, departments, and disciplines, disagreements can arise about roles, responsibilities, cost sharing, data sharing, schedules, changing priorities, etc. Detailed written agreements are crucial!
2	No software creation; uses commercial-off-the-shelf (COTS) or proven software	Custom software development is required	Custom software requires additional development, testing, training, documentation, maintenance, and product update procedures - all unique to one installation. This is very expensive, so hidden short-cuts are often taken to keep costs low. Additionally, integration with existing software can be challenging, especially because documentation is often not complete and out-of-date.
3	Proven COTS hardware and communications technology	Hardware or communications technology are "cutting edge" or not in common use.	New technologies are not "proven" until they have been installed and operated in a substantial number of different environments. New environments often uncover unforeseen problems. New technologies or new businesses can sometimes fail completely. Multiple proven technologies combined in the same project would be high risk if there are new interfaces between them.
4	No new interfaces	New interfaces to other systems are required.	New interfaces require that documentation for the "other" system be **complete and up-to-date.** If not (and often they are not), building a new interface can become difficult or impossible. Duplication of existing interfaces reduces the risk. "Open Standard" interfaces are usually well-documented and low risk.
5	System requirements fully detailed in writing	System Requirements not detailed or not fully documented	System Requirements are critical for an RFP. They must describe in detail all of the functions the system must perform, performance expected, plus the operating environment. Good requirements can be a dozen or more pages for a small system, and hundreds of pages for a large system. When existing systems are upgraded with new capabilities, requirements must be revised and rewritten.
6	Operating procedures fully detailed in writing	Operating procedures not detailed or not fully documented	Standard Operating Procedures are required for training, operations, and maintenance. For existing systems, they are often out-of-date.
7	None of the technologies used are near end of service life	Some technologies included are near end of service life	Computer technology changes rapidly (e.g. PC's and cell phones become obsolete in 2-4 years). Local area networks using internet standards have had a long life, but in contrast some mobile phones that use proprietary communications became obsolete quickly. Similarly, the useful life of ITS technology (hardware, software, and communications) is short. Whether your project is a new system or expanding an existing one, look carefully at **all** the technology elements to assess remaining cost-effective service life.

Table 8.1
Risk Assessment for ITS Projects

8.2 ARCHITECTURE

8.2.1 GENERAL

In areas served by a Planning Organization, the Planning Organization needs to identify potential Highway ITS projects to TDOT when reviewing local programs for inclusion in the TIP. A preliminary risk assessment will be made at the time of this identification. This information shall be documented in the **Tennessee ITS Project Identification Checklist**, which will be submitted to TDOT. It shall be the responsibility of TDOT to validate if a project is ITS, and if so, to verify the in preliminary risk assessment provided in the checklist. If the determination of whether a project is ITS or Exempt, or whether a project is a High Risk ITS Project or a Low Risk ITS Project is not obvious, the project shall be discussed with the TDOT Design Division to make a determination. TDOT will notify the Planning Organization and the project sponsor of the determination in writing.

A High Risk ITS Project will require a comprehensive effort that analyzes several options for each type of technology selected, since these types of projects tend to be multifaceted. Generally, there are several elements that need to be evaluated and more options are analyzed in a High Risk ITS Project. If a consultant is used for an ITS Project, these efforts should be included in the consultant's Scope of Work..

In areas not served by a Planning Organization, the TDOT Long Range Planning Office representative will perform the ITS project identifying function. This identification will be made with the **Tennessee ITS Project Identification Checklist**. TDOT will notify the project sponsor of the determination in writing.

8.2.2 ARCHITECTURE CONFORMITY

To ensure conformity with **23 CFR 940**, several requirements must be met. The rule stipulates that conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a Regional ITS Architecture, and the subsequent adherence of all ITS projects to that Regional ITS Architecture.

According to **23 CFR 940.3**, a Regional ITS Architecture is "a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects." It documents data flows and subsystems, roles and responsibilities, operating agreements, and ITS standards to be used for a particular region. In Tennessee, Regional ITS Architectures generally encompass a Planning Organization area. A Statewide ITS Architecture is a form of a Regional ITS Architecture. Tennessee has a Statewide ITS Architecture that was completed in December, 2005. Completed Regional ITS Architectures in Tennessee include Chattanooga, Knoxville, Clarksville, Jackson, Cleveland, Bristol, Kingsport, Johnson City, Memphis, and Nashville.

8.2.3 PROJECT LEVEL ITS ARCHITECTURE

A Project Level ITS Architecture, according to **23 CFR 940.3** is a framework that identifies the institutional agreement and technical integration necessary to interface an ITS project with other ITS projects and systems. The Project Level ITS Architecture indicates the data flows and subsystems that the project will implement. To achieve the significant benefits derived from the documentation, Project Level ITS Architectures needs to be developed for all ITS Projects. The project architecture is especially useful in higher risk projects that are implementing new aspects of a region's ITS architecture.

8.2.3.1 FOR PROJECTS WHERE A REGIONAL OR STATEWIDE ITS ARCHITECTURE EXISTS

If an ITS project falls within the boundaries of a Regional or Statewide ITS Architecture, the Project Level ITS Architecture should be developed as follows:

1.) If the project functions exist in the Regional or Statewide ITS Architecture: create a table of references identifying the data flows that will be addressed by the project. This will satisfy the requirements for a project Level ITS Architecture.
2.) If some project functions do not exist in the Regional or Statewide Architecture: The Project Level ITS Architecture must supplement the Regional or Statewide ITS Architecture with any missing data flows. Create a table of references identifying the data flows that will be addressed by the project and add the additional data flows that will be implemented. The Planning Organization maintaining the Regional ITS Architecture or TDOT for the Statewide Architecture also needs to be notified of the changes, for purposes of updating the ITS Architecture.
3.) If none of the project functions exist in the Regional or Statewide ITS Architecture: A Project Level ITS Architecture shall be created utilizing the Regional or Statewide ITS Architecture and the National ITS Architecture as the basis. The Planning Organization maintaining the Regional ITS Architecture or TDOT for the Statewide Architecture shall be notified of the changes, for purposes of updating the ITS Architecture.

The final design of all ITS projects shall accommodate the interface requirements and information exchanges as specified in the Regional or Statewide ITS Architecture. If the final design of the ITS project is inconsistent with the Regional or Statewide ITS Architecture, then the discrepancies shall be reconciled and the ITS Architecture or the project shall be modified as appropriate.

8.2.4 INTERFACING WITH PLANNING AND THE ITS ARCHITECTURE

Intelligent Transportation Systems at the project level are to be consistent with, and leverage from, the ITS architecture. The ITS architecture provides a framework that supports transportation planning and programming for ITS projects. This step describes what to expect from the ITS architecture and how to use the products at the project level. An existing ITS architecture provides

products / elements that can be leveraged for concept exploration, feasibility analysis, and project level developments.

Before the project level development begins, groundwork is laid in the planning process and the development of an ITS architecture. The ITS architecture includes a list of stakeholders, a system inventory, an identification of the needs and transportation services that meet those needs, a high-level operational concept, functional requirements, and interconnections and information exchanges. The project will refine and expand products from the ITS architecture. For example, it may expand an agency-level stakeholder to identify maintenance, IT, and operations divisions that were not specified at the regional or statewide level. As the project is defined, additional needs and approaches may be identified that were not envisioned at the regional or statewide level. Providing feedback to the planning process and the ITS architecture is essential so that the ITS architecture continues to provide an accurate high-level depiction of ITS implementation and vision for the region.

Tennessee has developed Architectures. These architectures provide a good starting point for project development and must be used to support project systems engineering analysis, per the FHWA Rule / FTA Policy. In some cases, more than one ITS architecture may apply. For example, a major metropolitan area may be included in a statewide architecture, a regional architecture for the metropolitan area, and sub-regional architectures that are developed for a particular agency or jurisdiction. Identify the ITS architecture that applies to the project, coordinating with the architecture maintainers in the region as necessary. Coordinate with the TDOT Design Division, the Planning Organization or architecture maintainer, to take advantage of all previous work that has been done.

Any given ITS project will implement only a small subset of the ITS architecture. The ITS architecture will most likely address many needs and issues that are outside the scope of the project. For example, in a simple signal system that does not interface with freeway devices, the aspects of the ITS architecture that address freeways are not relevant. The first step is to identify the portion of the ITS architecture that applies to the project. Using this subset of the ITS architecture, document any constraints that the architecture may place on the design, including ITS standards that are identified that may be applicable to the project.

Using an ITS architecture will provide a project that is consistent with other systems in the area, meets requirements for federal funding, and can be developed more efficiently and quickly using the ITS architecture content to get started. A good ITS architecture will provide region-level information that can be used and expanded in the project development, providing a good starting point for concept exploration and initial project development.

Confirm that the project fulfills a portion of the ITS architecture. If the project provides capabilities beyond the ITS architecture, the ITS architecture should be

updated to more accurately reflect the ITS project. These changes should be submitted to the maintainer of the architecture.

8.3 SYSTEMS ENGINEERING ANALYSIS (SEA)

8.3.1 GENERAL

Systems engineering is a systematic process that was developed specifically for complex technology projects. Systems engineering processes are required on all highway trust fund projects, as noted in 23 CFR 940.11. Systems engineering processes shall be used on all ITS projects regardless of the funding source.

Systems Engineering is a process-oriented means of deploying a system that leads to reduced risk, controlled cost and schedule, improved system quality, and a resultant system that meets user needs.

Using systems engineering on ITS projects has been shown to increase the likelihood of project success. Projects that are completed on-time and on-budget meet stakeholder / project sponsor expectations, and are efficient to operate and maintain.

There are multiple ways to represent the systems engineering process. One way, the Systems Engineering "V" Diagram (refer to Figure 8.1), represents the typical life cycle of any system or project. Whether the system being deployed consists of a basic computer-aided dispatch (CAD) system for a transit agency, or a more complex interface between a traffic management center and a public safety agency, all systems will follow some variation of this life cycle.

This process is shown as it relates to the traditional Project Development Process. As shown in the figure, the systems engineering process contains a number of stages that are not included in the traditional project delivery process.

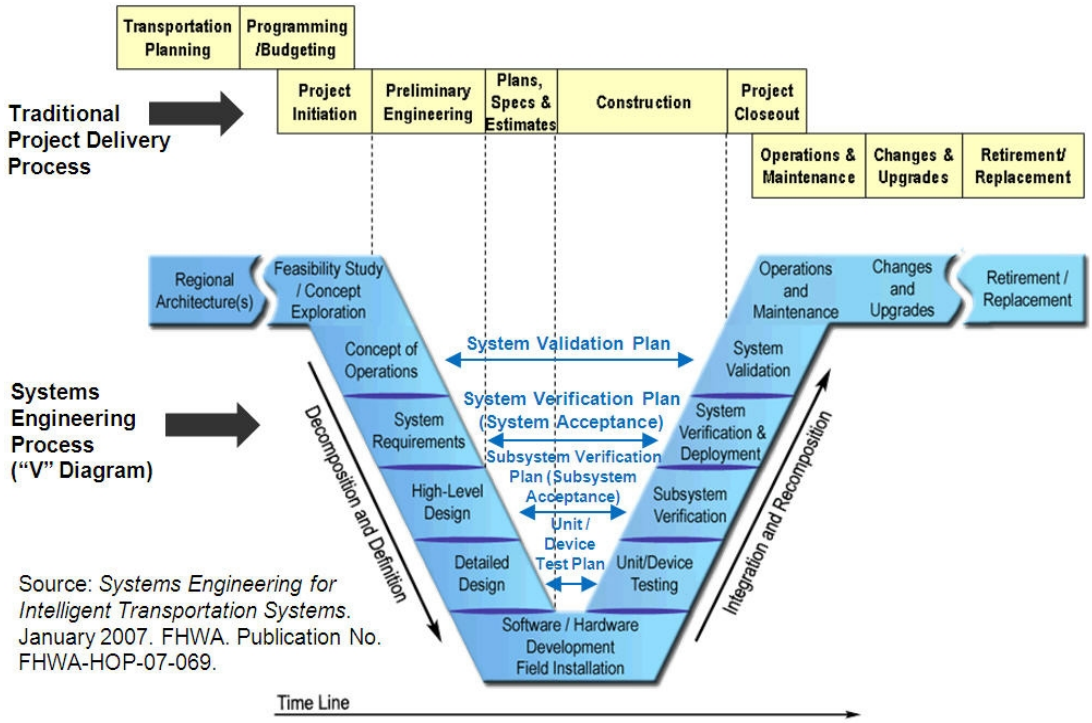

Figure 8.1 – Systems Engineering in Relation to the Project Development Process

Stage 1: Concept of Operations – The manner in which the system will be used is defined.

Stage 2: Requirements – High-level and detailed requirements define what the system will do.

Stage 3: Design – High-level and detailed specifications define how the system will meet the requirements.

Stage 4: Implementation – The components are built or deployed.

Stage 5: Integration & Testing – As each component of the system is completed, it is integrated into the overall system and tested to ensure that the specifications are satisfied.

Stage 6: System Verification – also called acceptance testing; this step ensures that the overall system is consistent with the design, and that it meets the requirements.

Stage 7: Operations & Maintenance – This stage represents the ongoing process of using the system in the manner in which it was intended (and validating that it can be used in this way) and maintaining the system.

An ITS project begins in the upper left side of the "V" diagram and progresses down the "V" and up the right side. Upon reaching the upper right corner, reverse the process to ensure the project being completed meets the initial requirements.

During the “Component Level Design,” specific subsystems and / or components (such as wireless communications, variable message signs, cameras, roadway weather information systems, highway advisory radio systems, or software) should be identified as requiring specialized knowledge and skills. These issues are to be coordinated between the Project Engineer and the TDOT Design Division.

Construction oversight and approvals are addressed in the systems engineering process as you validate / verify the right side of the “V” diagram with the left side. The key to successful construction oversight is traceability. Trace each step on the right side of the “V” diagram back to a requirement on the left side.

Completing the TDOT SEA Form (available on the TDOT Design Division website as outlined in Section 8.3.4.) will fulfill the minimum requirements for a project. However, the level of systems engineering used for a project should be on a scale commensurate with the scope, size, and risk of the project. High-risk ITS projects (such as developing a new custom software system for sharing control of traffic signal systems across multiple agencies) should follow and document each step of the “V” diagram by completing the Systems Engineering Management Plan.

Include all ITS systems engineering documentation in the Design Documentation Package. All systems engineering documentation requires TDOT Design Division approval. As each phase of an ITS project is completed, the SEA document is to be submitted to the TDOT Design Division.

Systems engineering costs are to be estimated and incorporated into the construction engineering (CE) and preliminary engineering (PE) portions of the construction estimate.

Since the SEA documentation is a “living document” as the project progresses, early stages of the documentation shall be updated and submitted with the current submission.

8.3.2 LEVEL OF DOCUMENTATION

The figure below outlines the procedures that should be followed in identifying the level of documentation necessary to meet the requirements for compliance.

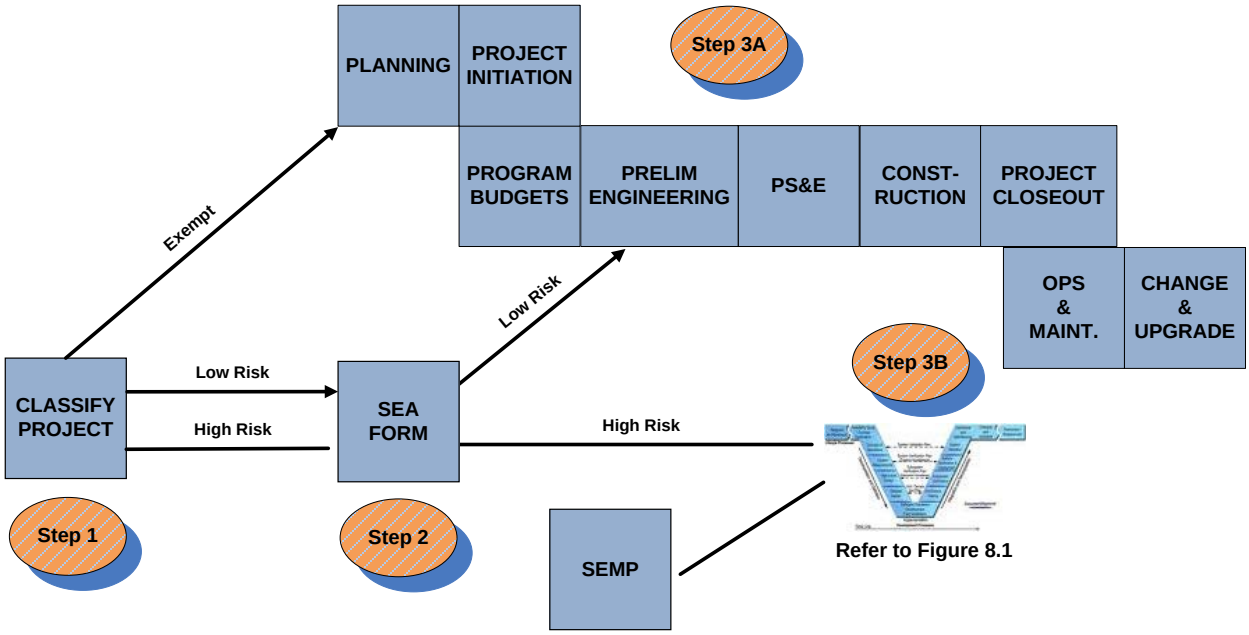

Figure 8.2 – Steps to ITS Compliance

Step 1

All ITS projects must be listed on the STIP / TIP prior to obligation of funds. However, many ITS projects are not required to be listed individually, since they are classed as air quality exempt. Such projects may be lumped together in the program. If a traditional roadway design project contains an ITS element, then the requirement for STIP / TIP listing is determined by the overall project.

Because of this variation in project classification, projects with ITS elements may not be identified. For this reason, the Planning Organization is encouraged to coordinate with the TDOT Design Division (project sponsors) to “flag” ITS projects, or at least note the High-Risk ITS projects, within their STIP submittal to TDOT / FHWA.

By using the guidelines contained in this chapter the TDOT Design Division will make a preliminary classification of the project’s risk as exempt, low, or high.

If the project is considered Exempt, then all activities of the traditional roadway project development life-cycle process will be followed. Exempt projects are not considered “ITS” for purposes of these procedures and no further ITS-specific action is necessary.

Step 1 occurs when the ITS project is added to the Transportation Improvement Program (TIP). The Design Division makes a preliminary classification of the project as High-Risk, Low-Risk, or Exempt. If the project is Exempt, then the remainder of the process is exactly the same as for a traditional road building project. Low-Risk and High-Risk projects proceed to Step 2.

Step 2

This step occurs when initial funding is requested. The Project Manager must fill out applicable sections of the Systems Engineering Analysis Form, which consists of 12 questions. This Form is available on the TDOT Design Division website as outlined in Section 8.3.4. Based on the level of detail, the project is classified as Low-Risk or High-Risk, then proceed accordingly.

Step 3a

For Low-Risk projects, the remainder of the process (after FHWA approval) is exactly the same as for a traditional road building project. However, as the project progresses all remaining undocumented questions shall be completed.

Step 3b

For High-Risk projects, the traditional road building process is not appropriate. Instead, the best approach is usually a Systems Engineering process. This is definitely the case for projects that include software development. A Systems Engineering Management Plan (SEMP) must be completed during the first funding cycle to help manage the implementation and testing. A sample template, along with a checklist, is available on the TDOT Design Division website as outlined in Section 8.3.4.

The required SEA documentation and information to be included at the appropriate Plans Submittal stage are outlined below:

a. Preliminary SEA Document
    i. Submitted during conceptual phase
    ii. Includes SEA Items 1 thru 4
b. 30% SEA Document
    i. Includes SEA Items 1 thru 4 and 10
c. 30% Plans
    i. Preliminary device locations
    ii. Communication alternatives
    iii. Possible power service locations
    iv. Sufficient right-of-way (ROW) to make a determination of proposed location
    v. Utility providers identified
d. 60% SEA Document
    i. Includes SEA Items 1 thru 7 and 10
e. 60% Plans
    i. Survey completed

ii. Detailed survey and device placement
iii. Communication and electric routing shown
iv. ROW determined
v. Bucket truck surveys completed
vi. Ongoing utility coordination
vii. Typical and communication details developed
viii. Utility conflicts identified
ix. Permit review information compiled
x. Erosion control plan
xi. Preliminary estimate in electronic format

f. 90% SEA Document
   i. Includes SEA Items 1 thru 12
   ii. Change management document outlining changes through prior phases

g. 90% Plans
   i. Final details
   ii. Final communication plans
   iii. Final items and quantities
   iv. Final special provisions
   v. Final bid documents

All ITS projects shall be based on a Systems Engineering Analysis (SEA). The scale of the analysis should be on a scale commensurate with the project scope of the ITS portion of the project.

An SEA is a process or a structured approach which can control costs, lead to reduced risks, maintain the project schedule, satisfy user needs, and meet the requirements of TDOT and the Federal regulation. The SEA effort will vary based on the complexity of the project and the type of ITS project.

An SEA will provide a description of the scope of the ITS project (the general location, conceptual alternative, and logical termini or service area of the proposed project), a concept of operations that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the ITS project, functional requirements of the ITS project, interface requirements and information exchanges between the ITS project and other planned and existing systems and subsystems, and identification of applicable ITS standards.

The SEA is broken into twelve items to be addressed. The twelve items are discussed in **Section 8.3.3.1 Required Systems Engineering Analysis Documentation for Low Risk and High Risk Projects**.

8.3.3 ITS STANDARDS IN THE SYSTEMS ENGINEERING PROCESS

National ITS Standards are primarily used in the design stage of the systems engineering process, after a high-level design (project architecture) has been developed. During the detailed design phase, specific messages, data elements, communications profiles, and design options are defined.

The systems engineering process is used during the development of ITS standards, as well. Some standards include sections which document this process to help ITS deployers with interpreting and using the standard. For example, the concept of operations developed for an ITS standard may help ITS project designers to conceptualize how messages might be exchanged between systems, such as the order in which control information is sent to a field device and the type of status returned. Additionally, the high-level and detailed requirements developed for an ITS standard might be used to create system functional requirements that could also be used later during system verification.

Standards can be included in a procurement specifications by documenting all of the standards applicable to the ITS systems deployment. You must also specify the definitions, references, options, and requirements, where applicable, for each standard to be used in the system. The procurement specifications will also include the standards conformance and acceptance tests that the systems must pass. Vague statements to the effect that the systems must be "ITS standards compliant" or must "conform to" specific standards are not sufficient. Resources that can be used for assistance with procurement specifications are:

- The NTCIP Guide available at:
  http://www.ntcip.org
- USDOT's ITS technical assistance resources available at:
  http://www.standards.its.dot.gov/deploy_Technical.asp

8.3.3.1 REQUIRED SYSTEMS ENGINEERING ANALYSIS DOCUMENTATION FOR LOW RISK AND HIGH RISK PROJECTS

All submissions required by the TDOT Project Development Process shall also be required for ITS projects. A Project Level ITS Architecture and a Systems Engineering Analysis (SEA) are required for any ITS project, whether High Risk ITS or Low Risk ITS. The documentation will be more extensive for High Risk ITS projects than for Low Risk ITS projects, and is expected to be commensurate with the scope of the ITS work. Both the Project Level ITS Architecture and the SEA must be completed and approved prior to authorization of construction funding. The SEA will consist of items 1 through 12, listed below. A SEA Form is available on the Design Division website as outlined in Section 8.3.4.

SEA Item #1 – Define the scope of work for the project (PIN#, State / Federal Project #, the general location, conceptual alternative, level of development and logical termini or service area of the proposed project). Scoping shall also include inter-agency coordination and possible effects on neighboring jurisdictions.

Include the location, project description, description of the ITS work, and the project background (summary of purpose and need).

Be as descriptive as possible and briefly address any proprietary equipment / software requirements.

SEA Item #2 – Identify portions of the Regional or Statewide ITS Architecture being implemented.

If the portion does not exist in the Architecture, identify applicable portions of the National ITS Architecture. Include identification of the ITS User Services which will apply to the project and a graphic from the Architecture illustrating the data flows that will be incorporated.

Inclusion of SEA Item #2 will satisfy the Project Level ITS Architecture requirements. The use of the FHWA software product *Turbo Architecture* is required by TDOT.

SEA Item #3 – Provide a list of all stakeholders that have a direct role in the project, including the roles and responsibilities of each, their Concept of Operations, and Operational Concept.

Provide an Operational Concept. The Operational Concept is a high level description of the roles and responsibilities of the primary stakeholders and the systems they operate.

Provide a Concept of Operations. The Concept of Operations is a more detailed description of how the system will be used. It should discuss what the project is to accomplish, including identifying stakeholder needs and resources that stakeholders can provide. It is non-technical and provides a bridge between the needs motivating the project and the specific technical requirements. The greater the expected impact on operations, the more detailed explanation will be required. For complex projects, operational scenarios may be necessary to illustrate the operations.

SEA Item# 4 – Define the functional requirements of the project.

The functional requirements of the project describe how the project will be built and operated. High level functional requirements should be listed and can further be used to develop specific contract specifications language.

Provide interface / communication requirements for all stakeholders in the project. This includes the existing systems already deployed in the region.

Functional requirements are statements of the capabilities that a system must have "functions", geared to addressing the business needs that a system must satisfy. Business needs are the objectives for which the system is built. These functional requirements will be traced through the life of the project.

A key aspect of the functional requirements is that they address what a system must do, but does not address how the system should accomplish the "what". In other words, a functional requirement should not go into the details of how to implement the function.

SEA Item# 5 – Provide analysis of alternative system configurations and technology options to meet requirements, including rationale for technology selection.

Describe the basis of the project scope and how it was developed. Identify any proprietary items and explain the necessity and rationale for these items. Show the link between the system design concept and the operations and maintenance of the constructed project.

SEA Item# 6 – Provide analysis of procurement methods considered including rationale for selected option.

Describe possible procurement methods for the design, construction, and operations / maintenance (as applicable) of the project and why the preferred method was selected. In some cases, the procurement methods may be determined by State law.

SEA Item# 7 – Identify the existing applicable ITS Standards that will be used in the project. An explanation is required for not using the applicable standards.

ITS Standards are available on-line from the FHWA website. List all ITS Standards which may be applicable to the project, indicate if the Standard is to be used in the project and if not used, and provide an explanation of why they are not being used. For more information, visit FHWA web page: http://www.standards.its.dot.gov/learn_Application.asp. Turbo Architecture includes a listing of the applicable standards to a region or project based on the interfaces selected. (Most regional architectures include this report, but it can be tailored further for a project.)

SEA Item# 8 – Identify the testing procedures to verify compliance with the standards as well as the requirement for interoperability.

The testing procedures verify the individual elements of the project comply with the project specifications. The specifications are based upon the high level functional requirements identified in SEA Item #4.

SEA Item# 9 – Provide a traceability matrix for documenting compliance with SEA #8.

The traceability matrix provides a mechanism for ensuring that each functional requirement is tested and that each item to be tested has been addressed in the specifications. It is meant to provide a trace from needs to requirements to design and verification

A sample traceability matrix can be found on the TDOT Design Division website as outlined in Section 8.3.4.

The traceability matrix will be included in the contract documents for use during construction.

The completed traceability matrix will include the results of the test and any necessary work needed to address failures during the test and will be included in the project construction records.

SEA Item# 10 – Provide change management control.

Provide a description of the change management control. Describe what changes were made during project development, how changes were accommodated, and how change orders will be processed and managed during construction, including identifying necessary approvals. In many cases, standard procedures used by TDOT will incorporate many of these items.

This item requires documentation of changes in design, construction, and operations.

SEA Item# 11 – Provide a Maintenance Plan and a funding analysis for the maintenance and operation of the system after completion. This includes an analysis of cost, personnel, software, utilities, and anything further required to maintain and operate the system, typically on an annual basis.

SEA Item# 12 – Provide documentation for revising the ITS Architecture after construction. This should highlight existing data flows (ones that currently exist), planned data flows (as part of this project), and future data flows (flows that are still planned to be implemented sometime in the future).

This information can be shown by utilizing a different line style representing the data flows between elements.

Contact the appropriate Planning Organization for preferred or required formats for submitting this information.

8.3.4 ADDITIONAL REQUIREMENTS

For TDOT managed projects, it is anticipated that the required documentation will be prepared by the TDOT Design Division.

Forms, templates, and checklists are provided on the TDOT Design Division website for use in the preparation of the SEA at the following address:

http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/TDM_Chapter_8_ITS_Templates_and_Checklists.zip.

The forms, templates, and checklists provided have been customized for TDOT and are based on the documents provided by the U.S. DOT Federal Highway Administration in the Systems Engineering Guidebook for ITS. This site is available at the following address:

http://www.fhwa.dot.gov/cadiv/segb/views/checklist/index.htm.

Documentation shall be submitted electronically.

In addition, when the project is covered by a ITS Architecture, the as-built Project Level ITS Architecture with any modifications noted, shall be submitted by the local agency to the appropriate planning organization for updating the Regional ITS Architecture.

If any uncertainty exists regarding design requirements, standards, forms, project risk category, or other ITS requirements, the project sponsor should contact the TDOT Design Division.

INDEX

Page

Accessible Pedestrian Signal Detectors 4-43
Accessible Pedestrian Signals 4-42
Actuated Timing Intervals 4-48
Added Initial 4-54
Advance Detection 4-27, 4-49
All Red Clearance Interval 4-59
Audible Conformation 4-43
Backplates 4-78
Box Span 4-92
Blank Out Signs 4-76, 6-5
Cable Lashing 4-99
Cable Sizing 4-99
Closed Loop Signal System 4-64
Collision Diagram 3-5
Condition Diagram 3-5
Concurrent Pedestrian Movement 4-38
Conduit 4-99, 4-102
Coordinated Timing Plans 4-65
Countdown Pedestrian Signals 4-38, 4-87
Critical Lane Volume Method 4-46
Crosswalks 6-8
Cycle Length 4-46
Dilemma Zone 4-27
Driveways Within Signalized Intersections 4-107
Dual Ring Controller Operation 4-8
Emergency Vehicle Preemption 4-67
Emergency Vehicle Traffic Control Signals 5-1
Exclusive Pedestrian Movement 4-38
Fixed Time ..... *See Pre-Timed Operation*
Flashing Beacons 5-1, 5-3
Flashing Don't Walk ..... *See Pedestrian Change Interval*
Flashing Operations 4-106
Fully-Actuated Operation 4-5
Gap Reduction 4-51, 4-54
Green Interval 4-46, 4-48
Ground Mounted Signs 6-6
Highway Traffic Signals 3-1, 5-1
Inductive Loop Detection 4-31
Initial Gap 4-56
Interchange Lighting 7-2
Intersection Control Beacons 5-1, 5-3
Lagging Left Turns 4-18
Lane Control Signs 6-3
Lane-Use Control Signals 5-1

Last Car Passage 4-57
Lead-Lag Left Turns 4-13, 4-18, 4-20
Leading Left Turns 4-15
LED 4-18
Left Turn “Yellow Trap” 4-78
Left Turn Phase Warrants 4-10
Left Turn Signal Signs 4-11, 6-3
Left Turn Signals 4-11, 4-85
Left Turn Movements 4,10 4-11, 4-15, 4-20
Left Turn Phasing ..... *See Left Turn Movements*
Locking Memory 4-25
Loop Detectors ..... *See Inductive Loop Detection*
Luminaire Mounting Height 4-105, 7-3
Maximum Green 4-49
Maximum Initial 4-52
Maximum Recall 4-37
Microwave Detection 4-34
Minimum Gap 4-56
Minimum Green 4-48, 4-52
Minimum Initial 4-52
Minimum Recall 4-37
New Traffic Signal Inspection 4-108
Non-Locking Memory 4-25
Offsets 4-66
Optically Activated Emergency Vehicle Preemption 4-69
Overhead Signs 6-3
Passage Time 4-49, 4-56
Pavement Markings 6-8
Pedestrian Actuation 4-40
Pedestrian Phase Timing 4-60
Pedestrian Pushbuttons 4-40
Pedestrian Signal Indications 4-85
Pedestrian Signal Interval 4-37
Pedestrian Signal Warrants 4-37
Pedestrian Signals 3-1, 4-37, 4-42, 4-60
Pedestrian Walking Speed 4-60
Permissive Only Left Turns 4-11
Phase Numbering 4-21
Phase Recalls 4-37
Pole Height 4-94, 4-98
Pole Location 4-95, 4-98
Polycarbonate Traffic Signal Heads 4-78
Preemption 4-66
Preformed Inductive Loops 4-31
Preset Timing Intervals 4-45
Pre-Signals 4-73
Pre-Timed Operation 4-3
Pre-Timed Timing Intervals 4-45

Priority Control 4-66, 4-67, 4-70
Programmable Signal Heads 4-87
Protected Only Left Turns 4-13
Protected/Permissive Left Turns 4-11
Pull Boxes 4-103
Pushbutton Locator Tone 4-43
Railroad Preemption 4-70
Railroad Preemption Warning Timing 4-76
Ramp Control Signal 5-1
Right Turn Indications 4-21, 4-85
Roadway Lighting 7-1
School Zone Speed Limit Beacons 5-5
Semi-Actuated Operation 4-7
Signal Ahead Beacons 5-7
Signal Wiring 4-98
Siren Activiated Emergency Vehicle Preemption 4-69
Span Wire 4-92
Speed Limit Sign Beacons 5-1, 5-5
Split Phase 4-15, 4-80, 4-107
Splits 4-46, 4-61
Spread Spectrum Radio 4-65
Stop Beacons 5-1, 5-5
Stop Line Detection 4-27
Stop Lines 6-8
Stop Signs At Signalized Intersections 4-107
Strain Poles 4-89, 4-92
Street Name Signs 6-6
Suspended Box Span 4-92
Tether Wire 4-95
Time Base Coordination 4-63
Time Before Reduction 4-56
Time To Reduce 4-56
Traffic Actuated Operation 4-5
Traffic Control Devices 1-1
Traffic Control Signals ..... *See Traffic Signals*
Traffic Counts 3-4
Traffic Signals 3-1, 4-1
Traffic Signal Activation Procedures 4-109
Traffic Signal Cabinets 4-88
Traffic Signal Controllers 4-3, 4-8, 4-87
Traffic Signal Coordination 4-63
Traffic Signal Design 4-2
Traffic Signal Heads 4-78, 4-80
Traffic Signal Mode Of Operation 4-3
Traffic Signal Movements 4-3
Traffic Signal Poles ..... *See Traffic Signal Supports*
Traffic Signal Related Signs 6-3
Traffic Signal Supports 4-89

Traffic Signal Timing....4-10, 4-45
Traffic Signal Warrants....3-5
Traffic Signals....1-1, 3-1, 4-1
Traffic Signs....6-1
Turn Prohibition Signs....6-5
Variable Initial....4-51, 4-54
Vehicle Clearance Intervals....4-58
Vehicle Detection....4-25
Vehicle Extension....*See Passage Time*
Vibrotactile Confirmation....4-43
Video Detection....4-34
Volume Density Timing Intervals....4-51
Volume-Density Operation....4-7
Walk Interval....4-37, 4-60
Walking Speed....*See Pedestrian Walking Speed*
Warning Beacons....5-1, 5-7
Yellow Change Interval....4-58
Yellow Clearance Interval....*See Yellow Change Interval*
Yellow Trap....*See Left Turn Yellow Trap*
Z Span....4-94

APPENDIX

GLOSSARY

Acceptance – an action by an authorized representative of the owner by which the acquirer assumes ownership of products/services as a partial or complete performance of contract.

Acceptance Criteria – the criteria a product must meet to successfully complete a test phase or meet delivery requirements.

Acceptance Test – formal testing conducted to determine whether or not a system satisfies its acceptance criteria and to enable the acquirer to determine whether or not to accept the system.

Accessible Pedestrian Signal – a device that communicates information about pedestrian timing in nonvisual format such as audible tones, verbal messages, and/or vibrating surfaces.

Active Grade Crossing Warning System – the flashing-light signals, with or without warning gates, together with the necessary control equipment used to inform road users of the approach or presence of trains at highway-rail grade crossings or highway-light rail transit grade crossings.

Actuated Operation – the type of traffic signal operation that responds and adjusts to vehicle or pedestrian detection.

Actuation – the presence of a vehicle or pedestrian as indicated by an input to the controller from a detector or the action of a vehicle or pedestrian which causes a detector to generate a call to the signal controller.

Acquirer – an organization that procures products for itself or another organization.

Added Initial Interval (or Portion) – a volume density controller feature where an amount of time added to the minimum initial green time to accommodate to vehicles which arrived during the preceding Red Interval.

Allowable Gap – same as “Passage Time” in basic actuated operation. In volume density operation, it is the initially the Passage Time, but is reduced to the Minimum Gap during the Time to Reduce.

All-Red Clearance Interval – an optional interval that follows a Yellow Change Interval and precedes the next conflicting Green Interval, during which all signal indications at the intersection display RED indications.

Anchor Bolt – a steel bolt used to connect a pole to the foundation. It is threaded at one end and bent at the other to resist pullout.

Approach – all lanes of traffic that enter the intersection from the same direction.

Approval – written notification by an authorized representative of the acquirer that the developer's plans, design, or other aspects of the project appear to be sound and can be used as the basis for further work. Such approval does not shift responsibility from the developer to meet contractual requirements.

Architecture – the organizational structure of a system, identifying its components, their interfaces, and a concept of execution among them.

Assembly – a number of parts or sub-assemblies, or any combination thereof joined together, to perform a specific function and capable of disassembly.

Audit – an evaluation of a system, process, project. A procedure performed to ascertain the validity and reliability of information; and to provide as assessment of a system.

Authentication – the procedure (essentially approval) used by the approving authority in verifying that specification content is acceptable. Authentication does not imply acceptance or responsibility for the specified item to perform successfully.

AWG – American Wire Gauge. The standard measurements of wire size. It is based on the circular mil system. 1 Mil equals .001"

Average Initial Illuminance - The average level of horizontal illuminance on the pavement area of a traveled way at the time the lighting system is installed when lamps are new and luminaires are clean, expressed in average footcandles (lux) for the pavement area.

Average Maintained Illuminance - The average level of horizontal illuminance on the roadway pavement when the output of the lamp and luminaire is diminished by the maintenance factors; expressed in average footcandles (lux) for the pavement area.

Background Cycle – term used in coordination systems to identify the cycle lengths established by coordination unit and master control.

Backplate – a thin strip of material that extends outward from and parallel to a signal face on all sides of a signal housing to provide a background for improved visibility of the signal indications.

Ballast - A device used with an electric-discharge lamp to obtain the necessary circuit conditions (voltage, current, and waveform) for starting and operating.

Bandwidth – the amount of green time available to a platoon of vehicles in a signal system.

Baseline – an approved product at a point in time. Any changes made to this product must go through a formal change process.

Beacon – a highway traffic signal with one or more signal sections that operates in a flashing mode.

Cable – A group of separately insulated conductors wrapped together and covered with an outer jacket.

Call (see Actuation also) – a registration of a demand for right-of-way by traffic (vehicular or pedestrian) to a controller.

Candela – the unit of luminous intensity (the force generating the luminous flux). Formerly the term "candle" was used.

Candela per square meter (cd/m^2) - The International System (SI) unit of luminance (photometric brightness) equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square meter, or the average luminance of any surface emitting or reflecting light at that rate. One candela per square meter equals 0.2919 footlambert.

Candlepower (cp) - candlepower (cp) luminous intensity expressed in candelas (not an indication of total light output.)

Certification – a process, which may be incremental, by which a contractor provides evidence to the owner that a product meets contractual or otherwise specified requirements.

Channelizing Island – curbed or painted area outside the vehicular path that is provided to separate and direct traffic movement, which also may serve as a refuge for pedestrians.

Clearance Interval – the interval from the end of the right-of-way of a phase to the beginning of a conflicting phase. This is usually the Yellow Change Interval plus any All Red timing for vehicles and flashing don't walk for pedestrians.

Clear Zone – the total roadside border area, starting at the edge of the traveled way that is available for an errant driver to stop or regain control of a vehicle. This area might consist of a shoulder, a recoverable slope, and/or a non-recoverable, traversable slope with a clear run-out area at its toe.

Closed-Loop System – a signal system capable of controlling some operation by implementing certain system strategies, receiving inputs which permit the rapid evaluation of the effects of the control, and then taking some action which modifies the strategy on the basis of the evaluation, all without the need for the operator input.

Coefficient of utilization (CU) - The ratio of the luminous flux (lumens) from a luminaire received on the surface of the roadway to the lumens emitted by the luminaire's lamps alone.

Commercial off-the-shelf Software (COTS) – commercially available applications sold by vendors through public catalogue listings, not intended to be customized or enhanced. (Contract-negotiated software developed for a specific application is not COTS software.)

Components – components are the named "pieces" of design and/or actual entities (sub-systems, hardware units, software units) of the system/sub-system. In system/sub-system architectures, components consist of sub-systems (or other variations), hardware units, software units, and manual operations.

Computer Database – see database.

Computer Hardware – devices capable of accepting and storing computer data, executing a systematic sequence of operations on computer data, or producing control outputs. Such devices can perform substantial interpretation, computation, communication, control, or other logical functions.

Computer Program – a combination of computer instructions and data definitions that enable computer hardware to perform computational or control functions.

Computer Software – see software.

Concept Exploration – the process of developing and comparing alternative conceptual approaches to meeting the needs that drive the project.

Concept of Operations – a document that defines the way the system is envisioned to work from multiple stakeholder viewpoints (Users including operators, maintenance, management).

Concept (Project Concept) – a high-level conceptual project description, including services provided and the operational structure.

Conductor – a medium for transmitting electrical current. A conductor usually consists of copper or other materials.

Conduit – a tube or enclosure for containing and protecting electrical wires or cables.

Configuration Item (CI) – a product such as a document or a unit of software or hardware that performs a complete function and has been chosen to be placed under change control. That means that any changes that are to be made must go through a change management process. A baseline is a configuration item.

Configuration Management – a discipline applying technical and administrative direction and surveillance to identify and document the functional and physical characteristics of Configuration Items (CI's); audit the CI's to verify conformance to specifications, manage interface control documents and other contract requirements control changes to CI's and their related documentation; and record and report

information needed to manage CI's effectively, including the status of proposed changes and the implementation status of approved changes.

Configuration Management Plan – a plan defining the implementation (including policies and methods) of configuration management on a particular program/project.

Configuration Status Accounting (CSA) – is the recording and reporting of information needed to manage configuration items effectively, including: 1) A record of the approved configuration documentation and identification numbers. 2) The status of proposed changes, deviations, and waivers to the configuration. 3) The implementation status of approved changes. 4) The configuration of all units of the configuration item in the operational inventory. 5) Discrepancies from Functional and Physical configuration audits.

Conflicting Call – a demand for service, which occurs on a conflicting phase not having the right-of-way at the time the demand for service is placed.

Conflict Monitor – see Malfunction Management Unit.

Contract – a mutually binding legal relationship obligating a seller to furnish the supplies or services (including construction) and a buyer to accept and pay for them. It includes all types of commitments, in writing, that obligate the buyer to an expenditure of appropriate funds. In addition to bilateral agreements, contracts include, but are not limited to, awards and notices of awards; job orders or task letters issued under purchase orders under which the contract becomes effective by written acceptance or performance; and bilateral modifications.

Contractor – an individual, partnership, company, corporation, association or other service, having a contract with a buyer for the design, development, manufacture, maintenance, modification, or supply of items under the terms of a contract.

Controller (or Controller Unit) – the device that determines which signal indications are to be illuminated at any given time. The controller is usually located in a cabinet near the intersection.

Coordination (Coordinated Mode) – the control of controller units in a manner to provide a relationship between specific green indications at adjacent intersections in accordance with a time schedule to permit continuous operation of groups of vehicles along the street at a planned speed.

Cross-cutting Activities – enabling activities used to support one or more of the life cycle process steps.

Crosswalk – that part of a roadway at an intersection that is included within the extensions of the lateral lines of the sidewalks on opposite sides of the roadway, measured from the curb line or, in the absence of curbs, from the edges of the roadway. Also, any portion of a roadway at an intersection or elsewhere that is distinctly indicated for pedestrian crossing by lines or other markings on the surface.

Curb Ramp – a ramp cutting through a curb or built up to it for pedestrians.

Cycle length – the time taken for a complete sequence of all phases at an intersection. This time is counted from the start of green for any phase until that same phase is started again. Pre-timed cycle lengths do not vary, but actuated cycle lengths do because of skipped phases, extensions, etc.

Data – recorded information, regardless of medium or characteristics, of any nature, including administrative, managerial, financial, and technical.

Database – a collection of related data stored in one or more computerized files in a manner that can be accessed by users or computer programs via a database management system.

Database Management System – an integrated set of computer programs that provide the capabilities needed to establish, modify, make available, and maintain the integrity of a database.

Data Product – information that is inherently generated as the result of work tasks cited in a Statement of Work (SOW) or in a source document invoked in the contract. Such information is produced as a separate entity (for example, drawing, specification, manual, report, records, and parts list).

Delay – time lost while traffic impeded in its movement by some element over which it has no control. Usually expressed in seconds per vehicle.

Delayed Call – a call from a detector whose output is delayed for a pre-determined length of time. Usually used in turn lanes where vehicles may frequently turn on a RED indication.

Density – a measure of the concentration of vehicles, stated as the number of vehicles per mile per lane. Density = Volume/Distance

Deployment Plan – is the final step in the development of a system. It is developed based on a thorough analysis of the steps necessary to achieve the deployment goals of the project. It both serves to justify the strategy for deployment and to inform all deployment participants (and other stakeholders) of what will happen and what they will be required to do.

Design – those characteristics of a system or components that are selected by the developer in response to the requirements

Design Specification – describe how the system is to be built. Take the requirements (what the system will do) and translate them into a hardware and software design that can be built. Collectively, the purpose of these documents is to:

- Provide a documented description of the design of the system that can be reviewed and approved by the stakeholders;

- Provide a description of the system in enough detail that its component parts can be procured and built;
- Provide a description of the hardware and software system components in sufficient detail for them to be maintained and upgraded.

For most projects, two levels of design specifications are developed. The High Level Design Specification Document supports the project architecture, interfaces, and sub-system requirements and is typically developed along with the Concept of Operations. The Detailed Design Specification Document provide the build-to specification for software and hardware construction and is developed during the Preliminary Engineering phase.

Detailed Design Document – the product baseline used to develop the hardware and software components of the system.

Detectable Warning – a surface feature built in or applied to walking surfaces or other elements to warn of hazards on a circulation path.

Detector – a device used for determining the presence or passage of vehicles or pedestrians.

Detector Mode – a term used to describe the operation “pulse” or “presence” of a detector channel output when the detection of a vehicle or pedestrian occurs.

Detection Zone – that area of the roadway within which a vehicle will be detected by a vehicle detector. This area may also be called the “zone of detection” or “sensing zone.”

Developer – an organization that develops products ("develops" may include new development, modification, reuse, reengineering, maintenance, or any other activity that results in products) for itself or another organization.

Development Model – a specific portion of the life cycle model that relates to the definition, decomposition, development, and implementation of a system or a part of a system.

Development Strategy – the way the development and deployment of the overall system will be carried out. For example, an evolutionary development strategy means that the system will be developed and deployed in multiple segments over time. These pieces are complete functional units that will perform independently from other functional pieces. Incremental development is the development of pieces that are done concurrently or nearly concurrently by the same or different development teams.

Dilemma Zone – a distance or time interval related to the onset of the Yellow Change Interval. The term describes a portion of the roadway in advance of the intersection which a driver can neither stop prior to the stop line nor clear the intersection after the initiation of the Yellow Change Interval and before conflicting traffic is released.

Disability glare - Glare resulting in reduced visual performance and visibility— often accompanied by discomfort. See veiling luminance.

Discomfort glare - Glare producing discomfort. It does not necessarily interfere with visual performance or visibility.

Elicitation – the process to draw out, to discover and to make known so to gain knowledge and information, often used in defining needs.

Emergency Vehicle Traffic Signal – a special traffic signal that assigns the right-of-way to an authorized emergency vehicle.

End Products – products that perform the desired capability; e.g. the hardware, software, communications, and databases.

Evaluation – the process of determining whether an item or activity meets the specified criteria.

Extendable Period (or Portion) – that variable length part of the Green Interval which follows the initial portion in an actuated controller.

Extension Limit – the maximum time allowed for the extendable portion of the green in an actuated controller.

Feasibility Assessment – a pre-development activity to evaluate alternative system concepts, selects the best one, and verifies that it is feasible within all of the project and system constraints.

Firmware – the combination of a hardware device and computer instructions and/or computer data that resides as read-only software on the hardware device.

Flasher – a device used to turn traffic signal indications on and off at a repetitive rate of approximately once per second.

Flashing Mode – a mode of operation in which a traffic signal indication is turned on and off repetitively.

Footcandle (fc) - The unit of illumination when the foot is taken as the unit of length. It is the illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illumination produced on a surface, all points of which are at a distance of one foot from a directionally uniform point source of one candela.

Footlambert (fl). A unit of luminance (photometric brightness) equal to 1/π candela per square foot, or to the uniform luminance of a perfectly diffusing surface emitting or

reflecting light at the rate of one lumen per aquare foot, or to the average luminance of any surface emitting or reflecting light at that rate. See luminance and candela per square meter.

Force-Off – a controller command that forces the termination of the right-of-way for a phase. Used in preemption and coordination.

Free Flow – traffic flow which is not impeded.

Free Mode – The operation of a traffic signal controller in an uncoordinated mode (opposite of coordinated mode). The controller may still be in a signal system, but does not operate in a coordinated mode at any time it is in free mode or isolated mode.

Fully Actuated Operation – a type of traffic signal operation in which all signal phases function on the basis of actuation.

Gap – the time interval time or distance from the back of one vehicle to the front of the following vehicle, usually measured in time.

Gap Analysis – a technique to assess how far current (legacy) capabilities are from meeting the identified needs, to be used to prioritize development activities. This is based both on how far the current capabilities are from meeting the needs (because of insufficient functionality, capabilities, performance or capacity) and whether the need is met in some places and not others.

Gap Out – in an actuated controller, the termination of a green phase due to an excessive time in between the actuation of vehicles arriving on the green.

Gap Reduction – a volume density controller feature whereby the Allowable Gap or allowed time spacing between successive vehicle actuations on the phase displaying the green in the extendable portion of the interval is reduced from the Passage Time to the Minimum Gap.

Glare - The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eves are adapted to cause annoyance, discomfort, or loss in visual performance and visibility. See disability glare and discomfort glare.

NOTE: The magnitude of the sensation of glare depends on such factors as they size, position, and luminance of a source, the number of sources, and the luminance to which the eyes are adapted.

Green Interval – the right-of-way portion of a traffic phase.

Grounding – a pole or cabinet attachment enabling a cable to make an electric connection from the pole or cabinet to earth.

Hardware – articles made of material, such as aircraft, ships, tools, computers, vehicles, fittings, and their components (mechanical, electrical, electronic, hydraulic, and pneumatic). Computer software and technical documentation are excluded.

Headway – the distance or (usually) time between vehicles measured from the front of one vehicle to the front of the next.

Highway-Rail Grade Crossing – the general area where a highway and a railroad's right-of-way cross at the same level, within which are included the railroad tracks, highway, and traffic control devices for highway traffic traversing that area.

Highway Traffic Signal (Traffic Signal) – any power operated traffic control device, other than a warning light or steady burning electric lamp, by which traffic is warned or directed to take some specific action, including traffic control signals, intersection beacons, emergency vehicle traffic control signals, ramps signals, warning beacons and others.

Hold – a controller command that retains the existing right-of-way for a phase.

Illuminance - The density of the luminous flux incident on a surface; it is the quotient derived by dividing the luminous flux by the area of the surface, when the latter is uniformly illuminated.

Incandescent Signal – a traffic signal head that uses incandescent lamp for illumination.

Inductive Loop – coiled wires in the pavement (usually sawcut), which create an electrical field that is processed by a detector unit in the traffic signal cabinet to register an actuation.

Initial Interval – See Minimum Green.

Integrity – a system characteristic that means that the system's functional, performance, physical, and enabling products are accurately documented by its requirements, design, and support specifications.

Intelligent Transportation Systems – a broad range of diverse technologies which, when applied to the current transportation system, can help improve safety, reduce congestion, enhance mobility, minimize environmental impacts, save energy, and promote economic productivity. ITS technologies are varied and include information processing, communications, control, and electronics.

Interface – the functional and physical characteristics required to exist at a common boundary - in development, a relationship among two or more entities (such as software-software, hardware-hardware, hardware-software, hardware-user, or software-user).

Interface Control – interface control comprises the delineation of the procedures and documentation, both administrative and technical, contractually necessary for identification of functional and physical characteristics between two or more configuration items that are provided by different contractors/acquiring agencies, and the resolution of the problems thereto.

Intersection Control Beacon – a flashing beacon used at an intersection to control two or more directions of travel.

Interval – any one of the several divisions of the cycle during which signal indications do not change.

Interval Sequence – the order of appearance of signal indications during successive intervals of a cycle.

.**Isolux line -** A line plotted on any appropriate coordinates to show all the points on a surface where the illumination is the same. For a complete exploration, the line is a closed curve. A series of such lines for various illumination values is called an isolux (isofootcandle) diagram.

Item – a non-specific term used to denote any product, including systems, sub-systems, assemblies, subassemblies, units, sets, accessories, computer programs, computer software, or parts

J-Hook – steel rod in the shape of a "J" to support wires.

Lamp lumen depreciation factor (lld) - The multiplier to be used in illumination calculations to relate the initial rated output of light sources to the anticipated minimum rated output based on the relamping program to be used. (see "Light Loss Factor" discussion earlier in Chapter 11).

Lane-Use Control Signal – 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.

Last Car Passage – a feature that allows a full (non-reduced) passage period for the last vehicle extending the green during Gap Reduction.

Lead-Lag Left Turn Phasing – a phasing sequence where both a leading and lagging left turn signal phase is provided on the same street.

LED Signal – traffic signal head that uses light emitting diode modules for illumination.

Legacy System – the existing system to which the upgrade or change will be applied.

Light standard (pole) - A pole provided with the necessary internal attachments for wiring and the external attachments for the bracket and luminaire.

Life Cycle – the end-to-end process from conception of a system to its retirement or disposal.

Life Cycle Model – a representation of the steps involved in the development and other phases of an ITS project.

Light-Loss Factor – a design factor used to depreciate the output of a luminaire due to life-cycle output reduction of the lamp and the accumulation of dirt.

Locator Tone – a repeating sound that identifies the location of the pedestrian push button.

Locking Memory – a mode of a controller phase in which a call is retained by the controller even if the vehicle leaves the detector. Protected only turn phases are typically placed in locking memory.

Lumen – the unit of luminous flux (time rate of flow of light). A lumen is defined as the luminous flux emitted by a point source having a uniform luminous intensity of one candela.

Luminaire – a complete lighting fixture consisting of a lamp or lamps together with the ballast, reflector, refractor, photocell when required, and the housing.

Luminance – the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction, expressed in, candela per square meter.

Lumen (lm) - The unit of luminous flux. It is equal to the flux through a unit solid angle (steradiam), from a uniform point source of one candela (candle), or to the flux on a unit surface all points of which are at unit distance from a uniform point source of one candela.

Luminaire - A complete fixture consisting of a lamp or lamps together with the parts designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.

Luminous Efficacy (lm/W) - Luminous efficacy of a source of light. The quotient of the total luminous flux emitted by the total lamp power input. It is expressed in lumens per watt.

Lux (lx) - The International System (SI) unit of illumination. It is the illumination on a surface one square meter in area on which there is a uniformly distributed flux of one lumen, or the illumination produced at a surface all points of which are at a distance of one meter from a uniform point source of one candela.

Maintenance factor (MF) - A factor formerly used to denote the ratio of the illumination of a given area after a period of time to the initial illumination on the same area.

Malfunction Management Unit (MMU) – a device used to detect and respond to improper or conflicting signal indications and improper operating voltages in a traffic controller assembly.

Market Packages – potential products or sub-systems that address specific services (as used in an ITS architecture).

Mast Arm Pole – a cantilever structure that permits the overhead installation of the signal faces without exposed messenger cables and signal wiring, which are run inside the arm structure.

Master Controller Unit – a device for supervising a system of local intersection controllers.

Maximum Green – a longest period of green time allowed when there is a demand on an opposing phase.

Metrics – measures used to indicate progress or achievement.

Microwave Detection – a method of detection that detects vehicles by transmitting a low power microwave signal toward a specific area.

Minimum Gap – a volume density controller setting that represents the minimum value to which allowable gap between actuations on phase with green can be reduced upon expiration of Time to Reduce.

Minimum Green – the first part of the Green Interval for a phase, which is not affected by actuation received during the Green Interval for that phase (the shortest green time allowed a phase).

Model – an abstraction of reality. Examples: A road map is an abstraction of the real road network. A globe is a model of the world. A simulation is a dynamic model of a time sequence of events.

Module – a self-contained part of a hardware item designed as a single replaceable unit, with a specific integral electronic function. It should require no installation other than mechanical mounting and completion of electrical connection.

Mounting Height – The vertical distance between the roadway surface and the center of the apparent light source of the luminaire.

National ITS Architecture – a general framework for planning, defining, and integrating ITS. It was developed to support ITS implementations over a 20-year time period in urban, interurban, and rural environments across the country. The National ITS Architecture is available as a resource for any region and is maintained by the USDOT independently of any specific system design or region in the nation.

Needs Assessment – an activity accomplished early in system development to ensure that the system will meet the most important needs of the project's stakeholders, specifically that the needs are well understood, de-conflicted, and prioritized.

Non-conformance – the failure of a unit or product to conform to specified requirements.

Non-Locking Memory – a mode of actuated-controller unit operation which will not retain a call if the calling vehicle leaves the detector.

Offset – the relationship in time between a point in the cycle at a particular intersection and a similar point in the cycle at another intersection or reference.

Operational Baseline – the system that is currently in use, including all of the design, development, test, support, and requirements documentation.

Operational Concept – the roles and responsibilities of the primary stakeholders and the systems they operate.

Operation & Maintenance Plan – a document prepared incrementally during system implementation, and revised as needed during on-going system operation. The first version should be produced as early in the project as possible, to ensure that operation and maintenance needs are understood and planned for. This initial version may be quite limited in content, focusing on issues such as staffing, funding, and documentation that need to be worked on well in advance of system startup. Details of specific operation and maintenance activities can be added as needed, and after the system is developed and its specific characteristics are known.

Overhang - The distance between a vertical line passing through the luminaire and the curb or edge of the roadway.

Overlap – a traffic phase that services two or more traffic phases at the same time.

Partial Interchange Lighting - Lighting consisting of a few luminairees located in the vicinity of some or all ramp terminals, intersections, or other decision-making areas.

Part – one piece, or two or more pieces joined together which are not normally subjected to disassembly without destruction or impairment of designed use (examples: gear, screws, transistors, capacitors, integrated circuits).

Passage Time – the time allowed for each vehicle actuation during the Green Interval.

Pattern – a set of controller cycles, splits, and off sets for a traffic signal system which determines the relative green indication sequencing of the intersections within the system.

Pedestrian Access Route – an accessible corridor for pedestrian use within the public highway right-of-way.

Pedestrian Change Interval – an interval during which the flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication is displayed.

Pedestrian Clearance Time – the time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the traveled way or to a median.

Pedestrian Phase – a separate traffic phase allocated exclusively to pedestrian traffic.

Pedestrian Signal Head – a signal head, which contains the symbols WALKING PERSON (symbolizing WALK) and UPRAISED HAND (symbolizing DONT WALK), that is installed to direct pedestrian traffic at a traffic signal.

Performance – a quantitative measure characterizing a physical or functional attribute relating to the execution of a mission/operation or function.

Permissive Movement – a left or right turn traffic movement which must yield to pedestrians and/or oncoming traffic (during a CIRCULAR GREEN signal indication).

Permissive Period – the time period in which the controller unit is allowed to leave a coordinated phase under coordinated control and go to other phases.

Phase – the part of a cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals, i.e. a left turn phase.

Phase Omit (Special skip, Force skip) – a command that causes omission of a phase.

Platoon – a group of vehicles or pedestrians traveling together as a group, either voluntarily or involuntarily, because of traffic signal controls, geometrics, or other factors.

Policy – a guiding principle typically established by senior management, which is adopted by an organization or project to influence and determine decisions.

Polycarbonate – a lightweight thermoplastic with high strength used in some traffic signal housings and backplates and is lighter than similar aluminum products.

Powder Coat – an electrostatically applied dry powder coating that creates a fused adhesion.

Preemption – The transfer of the normal control of signals to a special signal control mode, i.e. to accommodate emergency vehicles.

Presence Detector – a vehicle detector that registers the presence of a vehicle for as long as the vehicle occupies the field of detection.

Presence Mode – the ability of a vehicle detector to register the presence of a vehicle for as long as the vehicle occupies the field of detection.

Pre-Timed Operation – type of traffic signal operation where the cycle length, phases, green times, and change intervals are all preset.

Priority Control – a means by which the assignment of right-of-way is obtained or modified.

Process – an organized set of activities.

Product – a product is a given set of items. The set could consist of system, sub-system, hardware or software items, and their documentation.

Project – an undertaking requiring concerted effort, which is focused on developing and/or maintaining a specific product. The product may include hardware, software, and other components. Typically, a project has its own funding, cost accounting, and delivery schedule with the acquirer (customer).

Project Architecture – defines ITS elements (stakeholders, equipment, facilities, etc.) and computerized data flows between these elements.

Project Life Cycle – see Life Cycle.

Project Plan – a description (what is to be done, what funds are available, when it will be done and by whom) of the entire set of tasks that the project requires.

Protected Movement – a left or right turn traffic movement which does not have to yield to pedestrians and/or oncoming traffic (when a left or right GREEN ARROW signal indication is displayed).

Pulse Mode – The ability of a vehicle detector to register the presence of a vehicle as a short output pulse when a vehicle enters the field of detection.

Pushbutton – a button to activate pedestrian timing.

Qualification Testing – testing performed to demonstrate to the acquirer that an item, system, or sub-system meets its specified requirements.

Quality Assurance – a planned and systematic pattern of all actions necessary to provide confidence that management, technical planning, and controls are adequate to establish correct technical requirements for design and manufacturing. Also, a planned and systematic patter of actions to manage design activity standards, drawings, specifications, or other documents referenced on drawings, lists, or technical documents.

Ramp Control Signal – a highway traffic signal installed to control the flow of traffic onto a freeway at an entrance ramp or at a freeway-to-freeway ramp connection.

Recall – an actuated controller feature which causes the automatic return of the right-of-way to a phase whether or not there are calls for that phase.

Red Clearance Interval – See All Red.

Red Interval – the portion of a phase not including the Green Interval, the Yellow Change Interval and the All Red Clearance Interval. It is the portion of the phase that is serving the conflicting phases.

Regional ITS Architecture – a specific regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects in a particular region.

Regression Testing – a process that tests not only the area of change but also tests those areas that were not changed but are affected by the change.

Requirements – the total consideration as to WHAT is to be done (functional), HOW well it is to perform (performance), and under WHAT CONDITIONS it is to operate (Environmental and non-functional).

Rest – the state in which an actuated controller unit rest in a phase until it is called out of the phase by a call on a conflicting phase or system command.

Reverse Engineering – the process of documenting an existing Intelligent Transportation Systems functional (what it does – requirements), physical (how it does it – design), and support (the way it was built and maintained – enabling products) characteristics.

Right-of-Way (Highway) – land or property, usually in a corridor, that is acquired for or devoted to transportation purposes.

Right-of-Way (Signal) – the movement at an intersection that has a GREEN indication for which all other conflicting movements must yield to.

Risk Management – an organized process to identify what can go wrong, to quantify and access associated risks, and to implement/control the appropriate approach for preventing or handling each risk.

Roundabout – a circular intersection that has yield control of entering traffic, channelized approaches, counterclockwise circulation, and appropriate geometric curvature to limit travel speeds on the circulatory roadway.

Setback - The horizontal distance between the face of a light pole and the edge of traveled way.

Spacing - For roadway lighting the distance between successive lighting units, measured along the center line of the street.

Semi-Actuated Operation – type of traffic signal operation in which at least one, but not all, signal phases function on the basis of actuation.

Sidewalk – that portion of a public highway right-of-way between the curb line or lateral line of a roadway and the adjacent property line that is improved for use by pedestrians.

Signal Back Plate – a thin strip of material that extends outward from and parallel to a signal face on all sides of a signal housing to provide a background for improved visibility of the signal indications.

Signal Face – that part of a signal head used for controlling traffic in a single direction. Turning indications may be included in a signal face.

Signal Head – an assembly of one or more signal sections.

Signal Housing – that part of a signal section that protects the light source and other required components (either aluminum or polycarbonate).

Signal Indication – the illumination of a traffic signal lens or equivalent device or a combination of several lenses or equivalent devices at the same time.

Signal Lens – that part of the signal section that redirects the light coming directly from the light source and its reflector, if any.

Signal Louver – a device that can be mounted inside a signal visor to restrict visibility of a signal indication from the side or to limit the visibility of the signal indication to a certain lane or lanes, or to a certain distance from the stop line.

Signal Section – the assembly of a signal housing, signal lens, and light source with necessary components to be used for providing one signal indication.

Signal System – two or more traffic signals operating in coordination.

Skip – a feature of an actuated traffic signal controller which omits operation of a phase or movement that does not have a call (opposite of Recall).

Software – computer programs and computer databases. Note: Although some definitions of software include documentation, it is now limited to the definition of computer programs and computer databases.

Software Development – a set of activities that result in software products. Software development may include new development, modification, reuse, re-engineering, maintenance, or any other activities that result in software products.

Special Event Plan – a timing plan stored in memory which is activated to compensate for unusual traffic flow caused by a special event (such as football game).

Specification – a document that describes the essential technical requirements for items, materials or services including the procedures for determining whether or not the requirements have been met.

Speed Limit Sign Beacon – a flashing beacon used to supplement a SPEED LIMIT sign.

Split – a division of the cycle length allocated to each of the various phases, normally expressed in percent.

Splitter Island – a flush or raised island that separates entering and exiting traffic in a roundabout.

Stakeholders – the people for whom the system is being built, as well as anyone who will manage, develop, operate, maintain, use, benefit from, or otherwise be affected by the system.

Standby Mode – an operational status of a local controller or system which is not under central computer control but is capable of responding to central computer control.

Statement of Work – a document primarily for use in procurement, which specifies the work requirements for a project or program. It is used in conjunction with specifications and standards as a basis for a contract. The SOW will be used to determine whether the contractor meets stated performance requirements.

Stop Beacon – a flashing beacon used to supplement a STOP sign, a DO NOT ENTER sign, or a WRONG WAY sign.

Strain Pole – a pole to which span wire is attached for the purpose of supporting the signal heads.

Subcontractor – an individual, partnership, corporation, or an association that contracts with an organization (i.e., the prime contractor) to design, develop, and/or manufacture one or more products.

Subsystem – any portion of a traffic signal system which can be controlled by a single timing pattern.

Suppliers – the term 'suppliers' includes contractors, sub-contractors, vendors, developers, sellers or any other term used to identify the source from which products or services are obtained.

Surveillance – the monitoring of traffic performance and signal system operation.

Synthesis – the translation of input requirements (including performance, function, and interface) into possible solutions (resources and techniques) satisfying those inputs. This defines a physical architecture of people, product, and process solutions for logical groupings of requirements (performance, functions, and interface) and their designs for those solutions.

System – an integrated composite of people, products, and processes, which provide a capability to satisfy a stated need or objective.

System Detector – a counting detector that is used for surveillance and measures data like occupancy, speed, volume and delay.

System Elements – a system element is a balanced solution to a functional requirement or a set of functional requirements and must satisfy the performance requirements of the associated item. A system element is part of the system (hardware, software, facilities, personnel, data, material, services, and techniques) that, individually or in combination, satisfies a function (task) the system must perform.

Systems Engineering – an inter-disciplinary approach and a means to enable the realization of successful systems. Systems engineering requires a broad knowledge, a mindset that keeps the big picture in mind, a facilitator, and a skilled conductor of a team.

Systems Engineering Management Plan (SEMP) – a document used when a project is deemed High Risk and may be needed to supplement the details of the Project Plan. When used, the SEMP focuses on the technical plan of the project and the systems engineering processes to be used for the project. Its purpose is to detail out those engineering tasks; especially to provide detailed information on the processes to be used.

System Specification – a top level set of requirements for a system. A system specification may be a system/sub-system specification, Prime Item Development Specification, or a Critical Item Development Specification.

Tailoring – planning systems engineering activities that are appropriate and cost-effective for the size and complexity of the project. It may be based on cost, size, the number of stakeholders, the supporting relationships between them, complexity of systems (large number of interfaces to other systems, a large number of functions to perform, or the degree of coupling between systems.), level of ownership of system

products (custom development of software owned by the agency or commercial off the shelf products), existing software products, resources, risks.

Technical Reviews – a series of system engineering activities by which the technical progress on a project is assessed relative to its technical or contractual requirements. The formal reviews are conducted at logical transition points in the development effort to identify and correct problems resulting from the work completed thus far before the problem can disrupt or delay the technical progress. The reviews provide a method for the contractor and procuring activity to determine that the identification and development of a CI have met contract requirements.

Testable – a requirement or set of requirements is considered to be testable if an objective and feasible test can be designed to determine whether each requirement has been met.

Time-Base Coordination (TBC) – traffic signal coordination which uses an electronic clock, rather than an interconnect cable.

Time Before Reduction (TBR) – a volume density controller feature that sets the amount of time before which the allowable gap is reduced from the value of passage time to minimum gap (before Time to Reduce starts), measured in seconds.

Time-of-Day Pattern (TOD) – a timing pattern (set of cycles, splits, and offsets) for a section which can be implemented at certain time(s) in the day.

Time to Reduce (TTR) – a volume density controller feature that sets the amount of time in which the allowable gap is reduced from the value of passage time to minimum gap, measured in seconds.

Timing Plan – a set of cycle lengths splits and offsets within a group of signals. The particular timing for each intersection may vary with time of day within the plan.

Traceability – ensures that user needs and concepts are addressed by a set of requirements and that the requirements are fulfilled by the high level and detailed design. Traceability also ensures that system and sub-system requirements are fully verified. Traceability supports impact analysis and configuration management for long term maintenance, changes & upgrades, and replacement to the system.

The following are three aspects of traceability:

1) Pre-Requirements Specification traceability (Pre-RS traceability) in which user needs are traced to a set of system requirements;

2) Post-Requirements Specification traceability (Post-RS traceability) in which traceability ensures compliance after the system requirements baseline has been established;

3) Post delivery traceability (Post-Delivery traceability) in which traceability is maintained after delivery of the system; supporting changes & upgrades, and replacement activities.

Traceability Matrix – is a table that lists the User Needs, functional requirements, technical requirements, and the technical features or specifications needed to fulfill the associated requirements.

This helps the project team visually determine the genealogy of a specific requirement. If a functional requirement can't be traced to a specific user need, then it should be removed from the project.

Trade-off Study – an objective evaluation of alternative requirements, architectures, design approaches, or solutions using identical ground rules and criteria.

Traffic Control Signal – See Traffic Signal.

Traffic Management Center (TMC) – a location that contains the computer equipment, displays and personnel which operate a computerized traffic control system.

Traffic-Responsive – a signal system mode of operation in which a master controller or computer selects or computes signal timing based on the real-time demands of traffic as sensed by detectors.

Traffic Signal – a type of highway traffic signal, manually, electrically, or mechanically operated by which traffic is alternately directed to stop and permitted to proceed.

Transverse Roadway Line (TRL) - Any line across the roadway that is perpendicular to the curb line.

Uniformity of illuminance - The ratio of average footcandles (lux) of illuminance on the pavement area to the footcandles (lux) at the point of minimum illuminance on the pavement, commonly called the uniformity ratio.

Uniformity of luminance - The ration average level-to-maximum point of luminance or the maximum-to-minimum point. The average to minimum method uses the average luminance of the roadway design area between two adjacent luminaires, divided by the lowest value at any point in the area. Maximum-tominimum point method uses the maximum and minimum values between the same adjacent luminaires. The luminance uniformity (avg./min. and max./min) considers traveled portion of the roadway, except for divided highways having different designs on each side.

Unit Extension – see Passage Time and Allowable Gap.

User – the organization(s) or persons within those organizations who will operate and/or use the system for its intended purpose.

User Services – a catalog of features that could be provided by an ITS project (as used in an ITS architecture).

Utilization efficiency. A plot of the quantity of light falling on a horizontal plane both in front of and behind the luminaire. It shows only the percent of bare lamp lumens that fall on the horizontal surface, and is plotted as ratio of width of area to mounting height of the luminaire.

Validation – the process of determining that the requirements are correctly defined that they form a complete set of requirements. This is done in the early stages of the development process. Validation of the end product or system determines if the system meets the users' needs.

Variable Initial – a volume density controller function consisting of the capability of adding initial green time to the Minimum Green based on the amount of traffic waiting.

Vehicle Clearance Interval – the period of time consisting of the Yellow Change Interval and an optional All Red Clearance Interval.

Vehicle Extension – see Passage Time and Allowable Gap

Vehicular Phase – a traffic phase allocated to vehicular traffic.

Vendor – a manufacturer or supplier of an item.

Verification – the process of determining whether or not the products of a given phase of the system/software life cycle fulfill the requirements established during the preceding phase.

Vertical Lux – Lux measured in a vertical plane.

Video Detection – a method of detection that uses pattern recognition to detect vehicles.

Volume Density – an actuated controller operation that will automatically adjust the timing of a phase by using variable initial and/or gap reduction.

Walk Interval – an interval during which the WALKING PERSON (symbolizing WALK) signal indication is displayed.

Warning Beacon – a flashing beacon used only to supplement an appropriate warning or regulatory sign or marker.

Work Breakdown Structure – a product-oriented listing, in family tree order, of the hardware, software, services, and other work tasks, which completely defines a product

or program. The listing results from project engineering during the development and production of a materiel item. A WBS relates the elements of work to be accomplished to each other and to the end product.

Yellow Change Interval – the first interval following the green right-of-way interval in which the signal indication for that phase is YELLOW, indicating that the right-of-way for that phase is about to terminate.

Yellow Clearance Interval – See Yellow Change Interval.

Yellow Trap – a condition in which a permitted left turn phase ends in one direction while the opposing through movement continues through the succeeding phase. A hazard is introduced because the left turning drivers tend to perceive the end of their phase as an opportunity to clear the intersection as a “sneaker,” while the green indication in the opposing direction is displayed continuously during the transition from one phase to the next..

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STATE OF TENNESSEE
DEPARTMENT OF TRANSPORTATION
NASHVILLE, TENNESSEE 37243-1402

TRAFFIC DESIGN MANUAL
REVISION 12-01

TO: TDOT Traffic Design Manual Users

FROM: Ali R. Hangul, C.E. Manager 1
Standards and Guidelines Section

DATE: April 11, 2012

SUBJECT: Revision to Chapter 8 of the TDOT Traffic Design Manual

Chapter 8 of the TDOT Traffic Design Manual was revised on March 28, 2012 and is effective as of the date of this memo. The revisions are as follows:

- Chapter 8
  - Section 8.1.2 – Revised staff requirements for High Risk ITS Projects
  - Section 8.2.1 – Added reference to preliminary risk assessment & Tennessee ITS Project Identification Checklist.
  - Added Tennessee ITS Project Identification Checklist Template

ARH:pbf

STATE OF TENNESSEE
DEPARTMENT OF TRANSPORTATION
NASHVILLE, TENNESSEE 37243-1402

TRAFFIC DESIGN MANUAL
REVISION 12-02

TO: TDOT Traffic Design Manual Users

FROM: Ali R. Hangul, C.E. Manager 1
Standards and Guidelines Section

DATE: May 10, 2012

SUBJECT: Revision to Chapter 6 of the TDOT Traffic Design Manual

The entirety of Chapter 6 of the TDOT Traffic Design Manual was revised to conform to the 2009 MUTCD on March 30, 2012 and is effective as of the date of this memo.

ARH:mwc