



DISPLACED LEFT TURN INTERSECTION

Informational Guide

August 2014

FOREWORD

The Federal Highway Administration (FHWA) Every Day Counts (EDC) initiative is designed to identify and deploy innovation aimed at reducing project delivery time, enhancing safety and protecting the environment. In 2012, FHWA chose Intersection & Interchange Geometrics (IIG) to feature as one of the innovative technologies in EDC-2. Specifically, IIG consists of a family of alternative intersection designs that improve intersection safety while also reducing delay, and at lower cost and with fewer impacts than comparable traditional solutions.

As part of the effort to mainstream these intersections, FHWA has produced a series of guides to help transportation professionals routinely consider and implement these designs. Concurrent with this Displaced Left Turn (DLT) Informational Guide, FHWA developed and published guides for three other designs: Median U-turn (MUT), Restricted Crossing U-turn (RCUT), and Diverging Diamond Interchange (DDI). These guides represent summaries of the current state of knowledge and practice, and are intended to inform project planning, scoping, design and implementation decisions.

An electronic version of this document is available on the Office of Safety website at <http://safety.fhwa.dot.gov/>. Additionally, limited quantities of hard copies are available from the Report Center; inquiries may be directed to report.center@dot.gov or 814-239-1160.



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Director
Office of Safety Technologies

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16. Abstract This document provides information and guidance on the Displaced Left Turn (DLT) intersection. To the extent possible, the guide addresses a variety of conditions found in the United States, to achieve designs suitable for a wide array of potential users. This guide provides general information, planning techniques, evaluation procedures for assessing safety and operational performance, design guidelines, and principles to be considered for selecting and designing DLT intersections.			
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Displaced Left Turn Informational Guide

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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CHAPTER 1— INTRODUCTION

OVERVIEW OF ALTERNATIVE INTERSECTIONS AND INTERCHANGES

Alternative intersections and interchanges offer the potential to improve safety and reduce delay at a lower cost and with fewer impacts than traditional solutions. However, transportation professionals are generally unfamiliar with many alternative intersection and interchange forms, partially because some forms have only a few installations in operation or because installations are concentrated in a few states. Furthermore, at the national level, well-documented and substantive resources needed for planning, analysis, design, and public outreach and education were limited.

Concurrent with this Displaced Left Turn (DLT) Informational Guide, the Federal Highway Administration (FHWA) developed and published informational guides for three other alternative intersection and interchange forms: Median U-Turn (MUT), Restricted Crossing U-Turn (RCUT), and Diverging Diamond Interchange (DDI). These guides are intended to increase awareness of these specific alternative intersections and interchanges and provide guidance on how to plan, design, construct, and operate them. The guides represent summaries of the current state of knowledge with the intent of supporting decisions when considering and potentially selecting alternative intersection and interchange forms for appropriate applications.

INTERSECTION CONTROL EVALUATIONS AND CONSIDERATIONS

The term “intersection” means the junction of two or more streets. In some cases, this may specifically mean an “at-grade” intersection form. In others, it may include the junction of two or more streets requiring partial or complete grade separation (“interchanges”). A number of state and city transportation agencies have or are implementing intersection control evaluation processes or policies as a means of integrating the widest range of intersection forms as project solutions. For example, California, Indiana, Minnesota, and Wisconsin have policies or processes to objectively consider and select the most appropriate intersection form for a given project context.

Many of the policies or processes include common objectives in selecting the optimal or preferred intersection control alternative for a given project context. The common elements generally include but are not limited to the following:

- Understanding the intended context, and how operations, safety, and geometry fit the context for each intersection or corridor including intended users (pedestrians, bicyclists, passenger cars, transit vehicles, freight, emergency responders, and over size/over weight [OSOW] vehicles)
- Identifying and documenting the overall corridor or intersection context including the built, natural, and community environment and the intended performance outcomes of the intersection form
- Considering and assessing a wide range of traffic control strategies and other practical improvement concepts to identify worthy project-level technical evaluation

- Comparing engineering and economic analysis results of practical alternatives that consider implementation costs, performance benefits and impacts (safety, multimodal, operations, environment, etc.), and the estimated service life of alternatives

ORGANIZATION OF THE GUIDELINES

This guide has been structured to address the needs of a variety of readers, including the general public, policy makers, transportation planners, operations and safety analysts, and conceptual and detailed designers. This chapter distinguishes DLT intersections from conventional intersections and provides an overview of each chapter in this guide. The remaining chapters in this guide increase in the level of detail provided.

Chapter 2: Policy and Planning—This chapter provides guidance on when to consider alternative intersections in general and DLT intersections in particular. The transportation professional should consider policies, project challenges, performance measures, and the project development process throughout the duration of the project to balance trade-offs.

Chapter 3: Multimodal Considerations—This chapter provides an overview of multimodal facilities at DLT intersections and how the needs of various users should inform decisions to produce an intersection that optimally serves non-motorized and motorized traffic.

Chapter 4: Safety—This chapter summarizes documented safety performance and safety considerations at DLT intersections based on studies completed by state agencies and recent research efforts. Although the documented safety performance of DLT intersections is limited, information about conflict points, wrong-way maneuvers, and emergency services at the DLT are discussed.

Chapter 5: Operational Characteristics—This chapter provides information on the unique operational characteristics of DLT intersections and how they affect elements such as traffic signal phasing and coordination. The chapter also provides guidance for practitioners related to design elements such as driveways that may affect the operational performance of DLT intersections. It is intended to help readers understand the unique operational characteristics of DLT intersections and prepare readers for conducting operational analysis as described in Chapter 6.

Chapter 6: Operational Analysis—This chapter presents an overview of the approach and tools available for conducting a traffic operations analysis of a DLT intersection.

Chapter 7: Geometric Design—This chapter describes the typical DLT intersection design approach and provides guidance for geometric features. Design of a DLT intersection will also require review of the intersection's multimodal considerations (Chapter 3), safety assessment (Chapter 4), and traffic operational analysis (Chapters 5 and 6).

Chapter 8: Signal, Signing, Marking, and Lighting—This chapter presents information relating to the design and placement of traffic control devices at DLT intersections, including traffic signals, signs, and pavement markings, as well as intersection lighting.

Chapter 9: Construction and Maintenance—This chapter focuses on the constructability and maintenance of a DLT intersection.

An Appendix is included at the end of this guide for the purpose of providing more detailed information about many of the resources and best practices presented in the guide. The Appendix contains the following information:

- A - Catalog of All Known Installations in the United States
- B - Supplemental Operational and Safety Details
- C - Marketing and Outreach Materials
- D - Supplemental Construction and Design Details

SCOPE OF THE GUIDE

This document provides information and guidance on planning and designing DLT intersections for a variety of typical conditions commonly found in the United States. To the extent possible, the guide provides information on the wide array of potential users as it relates to the intersection form. The scope of this guide is to provide general information, planning techniques, evaluation procedures for assessing safety and operational performance, design guidelines, and principles to be considered for selecting and designing DLT intersections. This guide does not include specific legal or policy requirements; however, Chapter 2 provides information on planning topics and considerations when investigating intersection control forms. This first edition of the Displaced Left Turn Informational Guide has been developed from best practices and prior research. As more DLT intersections are built, the opportunity to conduct research that refines and develops better methods will result in improved future editions of this guide.

DLT INTERSECTION OVERVIEW

The displaced left turn (DLT) intersection is also known as a continuous flow intersection (CFI) and a crossover displaced left-turn intersection. For the purpose of this informational guide, DLT refers to any intersection form relocating one or more left-turn movements on an approach to the other side of the opposing traffic flow. This attribute consequently allows left-turn movements to proceed simultaneously with the through movements and eliminates the left-turn phase for this approach. The number of traffic signal phases and conflict points (locations where user paths cross) are reduced at a DLT intersection, which can result in improvements in traffic operations and safety performance. The green time formerly allocated for the left turn at a conventional intersection could be reallocated, including being used to facilitate pedestrian crossings.

As shown in Exhibit 1-1, traffic that would normally turn left at the main intersection would first cross the opposing through lanes at a signal-controlled intersection several hundred feet upstream of the main intersection. Left-turning vehicles then would travel on a new street parallel to the opposing lanes and execute the left-turn maneuver simultaneously with the through traffic at the main intersection. Traffic signals, operating in a coordinated manner, are present at the main intersection and the locations of the left-turn crossovers.

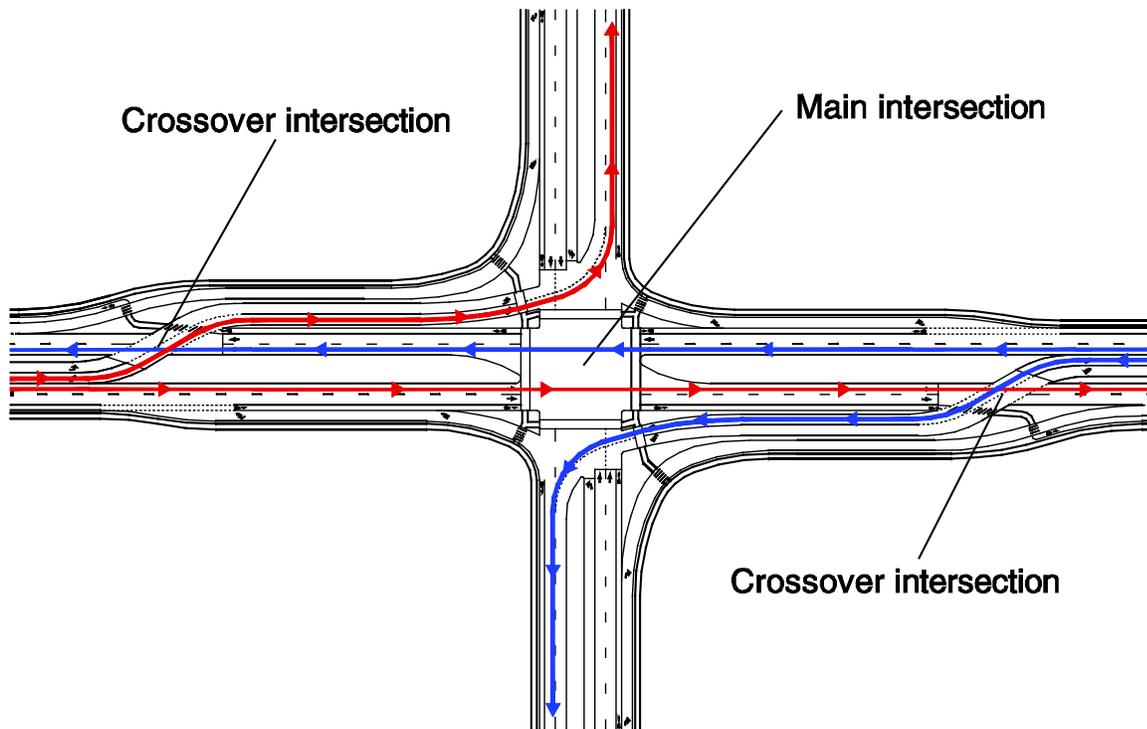


Exhibit 1-1. Four-legged DLT with displaced lefts on a major street.

Exhibit 1-1 shows a DLT intersection where the displaced left-turn movement has been implemented on two legs on the major street. In some cases, the displaced left turns are on the minor street instead of the major street. The left-turn movements for the minor road continue to take place at the main intersection. There are five junctions with traffic signal control at a four-leg DLT intersection: the main intersection and the four left-turn crossover intersections.

APPLICATION

Several DLT intersections have been installed throughout the United States, and each location is documented in the Appendix. Exhibit 1-2 shows the location of existing DLT intersections in the United States, as of the publication of this guide.



Exhibit 1-2. Locations of DLT intersections.

Exhibit 1-3 through Exhibit 1-11 feature photos of DLT intersections illustrating different contextual environments and a variety of design features.



Exhibit 1-3. Four-legged DLT intersection with four displaced lefts (West Valley City, UT).⁽¹⁾



Exhibit 1-4. Four-legged DLT intersection with major street displaced lefts and channelized right turns (Baton Rouge, LA).⁽¹⁾



Exhibit 1-5. Three-legged DLT intersection with major street displaced left and channelized right turns (Shirley, NY).⁽¹⁾



Exhibit 1-6. Example of a bus stop and bus only lane at the Bangerter Highway/3500 South Intersection in Utah.⁽²⁾



Exhibit 1-7. Crossover intersection at the Bangerter Highway/3100 South Intersection in Utah.⁽²⁾



Exhibit 1-8. Left-turn lane at the main intersection of the Bangerter Highway/3100 South Intersection in Utah.⁽²⁾



Exhibit 1-9. Main intersection at Bangerter Highway/3100 South Intersection in Utah.⁽²⁾



Exhibit 1-10. Lighting, pedestrian signage, and video detection at the right-turn channelization at the Bangerter Highway/3500 South Intersection in Utah.⁽²⁾



Exhibit 1-11. Bicyclist crossing with through vehicles at the Bangerter Highway/3500 South Intersection in Utah.⁽²⁾

GEOMETRIC DESIGN CONSIDERATIONS

Exhibit 1-12 and Exhibit 1-13 illustrate typical designs for DLT intersections with channelized right turns. Each of these exhibits depicts right-turn bypass lanes. A bypass lane is not always needed, and right-turning vehicles may also be served by turning right on the cross street similar to a conventional intersection. In this form, right-turning traffic volumes must pass through the downstream crossover.

There are existing DLT intersection installations without channelized right turns as shown in Exhibit 1-14. This reduces the overall footprint and cost of the intersection. The non-channelized right turns typically coincide with single displaced left turns, and their turning paths can be defined to discourage wrong-way movements (i.e., into the displaced left-turn lane). According to the Utah Department of Transportation (UDOT) DLT intersection guidelines, the main benefit of adding channelized right-turn or bypass lanes is to reduce the number of conflict points within the DLT intersection (effectively one conflict per leg bypassed), but the disadvantage is that this design requires a larger footprint.⁽³⁾

The design in Exhibit 1-12 is for a DLT intersection with displaced left-turn movements on all four approaches. This design reflects a shift of the through traffic lanes into the median in an attempt to minimize the need for additional right-of-way. At several locations where DLT intersections have been implemented as a retrofit to an existing conventional at-grade intersection, the existing median has been preserved, and there is no shift in the through lanes. Exhibit 1-13 illustrates a DLT movement at a three-leg intersection with the displacement on the major road.

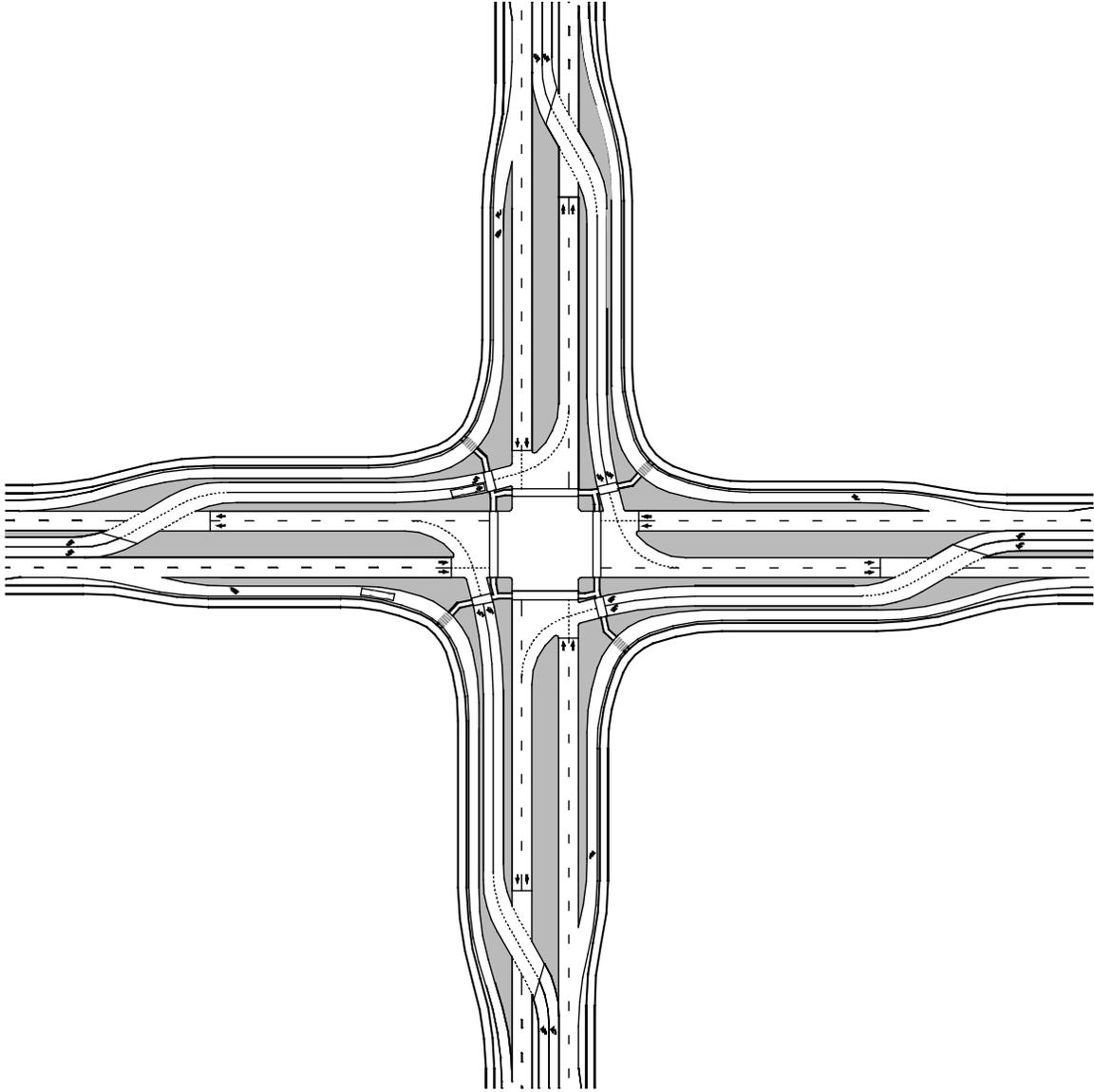


Exhibit 1-12. DLT intersection with displaced left turns on all approaches.

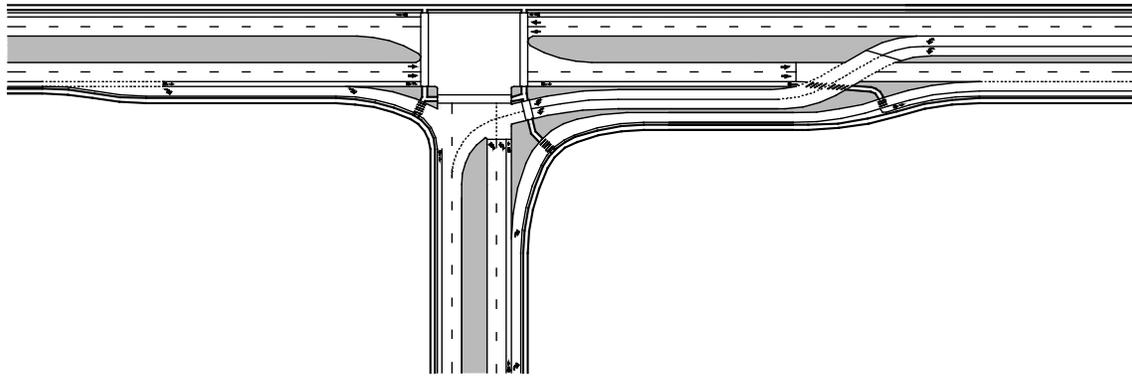


Exhibit 1-13. Three-legged DLT intersection with displaced left turns on major road approach.

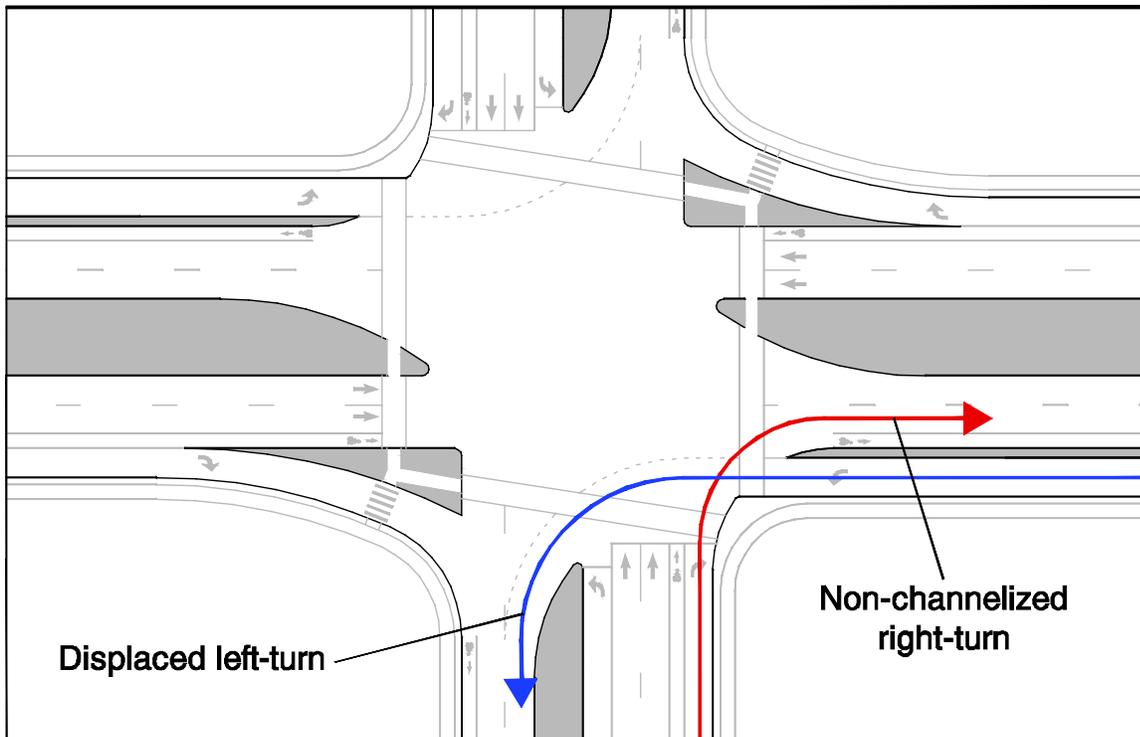


Exhibit 1-14. DLT without channelized right turns.

RESOURCE DOCUMENTS

This Displaced Left Turn Intersection Guide is supplemental to major resource documents including but not limited to:

- *A Policy on Geometric Design of Highways and Streets* (American Association of State Highway and Transportation Officials [AASHTO] Green Book)⁽⁴⁾
- *Highway Capacity Manual* (HCM)⁽⁵⁾

- *Manual of Uniform Traffic Control Devices (MUTCD)*⁽⁶⁾
- *Highway Safety Manual (HSM)*⁽⁷⁾
- Other research documents that appear in this guide and are more specialized to specific areas include various National Cooperative Highway Research Program (NCHRP) reports, Transportation Research Board (TRB) papers, and Federal Highway Administration (FHWA) publications

The following are supplemental resource documents specific to DLT intersections:

- *Design and Operational Performance of Crossover Displaced Left-turn Intersections*⁽⁸⁾
- *The Parallel Flow Intersection: A New Two-Phase Signal Alternative*⁽⁹⁾
- *Travel Time Comparisons between Seven Unconventional Arterial Intersection Designs*⁽¹⁰⁾
- *Operational Effects of CFI Geometrics: A Deterministic Model for Continuous Flow Intersections*⁽¹¹⁾
- *CFI Guideline: A UDOT Guide to Continuous Flow Intersections*⁽²⁾

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CHAPTER 2— POLICY AND PLANNING

This chapter contains guidance on how to consider alternative intersections in general and DLT intersections in particular. This chapter summarizes policy and planning considerations related to DLT intersections. The remaining chapters of this guide will provide specific details of the multimodal, safety, operations, geometric design, and traffic control features of DLT intersections.

Alternative intersections are often initially considered for operational or safety needs, and other key factors may include spatial requirements and multimodal needs. This chapter provides approximate footprints for different types of DLT intersections to allow for planning-level screening and feasibility analysis.

PLANNING CONSIDERATIONS FOR ALTERNATIVE INTERSECTIONS AND INTERCHANGES

Alternative intersection evaluations may vary depending on the stage of the project development process. Each project stage can affect how policy and technical considerations are assessed. While the operational, design, safety, human factors, and signing controls should be considered at every stage of the development process, a planning level design evaluation may not require the same level of analysis or detailed evaluation of each consideration projects in later development stages. Evaluations should be as comprehensive as needed to answer key project questions for each unique project context.

Serving Pedestrians and Bicycles

The most likely type of setting for a DLT intersection is along urban or suburban roads with high traffic volumes. These are locales where pedestrians and bicyclists regularly walk and bike. Therefore, roads and intersections must be specifically planned and designed to serve these users.

DLT intersections come with specific pedestrian and bicyclist considerations and should be evaluated on a case-by-case basis. Pedestrians crossing at a DLT intersection may be required to cross more travel lanes than at a conventional intersection. Even if the number of lanes is similar, the crossing needs, crossing stages, and pathway configurations may be different compared to traditional intersections. Depending on pedestrian and bicyclist volumes and motor vehicle traffic volumes, a DLT intersection may not be an appropriate option for some locations due to increased conflicts with motor vehicles. DLT intersections being advanced for consideration may need to include other ways to accommodate pedestrians, such as by providing grade-separated pedestrian facilities that coincide with the surrounding land use context.

Many DLT intersections are set up for pedestrians to cross in multiple stages with median islands providing a refuge. In these cases, storage provided for pedestrians should also be compliant with the Americans with Disabilities Act (ADA) and be developed using published information or principles from traditional intersection forms. Multi-stage crossings may increase crossing time and are

sometimes more indirect than comparable conventional intersections. These crossings must include elements or features supporting their ability to serve the range of pedestrians, including individuals with visual impairments or users with other special needs.

Accessible pedestrian signals (APS) are generally required where pedestrian signals are provided to serve pedestrians with visual impairments. APS should be included, or at least not precluded for future implementation, at DLT intersections. Transportation professionals, local agencies, and communities representatives may wish to jointly determine how to best implement APS equipment.

Depending on the crossing configuration at a DLT intersection, pedestrians may cross “diagonally” between refuge islands adjacent to the left-turn lanes. These pedestrians walk between left-turning and through traffic. This type of movement places moving traffic on two sides of pedestrians, and requires special care and consideration to develop design elements to serve pedestrians with visual or cognitive impairments. In these cases, wider median islands and/or wider outer separations may best serve pedestrian movements.

As with any intersection, facilities for bicyclists can be provided on the road using marked bicycle lanes, shared lanes and cycle tracks. However, special care is required for DLT intersections to consider and address how bicyclists will interact with different paths of vehicles. Off-street bicycle paths or shared-use paths can be included at DLT intersections if they are configured to cross at appropriate locations at the intersection (e.g., at stop bars where conflicting traffic movements enter). Typical locations for shared-use path crossings would be the same as the locations of crosswalks.

Traffic Volume Relationship

Exhibit 2-1 conceptually depicts the relationship of conventional intersections, alternative intersections, and grade separations in their ability to serve increasing traffic volumes.

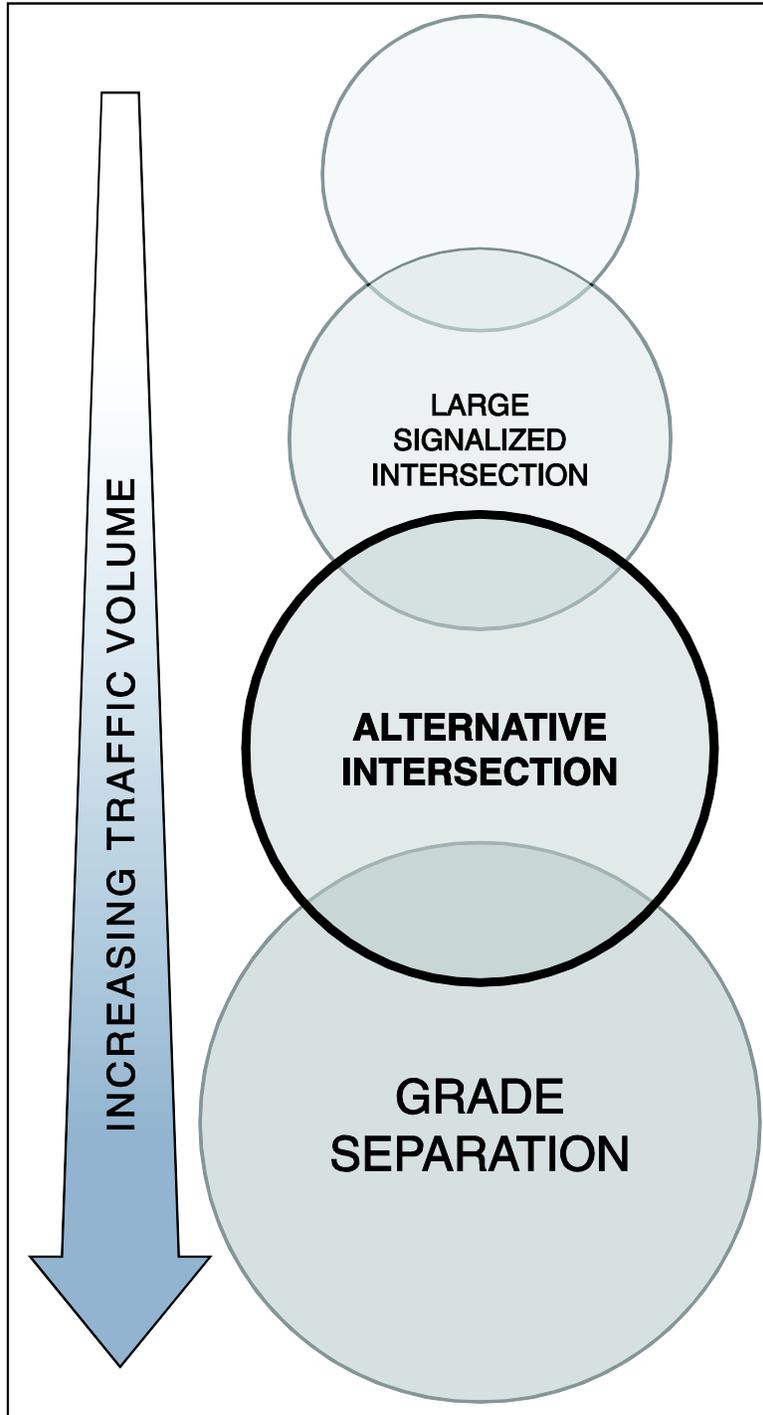


Exhibit 2-1. Relationship between total entering volume and intersection type.

A DLT intersection has a larger footprint compared to conventional intersections. With right-of-way restrictions, it can be difficult to widen or add lanes; therefore, careful planning is required during the initial design of a DLT intersection. Exhibit 2-2 and Exhibit 2-3 illustrate the estimated footprint for a DLT intersection compared to a conventional intersection. Exhibit 2-2 shows a tangent alignment for through movements at the crossover intersections, while Exhibit

2-3 illustrates the undesirable deflections at the crossover intersections. The right-of-way footprint may affect any agency's decision on whether to construct this type of intersection.

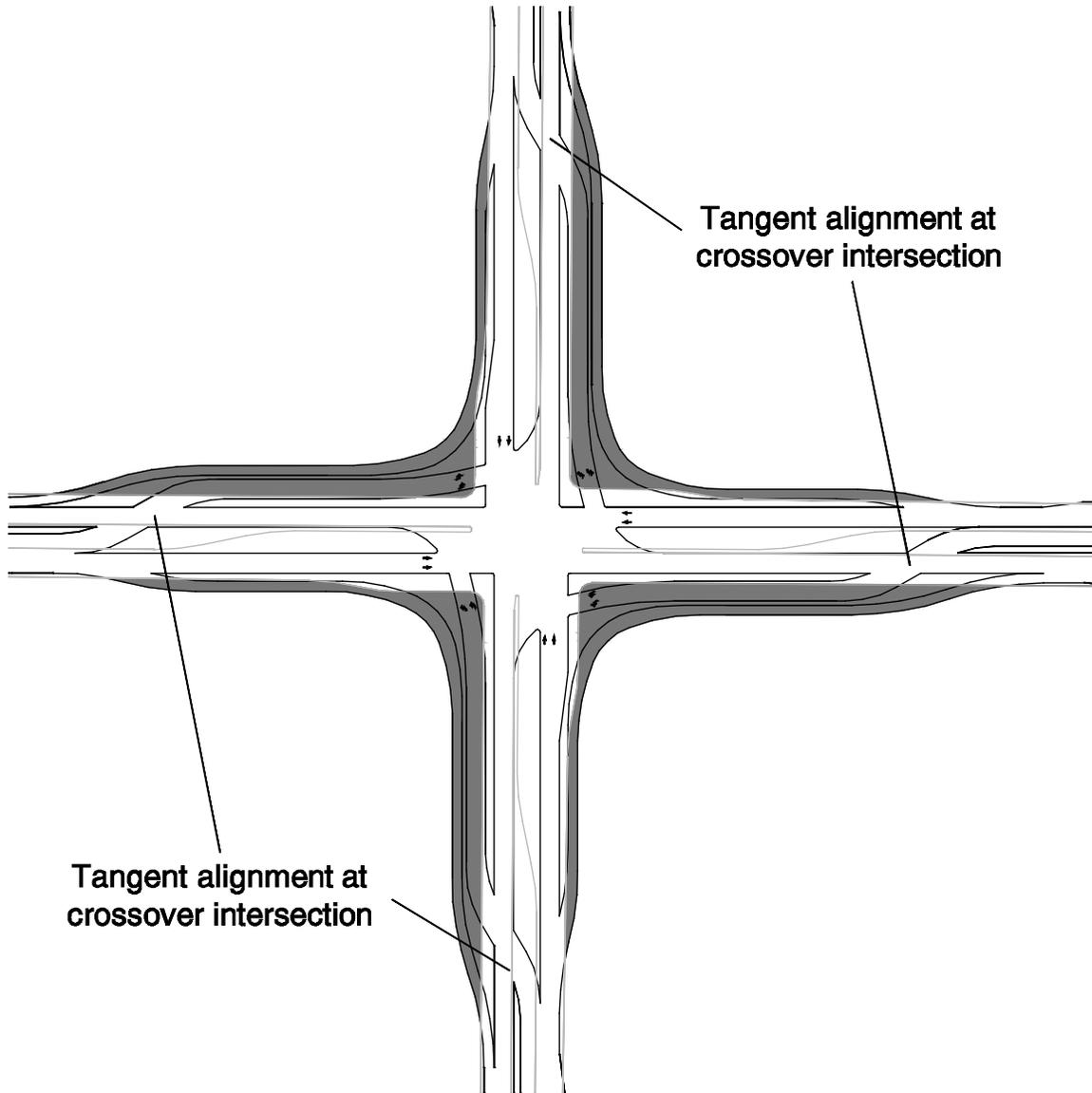


Exhibit 2-2. Footprint comparison of a DLT intersection with tangent alignments versus a conventional intersection.

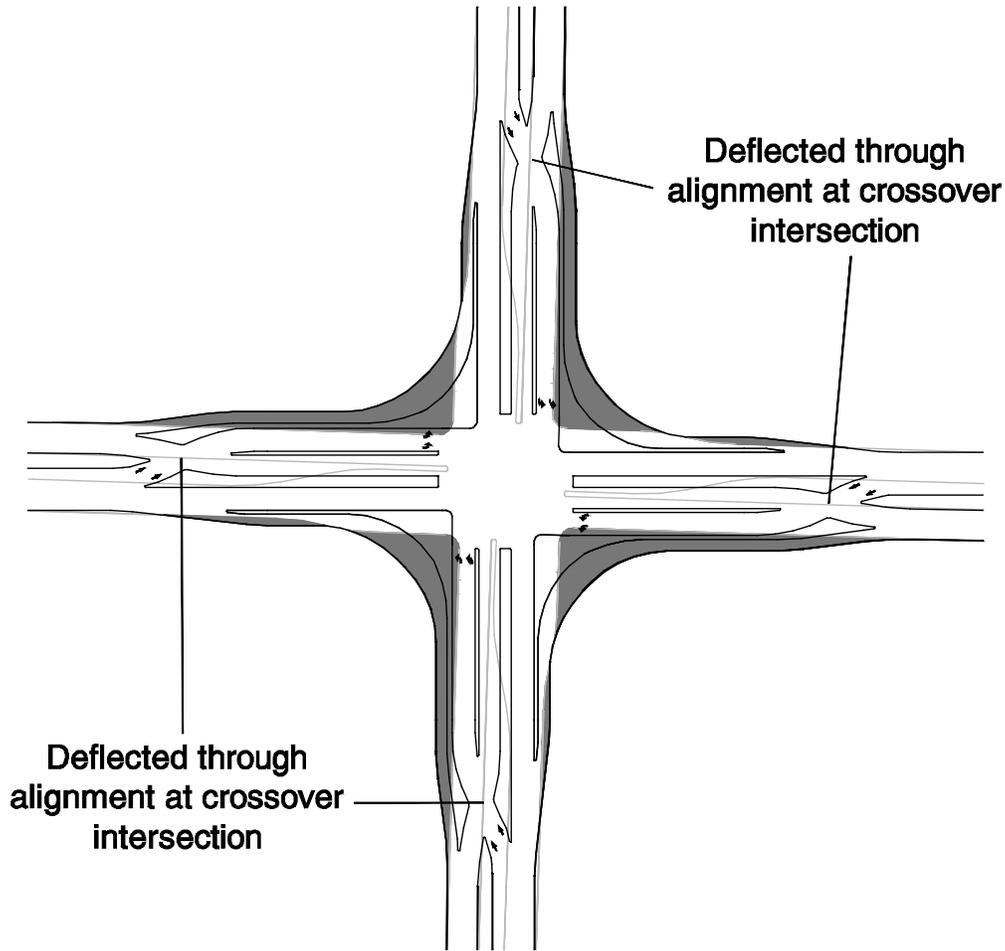


Exhibit 2-3. Footprint comparison of a DLT intersection with deflected through alignments versus a conventional intersection.

Costs specific to a DLT intersection are related to increased materials and additional signs and signals compared to conventional intersections. Additional signals can become a significant cost, particularly for a DLT intersection with left-turn crossovers on all four approaches. Construction costs associated with the DLT intersection may be offset to some extent by safety and operational improvements; however, this should be explored on a project basis through additional analysis.

STAKEHOLDER OUTREACH

Similar to other transportation projects, stakeholder outreach is a critical part of the overall planning process. Successful implementation of the first DLT intersection in a community may result from explicit and proactive outreach and education to affected stakeholders and the general public. This would create opportunities to familiarize others with how the intersection works while creating opportunities to hear of general project and DLT intersection specific issues and considerations. Special considerations may include sharing how the left-turn movements of the DLT intersection require drivers to turn left prior to the main intersection and how pedestrian

While not strictly public outreach, another newsletter was distributed to members of Ohio DOT in 2003 before any DLT intersections were constructed there. The one-page flier introduces the DLT intersection and describes its geometric layout and benefits (including benefits for automobiles and pedestrians).⁽¹⁴⁾ The flier goes on to explain the economic benefit of a DLT intersection compared to a interchange and identifies possible locations for construction.

The following communications and public involvement elements may be considered as part of the public outreach:

- Expect opposition
- Budget proactively
- Understand your audience
- Identify and measure success
- Manage expectations
- Demonstrate public accountability
- Tell an engaging story

FHWA has created alternative intersection and interchange informational videos and video case studies, which can be viewed on the FHWA YouTube channel (<https://www.youtube.com/user/USDOTFHWA>).⁽¹⁵⁾ In addition, FHWA has developed alternative intersection brochures that can be found on the FHWA website (<http://safety.fhwa.dot.gov>).⁽¹⁶⁾ Examples of this information are shown in the appendix.

POLICY CONSIDERATIONS

Designing, operating, and managing a street and its intersections should align with the appropriate jurisdictional policies associated with that facility. The facility location and type can often dictate the appropriateness of the right-of-way and access management needs associated with alternative intersections. The degree to which motor vehicle throughput should or should not be prioritized over other modes also plays a role in determining the appropriateness of alternative intersections at specific locations.

Some of the policy considerations of a DLT intersection include the following:

- Access management
 - Locations relative to adjacent signalized intersections – greater separation is needed between a DLT intersection and a conventional intersection than is needed between two conventional intersections

- U-turns – prohibited at the main intersection and generally not possible
- Frontage roads – these are encouraged since access is typically restricted in a DLT intersection footprint
- Operational measures of effectiveness
- Pedestrian facilities with access and wayfinding for persons with disabilities, including the requirements of the ADA and Section 504 (the Rehabilitation Act).⁽¹⁷⁾
- Bicycle facilities
- Design vehicle
- Snow removal and storage
- Incident management
- Emergency response needs

PLANNING CONSIDERATIONS

The following are planning considerations for an alternative intersection design:

- **Community goals** – Outside of formalized land use policies, cities and communities often have general goals that provide insights about the nature and character of their community. These goals can range from concepts that preserve a historic character or identified heritage to creating walkable communities or complete streets. Other goals can be to encourage economic development by preserving existing business or residential areas while encouraging thoughtful development. Regardless of the specific goals or vision, these considerations may influence street and intersection design.
- **Surrounding land uses and zoning** – DLT intersections are well suited for suburban and urban environments with relatively large parcels of auto-oriented land uses. They are more challenging to implement in urban environments, on streets with short block spacing or numerous driveways, or in dense areas with constrained right-of-way.
- **Project context** – Key questions that help to identify stakeholders for a particular project might include:
 - What is the purpose and function of the existing or planned road facilities?
 - What are the existing and planned land uses adjacent to and in the vicinity of the road facilities?
 - Who will likely desire to use the road facilities given the existing and planned land uses?

- What are the existing and anticipated future socio-demographic characteristics of the populations adjacent to and in the vicinity of the existing or planned road facilities?
- What are the perceived or actual shortcomings of the existing road facilities?
- Who has jurisdiction over the facility?
- Where is capital funding for the project originating (or expected to originate)?
- Who will operate and maintain the facility?
- **Multimodal considerations** – Pedestrian, bicycle, and transit needs should play a role in selecting an intersection form and developing design elements.
- **Access management** – Access will need to be restricted for several hundred feet on an intersection approach with a DLT intersection.
- **Design vehicles** – The intersection geometry will need to accommodate transit, emergency vehicles, freight, and potentially oversize and over weight vehicles.

PLANNING CHALLENGES

The following are several challenges associated with planning DLT intersections:

- **Driver education** – Successful implementations of DLT intersections are often preceded by public outreach and education campaigns, which are typically not conducted for conventional intersection improvements.
- **Driver expectation** – DLT intersections relocate left-turn movements from their conventional location. This is different from what most drivers would expect, and must be accounted for in the intersection planning and design.
- **Multimodal accommodation** – As with any street segment or intersection, each configuration must consider and serve the various users who currently or may be expected to use the facilities. This should always include pedestrians and bicycles, understanding that the exact provisions may necessarily vary for each site. However, pedestrian facilities must always be made accessible. DLT intersections are generally compatible with transit as well.
- **Sufficient corridor right-of-way** – Most DLT intersections have a larger footprint and require more right-of-way than conventional intersections. An intersection approach with a DLT configuration can include at least two lanes (one left-turn lane and one right-turn lane) beyond the typical section of the street. Such right-of-way is prohibitively expensive or impactful at many intersections. On the other hand, the potential footprint of a DLT intersection configuration may be smaller compared to a conventional interchange configuration that provides a comparable level of operational performance.

- **Frontage roads** – These must be further offset from the main road. The intersection of the frontage road and cross street becomes challenging due to the adjacent intersection of the (displaced) left-turn lane and the cross street.

PROJECT PERFORMANCE CONSIDERATIONS

Measuring the effectiveness of overall project performance depends on the nature or catalyst for the project. Understanding the intended specific operational, safety, and geometric performance context for each intersection or corridor including intended users can guide help determine project-specific performance measures. The project performance may be directly linked to the specific design choices and the specific performance of the alternatives considered. The project performance categories described below can influence and are influenced by the specific DLT design elements and their characteristics.⁽¹⁸⁾

Accessibility

Chapter 3 of this guide describes accessibility as it relates to special consideration given to pedestrians with disabilities including accommodating pedestrians with vision or mobility impairments. However, for the purposes of considering a project's general context and the performance considerations, the term "accessibility" goes beyond the conversation of policy related to ADA and Public Rights-of-Way Accessibility Guidelines (PROWAG) and is meant to be considered in broader terms.⁽¹⁷⁾ With respect to considering applicable intersection forms for a given project context, accessibility is defined broadly as the ability to approach a desired destination or potential opportunity for activity using highways and streets (including the sidewalks and/or bicycle lanes provided within those rights-of-way). This could include the ability for a large design vehicle to navigate an intersection as much as it might pertain to the application of snow mobiles or equestrian uses in some environments or conditions.

Mobility

Mobility is defined as the ability to move various users efficiently from one place to another using highways and streets. The term "mobility" can sometimes be associated with motorized vehicular movement and capacity. For the purposes of this guide, "mobility" is meant to be independent of any particular travel mode.

Quality of Service

Quality of service is defined as the perceived quality of travel by a road user. It is used in the *2010 Highway Capacity Manual* to assess multimodal level of service for motorists, pedestrians, bicyclists, and transit riders.⁽⁵⁾ Quality of service may also include the perceived quality of travel by design vehicle users such as truck or bus drivers.

Reliability

Reliability is defined as the consistency of performance over a series of time periods (e.g., hour-to-hour, day-to-day, year-to-year).

Safety

Safety is defined as the expected frequency and severity of crashes occurring on highways and streets. Expected crash frequencies and severities are often disaggregated by type, including whether or not a crash involves a non-motorized user or a specific vehicle type (e.g., heavy vehicle, transit vehicle, motorcycle). In cases where certain crash types or severities are small in number, as is often the case with pedestrian- or bicycle-involved, it may be necessary to review a longer period of time to gain a more accurate understanding.

PROJECT DEVELOPMENT PROCESS

For the purposes of this report, the project development process is defined as consisting of the stages described below. Federal, state, and local agencies may have different names or other nomenclature with the overall intent of advancing from planning to implementation. Exhibit 2-5 illustrates the overall project development process.

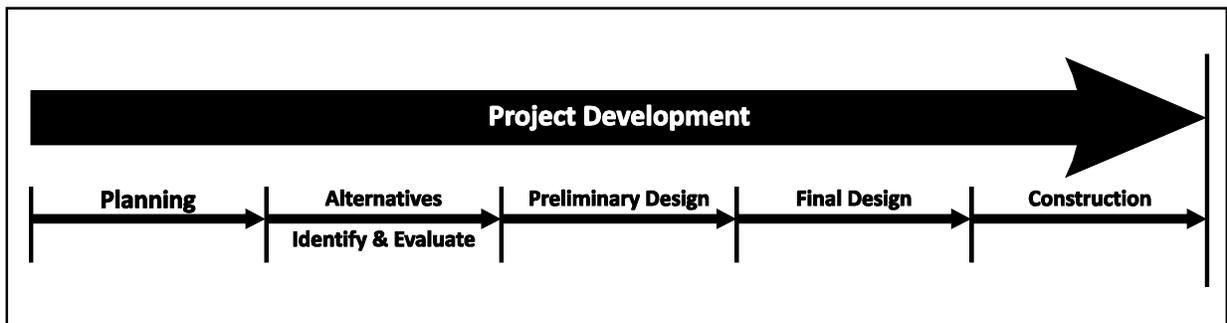


Exhibit 2-5. Project development process.

Planning Studies

Planning studies often include exercises such as problem identification and other similar steps to ensure there is a connection between the project purpose and need and the geometric concepts being considered. Planning studies could include limited geometric concepts on the general type or magnitude of project solutions to support programming.

Alternatives Identification and Evaluation

The project needs identified in prior planning studies inform concept identification, development, and evaluation. At this stage, it is critical to understand the project context and intended outcomes so potential solutions may be tailored to meet project needs within the opportunities and constraints of a given effort. FHWA describes context sensitive solutions as “... a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting.”⁽¹⁹⁾ In considering the concept of “context sensitive design/solutions, this stage calls for meaningful and continuous stakeholder engagement to progress through the project development process.

Preliminary Design

Concepts advancing from the previous stage are further refined and screened during preliminary design. For more complex, detailed, or impactful projects, the preliminary design (typically 30-percent design level plans) and subsequent documentation are used to support more complex state or federal environmental clearance activities. The corresponding increased geometric design detail allows for refined technical evaluations and analyses that inform environmental clearance activities. Preliminary design builds upon the work and geometric evaluations conducted as part of the previous stage (alternatives identification and evaluation). Some of the common components of preliminary design include:

- Horizontal and vertical alignment design
- Typical sections
- Grading plans
- Structures
- Traffic/intelligent transportation systems (ITS)
- Signing and pavement markings
- Illumination
- Utilities

Final Design

The design elements are advanced and refined in final design. Typical review periods include 60-percent, 90-percent, and 100-percent plans before completing the final set of PS&E. During this stage, there is relatively little variation in design decisions as the plan advances to 100 percent. Functionally, in this stage of the project development process, the targeted performance measures have a lesser degree of influence on the form of the project.

Construction

Construction activities could include geometric design decisions related to temporary streets, connections, or conditions that facilitate construction. Project performance measures may relate to project context elements.

SUMMARY OF DLT ADVANTAGES AND DISADVANTAGES

As described in Chapter 1 and the previous sections of this chapter, DLT intersections have unique features and characteristics related to multimodal considerations, safety performance, operations, geometric design, spatial requirements, constructability, and maintenance.

Exhibit 2-6 provides an overview of the primary advantages and disadvantages of DLT intersections for users, policy makers, designers, and planners to understand when considering this type of alternative intersection form.

Exhibit 2-6. Summary of DLT advantages and disadvantages.

Advantages	Disadvantages
Non-Motorized Users	
<ul style="list-style-type: none"> • Bicycles and pedestrians can be accommodated at-grade • Bicyclists have refuge (room for bicycle box) in making two-stage left turns 	<ul style="list-style-type: none"> • Pedestrians may require 2-stage crossings • Some indirect movements may be necessary for pedestrians • Longer pedestrian crossings • Unique challenges for visually impaired pedestrians
Safety	
<ul style="list-style-type: none"> • Fewer conflict points than interchanges (ramp terminals, exit/entrance ramps) and conventional intersections • Lower delay and fewer stops on major street could reduce rear-end crash rates 	<ul style="list-style-type: none"> • Drivers may be less familiar with intersection • Potential for wrong-way movements • Issues with signal in flashing mode / going dark
Operations	
<ul style="list-style-type: none"> • Increase in lane-by-lane capacity due to efficient 2-phase or 3-phase signal operation • Compatible with high-volume turning movements • More green time for major movements offers better progression when used as a corridor solution 	<ul style="list-style-type: none"> • Complex signal operations • Pedestrian crossing time and phasing may limit cycle length flexibility • Potential for additional user delay during off-peak periods • No right turn on red without bypass right turn lane
Access Management	
<ul style="list-style-type: none"> • Compatible with access-restricted corridors 	<ul style="list-style-type: none"> • May change ingress/egress patterns to corner businesses or development • Medians and wide separators required
Cost and Right-of-Way Impact	
<ul style="list-style-type: none"> • Smaller footprint than interchange • Lower cost than interchange 	<ul style="list-style-type: none"> • Required right of way likely larger than conventional intersection • More traffic signals, pavement, curbs and median/refuge islands

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CHAPTER 3— MULTIMODAL CONSIDERATIONS

This chapter provides an overview of multimodal facilities at DLT intersections and how provisions for pedestrians and bicycles should influence the overall planning and design of these intersections. Several of the guidelines presented here are based on elements of the AASHTO Green Book, but applied within the unique context of a DLT intersection.⁽⁴⁾ The overall objective is to develop a design, regardless of the type of intersection, compatible with a Complete Street. A Complete Street is a facility that serves many types of users including freight, transit, and non-motorized users.

DESIGN PRINCIPLES AND APPROACH

DLT intersection planning and design should consider a variety of transportation modes. The following elements should be considered when evaluating a DLT intersection:

- A DLT intersection footprint may result in a wider overall street at the intersection, thereby widening the total pedestrian crossing distance. This can also increase the time it takes for bicyclists to ride through the main intersection area. Additional treatments may be necessary to mitigate these effects.
- The unique movements of the DLT intersection (e.g., prohibited major street left turns at the main intersection) may create added enforcement needs for automobiles and bicycles.
- Large vehicles require adequate lane widths at the crossover intersections to accommodate swept paths. Therefore, the geometry of the overall intersection and all its associated movements need to accommodate the design vehicle for the facility.
- Transit stops near a DLT intersection configuration will need to be strategically placed to support pedestrian access.

This chapter describes the unique characteristics of the four primary non-auto modes (pedestrians, bicyclists, transit, and potentially oversize and overweight vehicles) that should be considered when analyzing and designing DLT intersections.

PEDESTRIANS

DLT intersections require pedestrian crossings that differ from conventional intersections. The position of left-turn lanes between opposing through lanes and right-turn lanes presents pedestrians with an unfamiliar crossing scenario, and the DLT intersection's wide geometric footprint can make it challenging to accommodate pedestrians as part of the traffic signal timing. To mitigate these issues, the design should include pedestrian islands (e.g., medians) to provide refuge, and the short cycle lengths associated with DLT intersection operations can help make pedestrian movements more comparable to crossing times at conventional intersections.

Pedestrian crossing distances at DLT intersections are similar to those of large conventional intersections with channelized right turns. The design focus is to create crosswalks allowing pedestrians to move from the channelization to the outside of the intersection. The crosswalks

across the channelized right-turning streets can be configured with or without signals at the crosswalk. If there are multiple right-turn lanes, then a signalized pedestrian crossing should be provided.

There are two ways to treat pedestrian crossings at DLT intersections. The first option is illustrated by the DLT intersection with displaced major street left turns shown in Exhibit 3-1. This DLT intersection in Dayton, Ohio uses pedestrian signals at the channelized right turns (with right turn on red [RTOR] prohibited) to facilitate pedestrians crossing the channelized right-turn lanes. Another feature of this DLT is that the crosswalks and pedestrian refuges are placed between the crossover left turns and the through-movement lanes so that left-turning vehicles do not conflict with pedestrians. The pedestrian refuges need to be adequate in size and width to meet ADA guidance, as well as accommodate larger volumes of pedestrians when appropriate, including people walking bikes and strollers. Note that no central median island is provided for a pedestrian refuge. Instead, pedestrians cross the through-movement lanes in one stage.

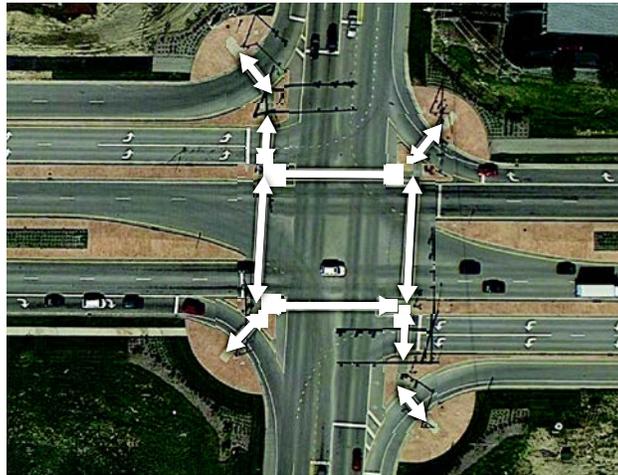


Exhibit 3-1. DLT in Dayton, OH with two-stage crossings of main line.⁽¹⁾

In the second option, as reflected in several DLT intersection installations, the displaced left turns will yield to the pedestrians in the crosswalk (Exhibit 3-2). A separate signal phase is needed for a protected pedestrian crossing by providing protected-permissive left-turn phasing for the displaced left turns.

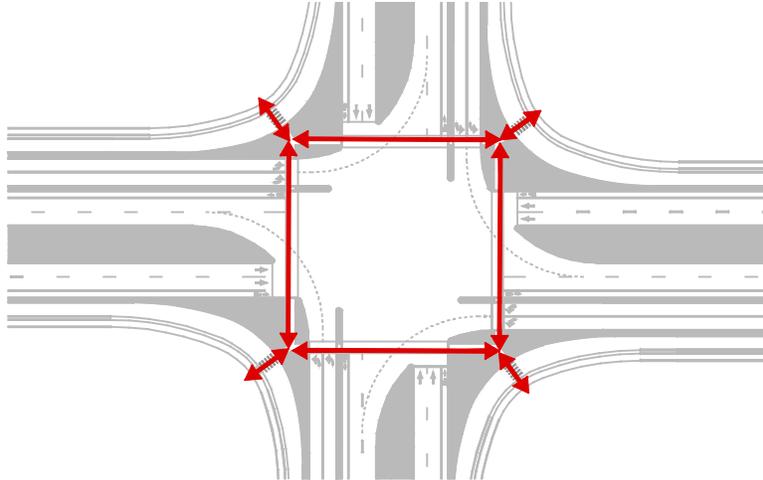


Exhibit 3-2. Possible pedestrian movements with one-stage crossings of main line at a DLT intersection.

Signalized and Unsignalized Pedestrian Crossings

The channelized right-turn lanes at a DLT intersection may be unsignalized. NCHRP Report 674 provides crossing solutions at channelized turn lanes for pedestrians with vision disabilities.⁽²⁰⁾ The following are considerations when planning or designing the channelized right turn to accommodate pedestrians:

- Provide geometric layouts resulting in target speeds for the right-turn lane by considering an arrangement of compound curves rather than a single sweeping circular curve
- Provide appropriate sight distance and lighting for approaching motorists to see activity at the crosswalk, as well as sight distance for pedestrians to see oncoming traffic
- Strongly consider signalized treatment at multilane channelized turn movements

NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings, supplemented with research on the rectangular rapid-flashing beacon (RRFB), provides guidance on improving pedestrian safety at unsignalized crossings.⁽²¹⁾ The RRFB is a pedestrian-actuated set of amber light-emitting diodes (LEDs) that rapidly flashes when actuated. The two NCHRP reports noted in this section provide tools for developing appropriate crossing treatments based on vehicle speeds, traffic volumes, and anticipated number of pedestrian crossings. Potential crossing treatments may include any of the following, or in some cases a combination of two or more of these: pavement markings, signing, flashing beacons, RRFBs, pedestrian hybrid beacons (PHBs), raised crosswalks and fully signalized crossings that are coordinated with the main intersection, each with the consideration for speech messages for visually impaired pedestrians. Exhibit 3-3 suggests potential channelized right-turn geometry.⁽²²⁾

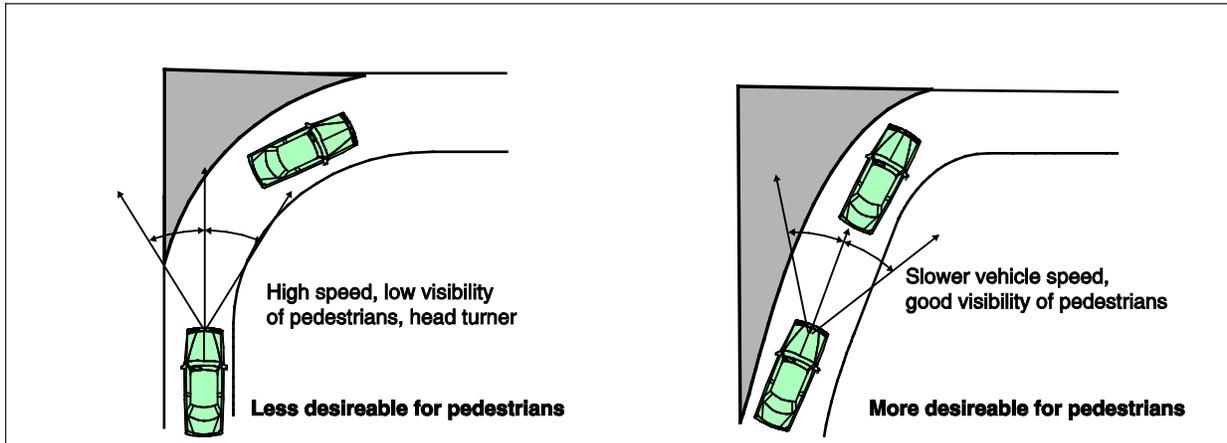


Exhibit 3-3. Channelized right-turn design.⁽²²⁾

Single versus Two-Stage Pedestrian Crossings

The signal control at the main DLT intersection typically operates as a two-phase signal with short cycle lengths to promote signal progression. Short cycle lengths are generally not possible with single-stage pedestrian crossings due to the time required to serve the pedestrian phase on a long crossing. However, short cycle lengths are possible if pedestrians are required to cross in two stages.⁽²³⁾ The tradeoff from a pedestrian standpoint is a potentially long delay for a one-stage crossing versus two shorter increments of delay for a two-stage crossing, plus the need to wait in a refuge between crossing stages.

Depending on the crossing scenario, pedestrians may cross between refuge islands adjacent to the left-turn lanes, as shown in Exhibit 3-4. These pedestrians stand between left-turning and through traffic. This type of movement places moving traffic on two sides of pedestrians, which can be especially challenging for pedestrians with visual or cognitive impairments. Wider median islands and/or wider outer separations are highly recommended to store pedestrians and allow space for bicycles.

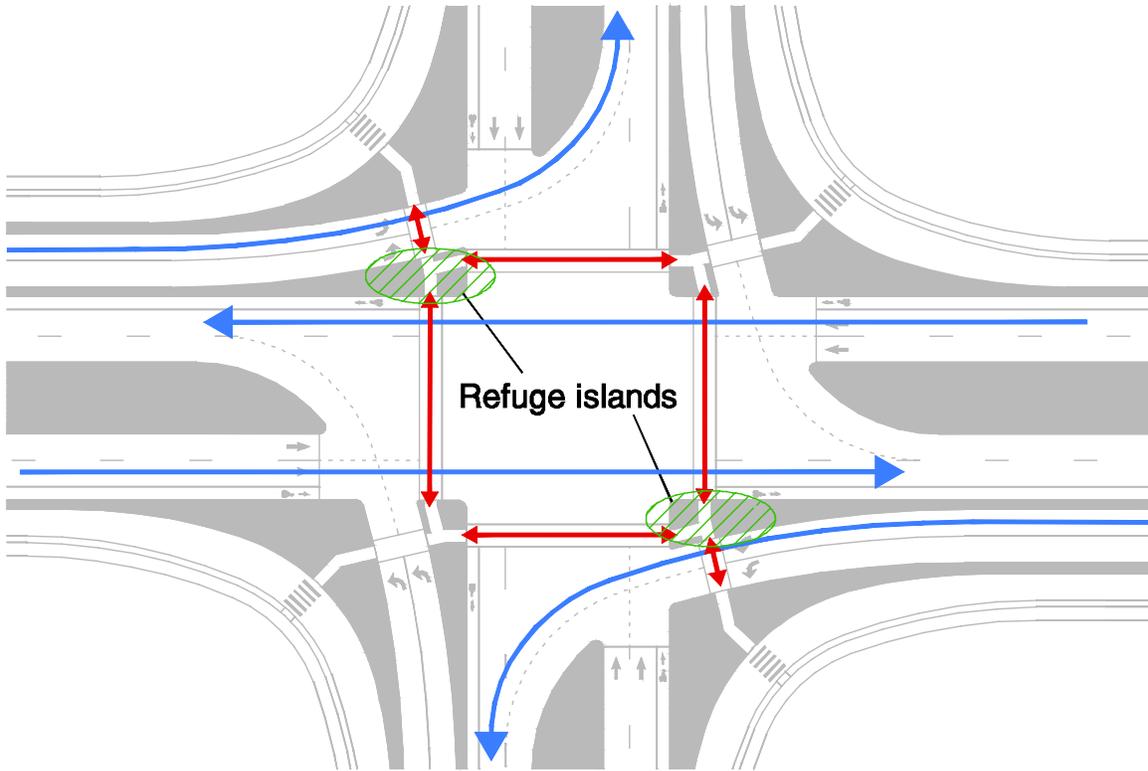


Exhibit 3-4. Refuge islands between left-turn and through lanes.

Conflict Points

A pedestrian/vehicle conflict point exists anywhere a pedestrian walkway crosses the vehicular travel lanes. The conflict points for single-stage crossing DLT intersections with displaced left turns on two approaches and four approaches are illustrated in Exhibit 3-5 and Exhibit 3-6. The conflict points for two-stage crossing DLT intersections with displaced left turns on two approaches and four approaches are illustrated in Exhibit 3-7 and Exhibit 3-8.

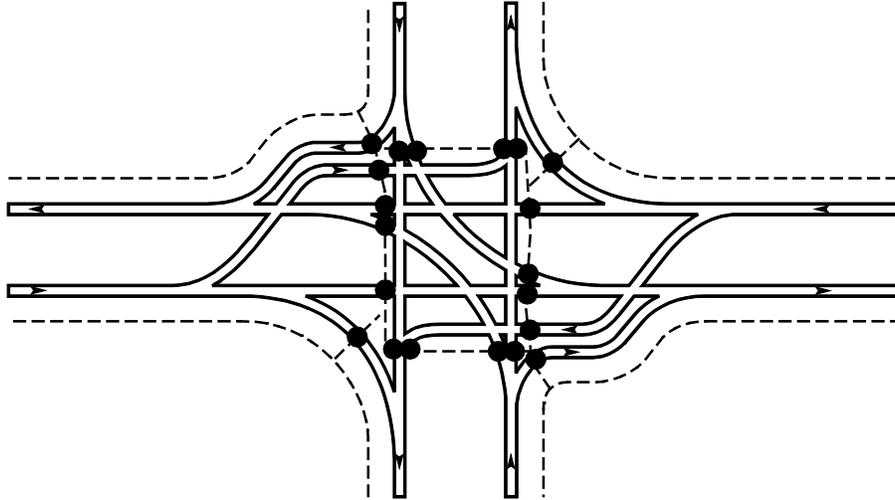


Exhibit 3-5. Pedestrian-vehicle conflict point diagram for a DLT intersection with two displaced left turns with a single-stage crossing.

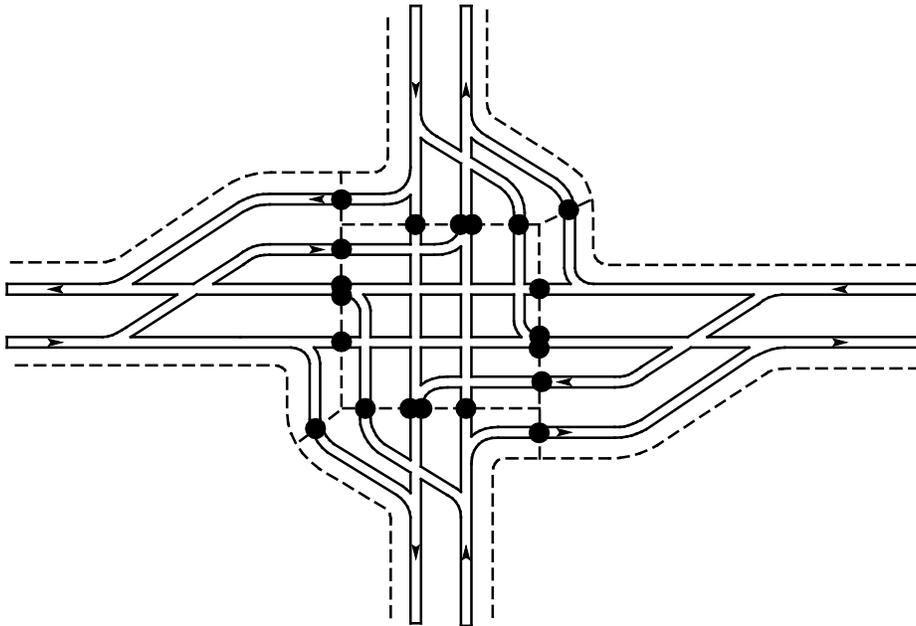


Exhibit 3-6. Pedestrian-vehicle conflict point diagram for a DLT intersection with four displaced left turns with a single-stage crossing.

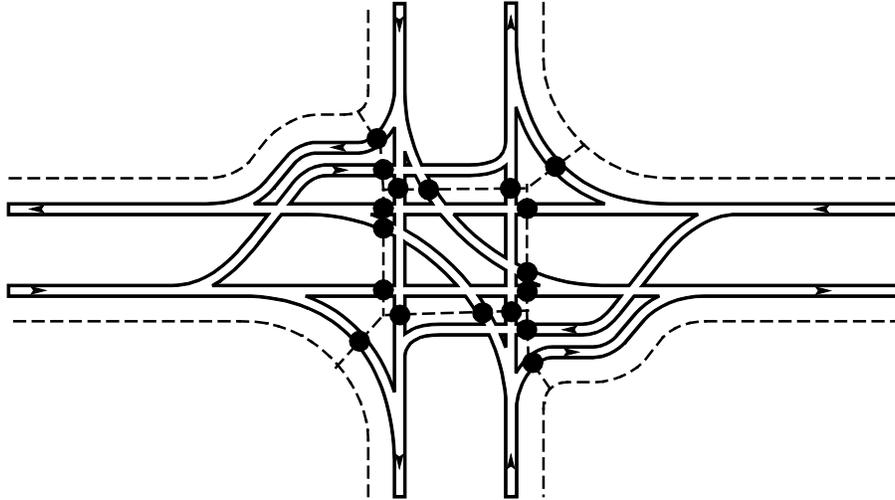


Exhibit 3-7. Pedestrian-vehicle conflict point diagram for a DLT intersection with two displaced left turns with a two-stage crossing.

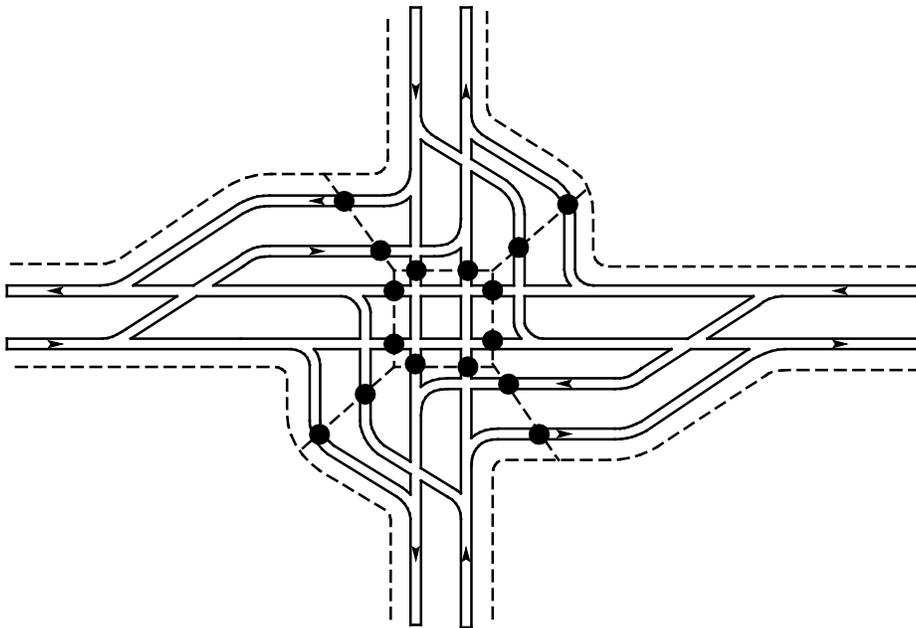


Exhibit 3-8. Pedestrian-vehicle conflict point diagram for a DLT intersection with four displaced left turns with a two-stage crossing.

For comparison, Exhibit 3-9 shows pedestrian-vehicle conflict points for a conventional intersection.

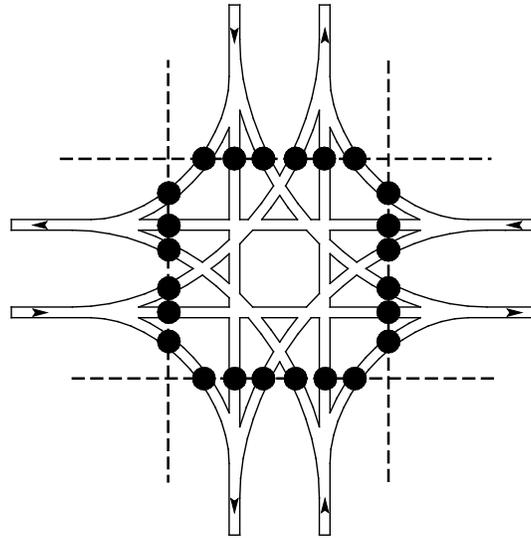


Exhibit 3-9. Pedestrian-vehicle conflict point diagram for a conventional intersection.

A DLT intersection with two displaced left turns has 20 pedestrian-vehicle conflict points for a one-stage crossing and 18 for a two-stage crossing. A DLT intersection with four displaced left turns has 20 pedestrian-vehicle conflict points for a one-stage crossing and 16 for a two-stage crossing. A conventional intersection has 24 pedestrian-vehicle conflict points. Thus, each of the four DLT crossing configurations has fewer pedestrian-vehicle conflict points than a conventional intersection.

ADA and PROWAG Accessibility Considerations

Accessibility was previously described in Chapter 2 in the broader contexts of considering a project's contextual environment and the ability for various users to approach a desired destination or potential opportunity for activity using highways and streets (including the sidewalks and/or bicycle lanes provided within those rights-of-way). In this section, accessibility is explicitly focused on the policies related to ADA and Public Rights-of-Way Accessibility Guidelines (PROWAG).⁽¹⁷⁾ Special consideration should be given to pedestrians with disabilities, including accommodating pedestrians with vision or mobility impairments. Being relatively new on a national level, specific guidance for “Accessible MUTs” is not yet available. However, general accessibility principles can be borrowed from other forms of intersections and applied here. The United States Access Board provides many additional resources on accessibility and specific requirements for Accessible Public Rights of Way, which the transportation professional should refer to and be familiar with.⁽¹⁷⁾

The basic principles for accessible design can be divided into the pedestrian walkway and the pedestrian crossing location. For the pedestrian walkways, the following considerations apply:

- Delineate the walkway through landscaping, curbing, or fencing to assist with wayfinding for blind pedestrians

- Provide sufficient space (length and width) and recommended slope rates for wheelchair users and other non-motorized users such as people pushing strollers and walking bicycles
- Construct an appropriate landing with flat slope and sufficient size at crossing points

For pedestrian crossing locations, these additional considerations apply:

- Provide curb ramps and detectable warning surfaces at the edge of the sidewalk and transition to the street
- Provide accessible pedestrian signals with locator tone at signalized crossings
- Locate push-buttons to be accessible by wheelchairs and adjacent to the crossing at a minimum separation of 10 feet
- Use audible speech messages where spacing is less than 10 feet, or where additional narrative for the expected direction of traffic is needed
- Align the crosswalk landing to the intended crossing direction
- Crosswalk width through the intersection should be wide enough to permit pedestrian and wheelchairs to pass without delay from opposing directions, and the medians should provide sufficient storage for all non-motorized users to safely wait when two-stage crossings are required

All pedestrians—but especially those with vision, mobility, or cognitive impairments—may benefit from targeted outreach and additional informational material created with pedestrians in mind. These outreach materials include information on crosswalk placement and intended behavior, as well as answers to frequently asked questions. For blind pedestrians, materials need to be presented in an accessible format, with sufficient descriptions of all features of the DLT intersection.

BICYCLISTS

A DLT intersection and its approach streets need to be designed with bicyclists in mind. Separated bicycle paths and shared-use paths should cross at stop bar locations where conflicting traffic movements are typically controlled by signals. Another approach is to provide grade separation for bicyclists.

Bike Lane Design at Right Turns

Four locations need to be addressed when planning and designing for bicycles at a DLT intersection:

1. The entrance to the channelized right turn, which is a bicycle-vehicle conflict point

- If a bicycle lane is present, this movement can be accomplished similarly to the entrance to a channelized right turn at a conventional intersection.
2. Traveling along the right-turn lane
 - Typically, right-turning vehicles and bicycles share the travel lane and, depending on their respective volumes and travel speeds, bicycles may choose to use the sidewalk.
 3. Traveling through the DLT intersection
 - Green paint (see Chapter 8 for details) indicating the continuation of the bicycle lane can delineate bicycle travel areas through the intersections.
 4. The right-turn lane end
 - Bicyclists traveling through on the cross road will conflict with right-turning vehicles trying to merge with traffic along the cross street. To address the bicyclist exposure at this location, the transportation professional can consider a perpendicular bicycle crossing of the right-turn lane, as illustrated in Exhibit 3-5 above.

Exhibit 3-10 and 3-11 highlight these conflict areas and summarize potential routes for bicyclists traveling through DLT intersections via on- and off-street facilities, respectively.

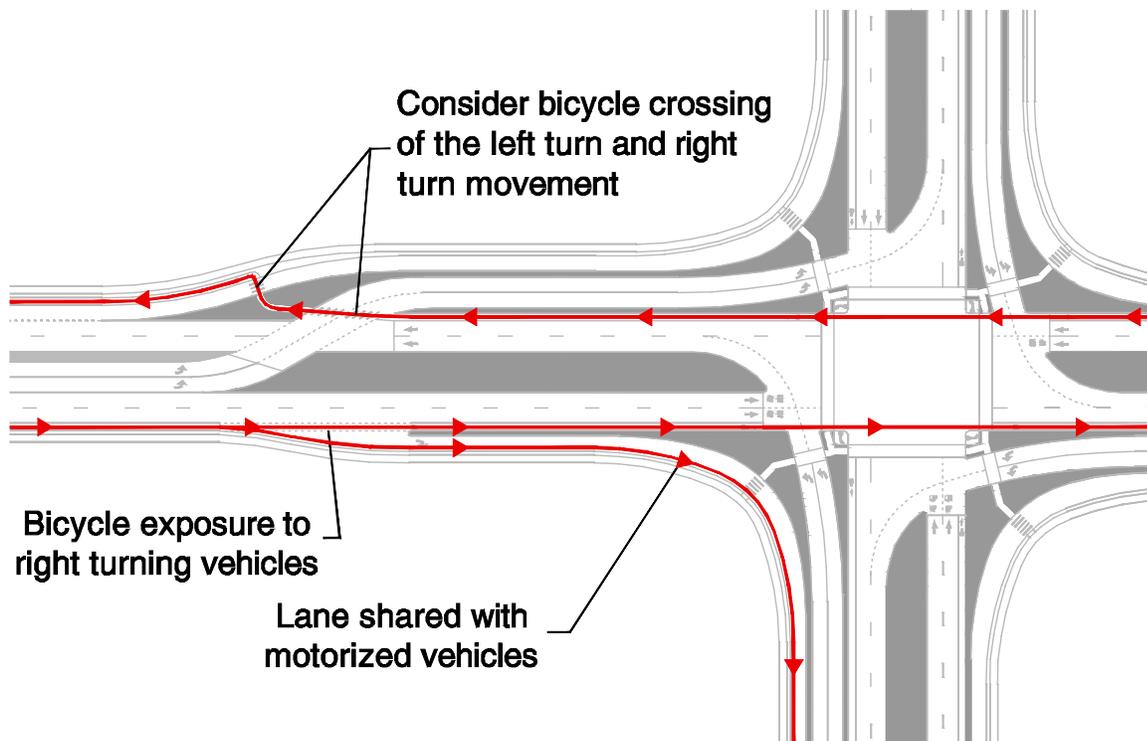


Exhibit 3-10. Accommodating on-street bicycles through a DLT intersection.

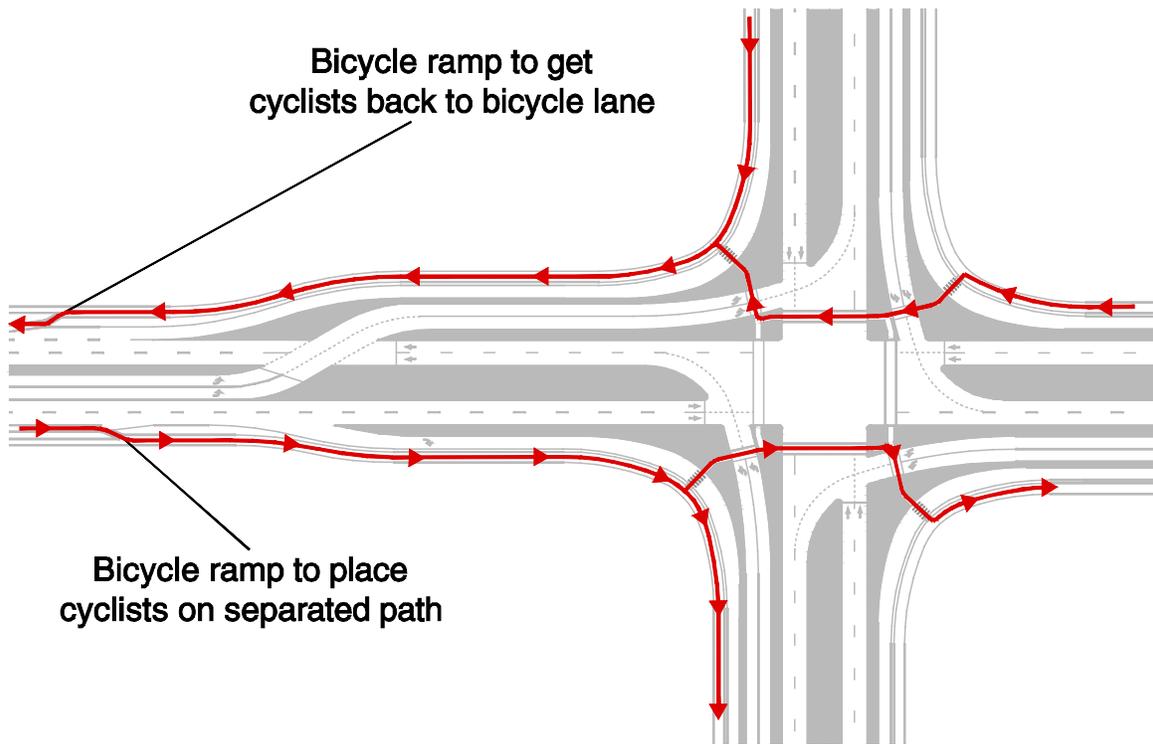


Exhibit 3-11. Accommodating off-street bicycles through a DLT intersection.

Bicycle Design for Left Turns

For bicyclists completing a left turn through the intersection, DLT intersections present similar challenges as large conventional intersections. There are three ways for a bicycle to complete a left turn at a DLT intersection:

- Using a traffic lane to make the crossover movement, as a passenger car would make.
- With bicycle ramps to/from the sidewalks or shared-use paths in the vicinity of the DLT intersection. With this configuration, bicyclists will cross in the crosswalks.
- If the DLT intersection geometry provides a pedestrian refuge island between the through lanes and the displaced left turns (as shown previously in Exhibit 3-4), a bicycle box can be placed in front of the far-side refuge to allow a two-stage left turn by bicyclists. This is shown in Exhibit 3-12.

Exhibits 3-12 and 3-13 illustrate potential left-turning bicycle routes for two DLT configurations. Transportation professionals need to work with local agencies to determine dimensions for shared bicycle/pedestrian paths.

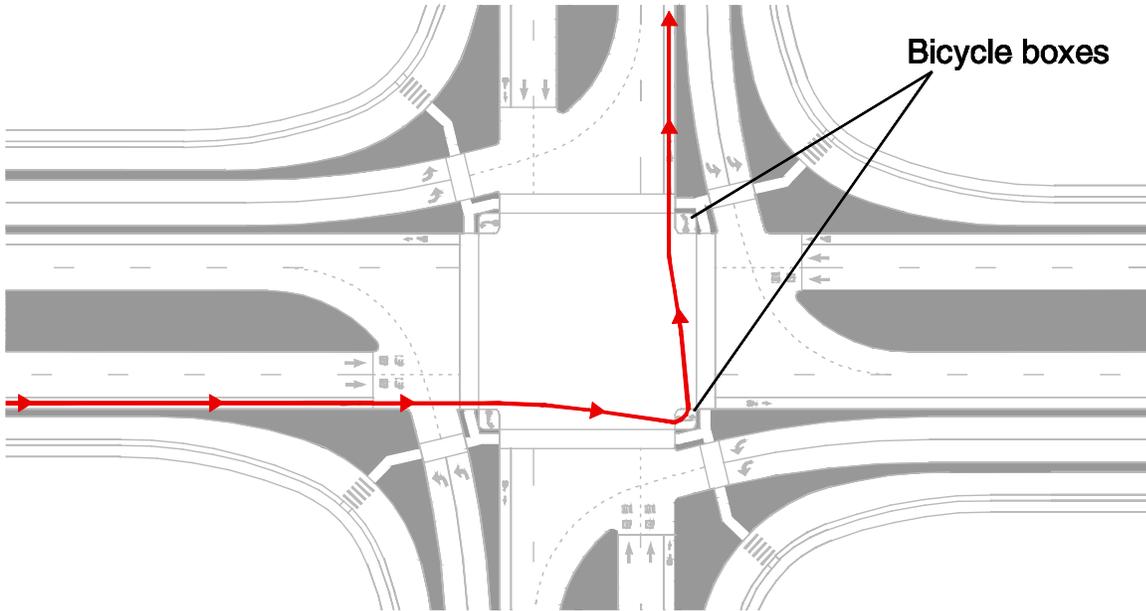


Exhibit 3-12. Accommodating on-street left-turning bicycles with a bicycle box through a DLT intersection.

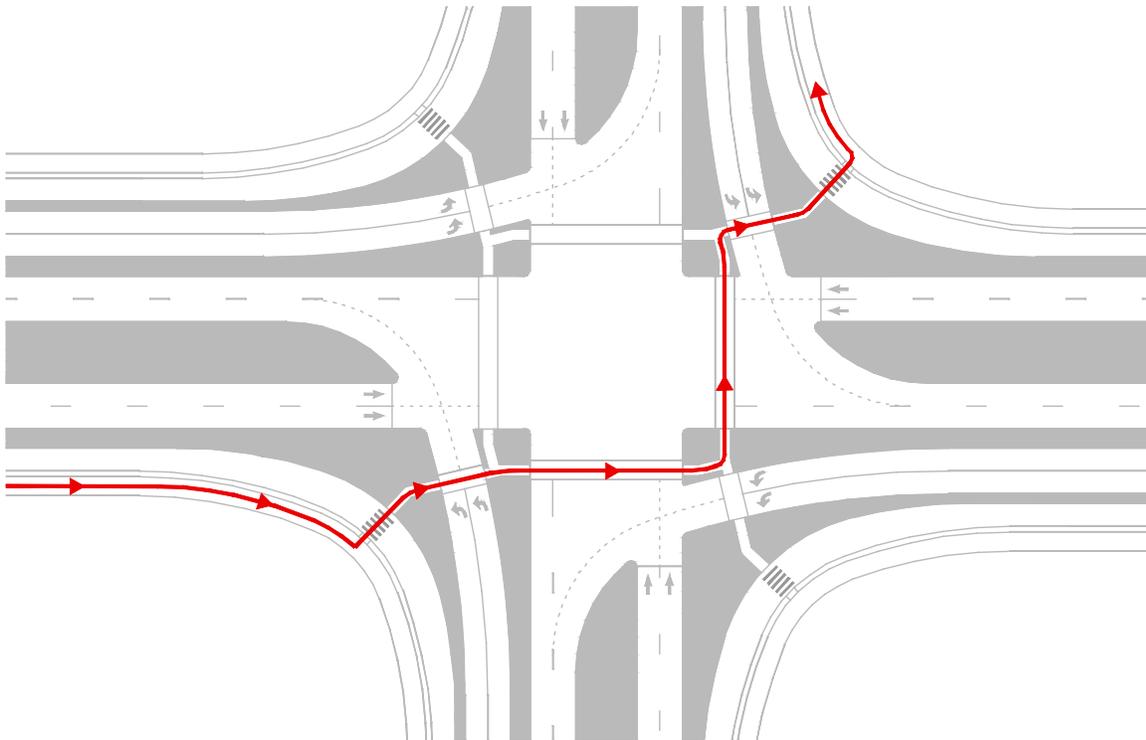


Exhibit 3-13. Accommodating off-street left-turning bicycles through a DLT intersection.

TRANSIT VEHICLE CONSIDERATION

Buses travel through DLT intersections in the same manner as passenger cars. Stops are placed away from the main intersection. Location considerations are described as follows.

Bus Stop Locations

The left-turn, through-, and right-turn movements at a DLT intersection do not merge or diverge at a single point near the main intersection. This runs counter to the traditional practice of locating transit stops near the crosswalk at the main intersection. Transportation professionals can consider two strategies to place transit stops and need to work collaboratively with transit agencies to finalize transit stop locations.

Midblock

Locating a transit stop farther upstream or downstream of the DLT intersection could result in pedestrians crossing away from the main intersection. In these cases, a well-placed and well-designed midblock pedestrian crossing needs to be considered. Exhibit 3-14 shows the potential location of a transit stop at a midblock location for one approach of a DLT intersection; the following elements regarding the location of the bus stop should also be taken into consideration:

- It potentially forces passengers to walk a long way back to the intersection
- It may encourage passengers to jaywalk rather than walk to a legal crossing point
- It makes it difficult to accommodate transfer between routes on the crossing streets because of the long walking distances involved

However, other factors may require such a bus stop placement. When midblock stops are used, signal control such as a RRFP, a pedestrian hybrid beacon, or a traditional midblock signalized crossing should be considered.

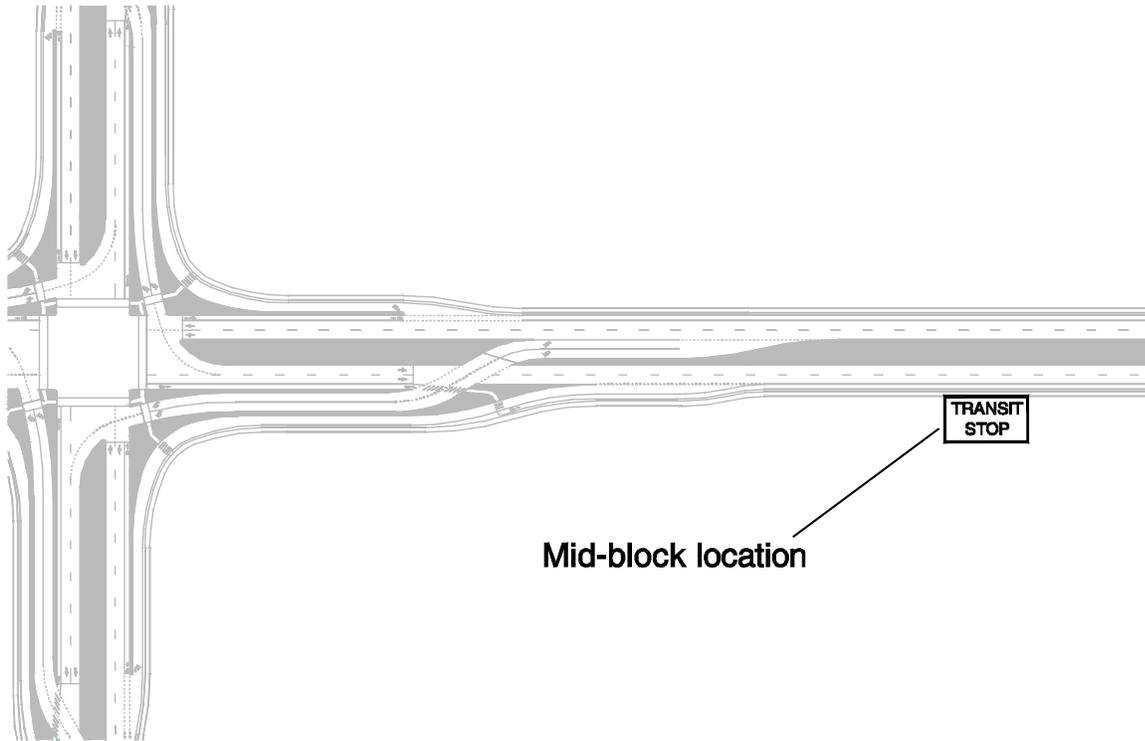


Exhibit 3-14. Potential transit midblock stop location in a DLT intersection.

Main Intersection

The second option is to develop a near-side bus stop on the channelizing island at the main signal. Exhibit 3-15 shows a potential near-side location using a short bus lane, while Exhibit 3-16 illustrates a bus stop located in the travel lane. The following considerations apply to near-side bus stops:

- At conventional intersections, when bus routes cross at an intersection, it is often desirable to locate pairs of stops on the same corner (one near-side, the other far-side) to accommodate transfers between routes. However, this approach is not possible at a DLT intersection—passengers must cross the street to transfer—but it is nevertheless preferable to the long walk involved with transferring between midblock stops.
- Through buses can stop at the stop bar at the main intersection in the travel lane, or in a short bus lane or pullout adjacent to the channelizing island. The island needs to be long enough to accommodate a design bus and wide enough to meet ADA standards at the door locations. As buses may experience delay re-entering the travel lane from a pullout or bus lane, a queue-jump signal phase can be considered. A queue-jump signal provides the bus a few seconds of green before or after the parallel signal phase to allow the bus to merge into the general travel lane with minimal delay. The stop bar for a bus lane may be set forward from the general traffic stop bar, as it does not conflict with the swept path of left-turning traffic from the cross street.

- Bus stops for right-turning buses should stop close to the crosswalk in the right-turn bypass lane. The bus stop is typically before the crosswalk if the bus stops in the lane (no vehicle can pass the bus), or just after the crosswalk in a pullout so pedestrians can cross behind the stopped bus.
- Transit stops for left-turning buses can stop in the displaced left-turn lane at the stop bar if a wide-enough median is provided to accommodate passengers (see Exhibit 3-16). Another bus stop option for left-turning buses uses the short bus lane or pullout option described above (see Exhibit 3-15); in this case, a special bus phase will need to be provided for the bus to safely make its turn.

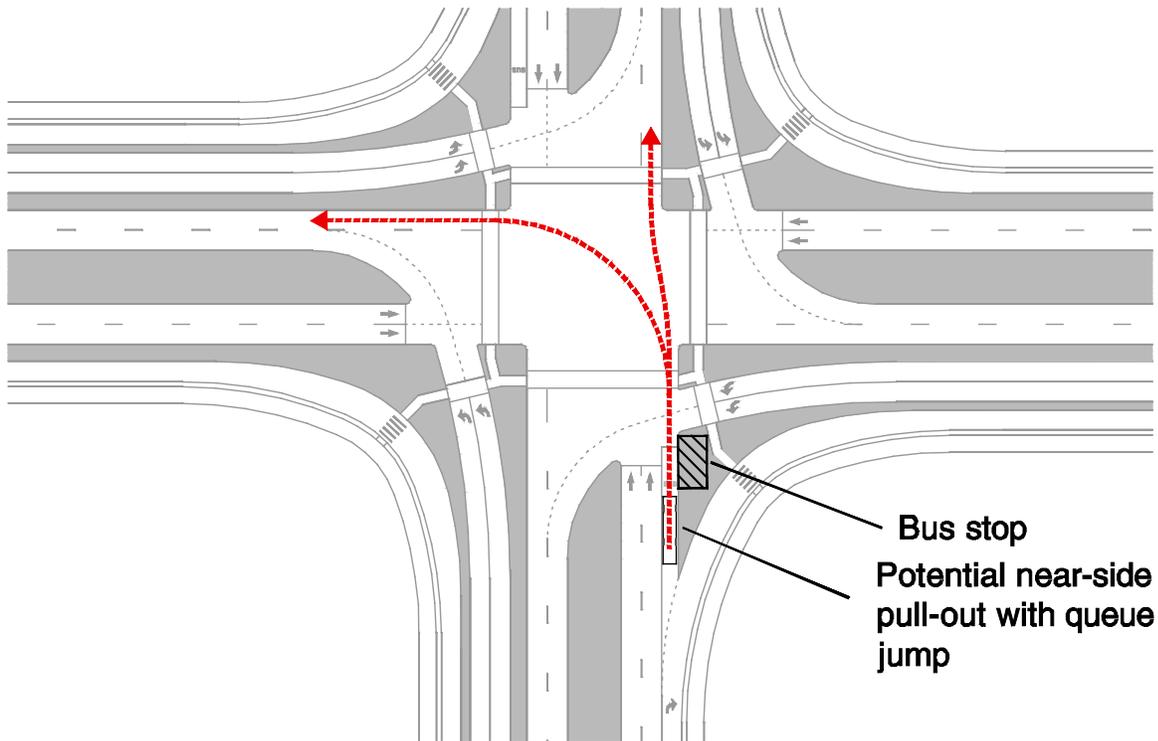


Exhibit 3-15. Potential nearside stop locations with pullouts.

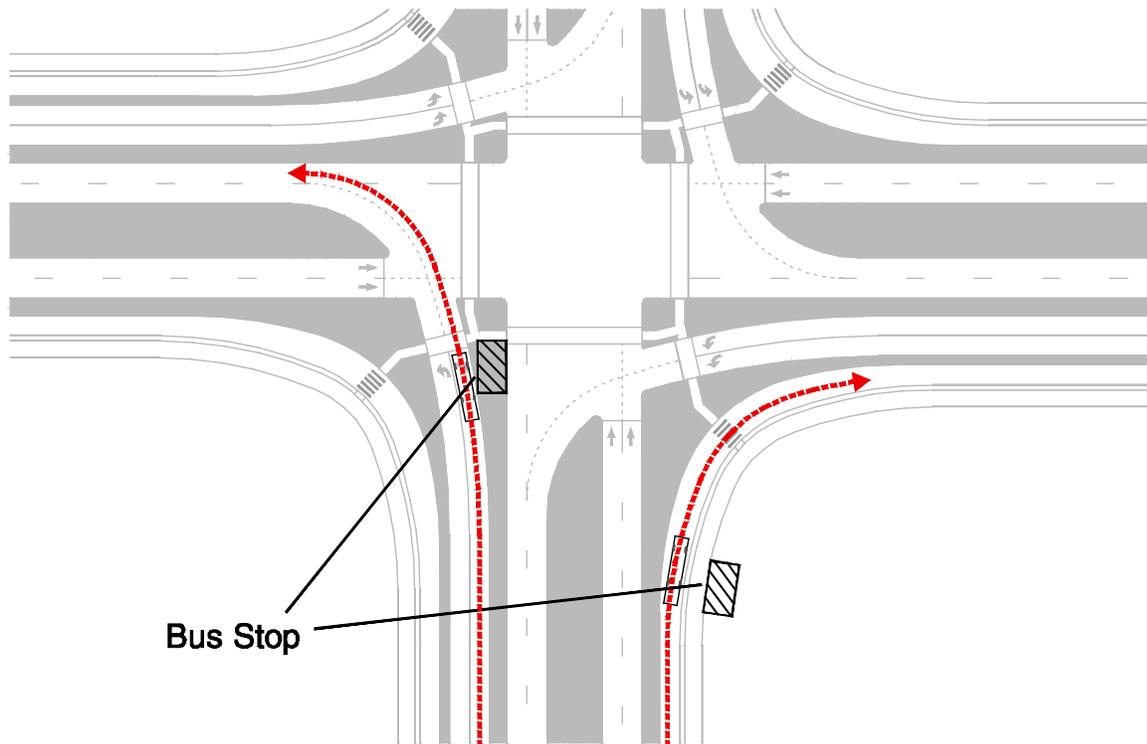


Exhibit 3-16. Potential stop locations in travel lanes.

Bus stops are not necessarily provided at every DLT intersection because the surrounding land uses may not be oriented toward transit users. Should stops be necessary, a collaborative process between street and transit agencies can help finalize the stop locations and assess implementing transit-supportive treatments, such as queue jumps.

HEAVY VEHICLE CONSIDERATIONS

The effects of the DLT crossover and other turning movements should also be considered with regard to heavy vehicles. Unlike alternative intersection treatments such as roundabouts, DLT intersections do not usually contain aprons or other design elements that are intended to be traversable by trucks and other large vehicles. When designing the specific elements of the DLT—such as left-turn crossovers, left turns onto the cross street at the main intersection, and right-turn bypass lanes—it is crucial to consider the appropriate design vehicle and the possibility that large vehicles may travel through the DLT.

CHAPTER 4— SAFETY

At this time, little is documented about the safety performance of DLT intersections as there have been insufficient numbers of intersections open for an extended period of time. DLT intersections, like many alternative intersection designs, offer several potential safety advantages compared to the conventional intersection by reducing conflict points and channelizing turning movements. This chapter summarizes the safety performance at DLT intersections based on studies completed by state agencies and recent research efforts.

SAFETY PRINCIPLES

An appropriate level of safety assessment corresponding to the stage of the project development process (planning, alternatives identification and evaluation, preliminary design, final design, and construction) supports decisions about DLT intersections. The analysis should be consistent with the available data, and the data should be consistent with the applied tools. Multimodal safety principle—including vehicle-pedestrian and vehicle-bicycle conflict points, accessibility, and crossing options—are discussed in Chapter 3.

Reduced Vehicle-Vehicle Conflict Points

While crash data are often used to develop models or other tools that can ultimately help professionals make safety decisions about transportation facilities, crash data are often limited or completely unavailable for some types of facilities. In the case of DLT intersections, the small number of existing intersections (approximately ten) makes it difficult to make inferences or develop tools related to their safety performance or expected crash frequency or severity.

Based on the design and operation of the intersection, however, it is possible for a DLT intersection to offer better safety performance over a conventional intersection. In lieu of crash data, one often-applied strategy is to examine the number of conflict points at an intersection. While no mathematical relationship between conflicts and collisions has been clearly documented, conflicts are correlated with collisions and are often used as a surrogate measure, particularly to compare different intersection forms. It is common to consider both lane-by-lane conflicts and an aggregated conflict analysis that treats each movement as one lane; the latter approach will be presented here for the sake of simplicity. Exhibit 4-1 shows the number of vehicle-to-vehicle conflict points present at various forms of the DLT intersection compared with conventional intersections. While the DLT intersection offers no reduction in conflict points for a three-leg intersection, it results in a 6- to 12-percent decrease in conflict points for a four-leg intersection.

Exhibit 4-1. Conflict point comparison.

Number of Intersection Legs	Number of Crossovers on DLT	Conflict Points	
		Conventional	DLT
3	1	9	9
4	2	32	30
4	4	32	28

Exhibit 4-2 shows the conflict points of a conventional intersection. The total number of conflict points is 32. Exhibit 4-3 shows the conflict points of a DLT intersection with left-turn crossovers present on the mainline approaches. The total number of conflict points in this case is 30 compared to the 32 conflict points at a conventional intersection. Exhibit 4-4 shows the conflict points of a DLT intersection with left-turn crossovers present on all approaches. The total number of conflict points in this case is 28. The slightly lower number of conflict points could translate to fewer potential collisions.

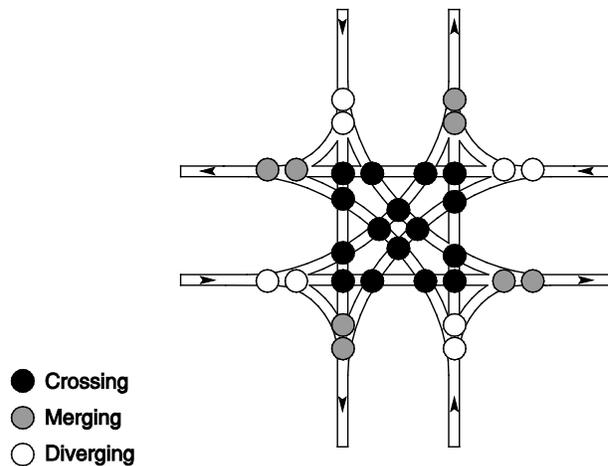


Exhibit 4-2. Conflict point diagram for a conventional intersection.

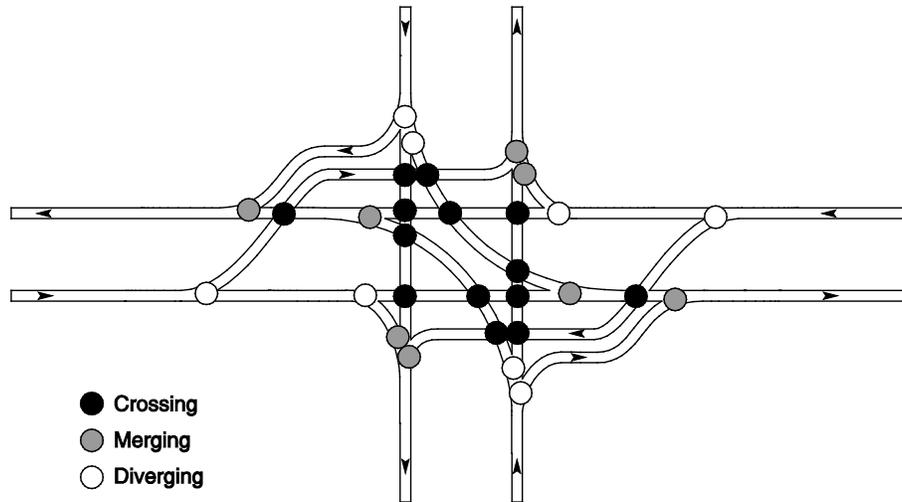


Exhibit 4-3. Conflict point diagram for a DLT intersection with two displaced left turns.

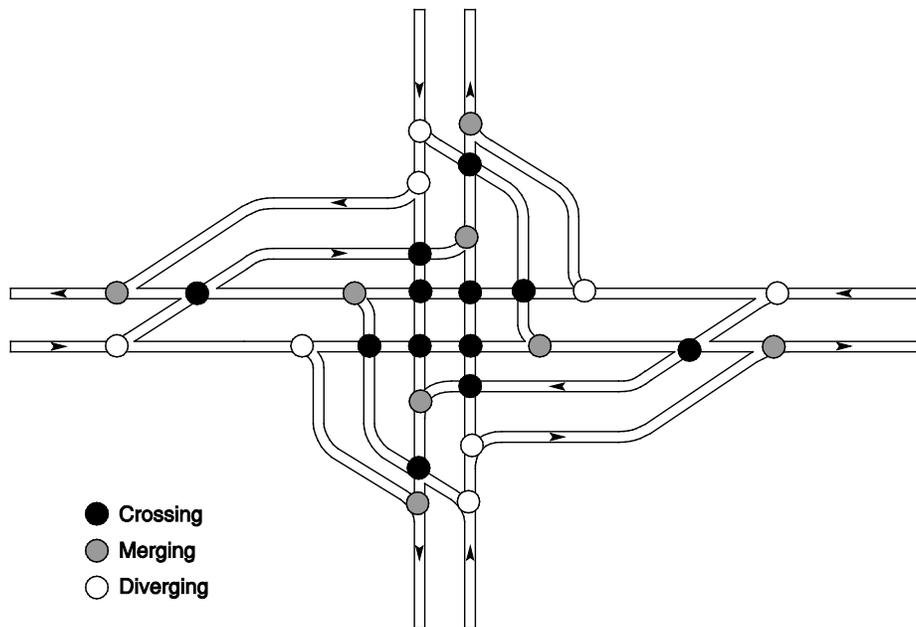


Exhibit 4-4. Conflict point diagram for a DLT intersection with four displaced left turns.

Human Factors, Principles, and Considerations

A human factors study performed by Dowling College examined a DLT intersection in Shirley, NY (shown in Exhibit 4-5) to explore driver comfort and confusion. The study found “about 80 percent of the first time users of the [DLT intersection] expressed positive comments about the design,” with that figure increasing to 100 percent after a week of driving.⁽²⁴⁾



Exhibit 4-5. Dowling College DLT intersection in Shirley, NY.⁽¹⁾

There are several design features of the DLT configuration that may be counterintuitive to some drivers. The following information could help minimize driver confusion:

- Drivers are familiar with making left-turn maneuvers at the main intersection. In the case of a DLT intersection, the indirect left turn occurs several hundred feet in advance of the main intersection. This requires drivers to anticipate the left turn in advance of the main intersection, so signing needs to be well-designed and complement the geometry of the intersection.⁽⁵⁾
- The design features of a DLT intersection and the relocation of turn movements at the main intersection presents the possibility of wrong-way movements. Wrong-way movements can be reduced by providing adequate signage, pavement markings, and, most of all, the geometric design of the street, including appropriate channelization and orientation of the horizontal alignments (see Chapters 7 and 8).⁽⁹⁾

OBSERVED SAFETY PERFORMANCE

There are limited safety related studies for the small number of existing DLT intersections to conclude safety performance based on observed data.

SAFETY CONSIDERATIONS

The DLT intersection introduces some unique operational qualities not present in the conventional intersection. These elements are discussed in the following sections.

Pedestrian and Bicyclist Right-turn Movements

Similar to conventional intersections, four conflict areas exist between vehicles and bicyclists, as well as between vehicles and pedestrians along the length of the right-turn bypass lane at DLT intersections:

- Conflict between vehicles and pedestrians at the signalized or unsignalized pedestrian crossing at the 90-degree turn of the right-turn bypass lane
- Conflict between right-turning vehicles and through bicyclists at the entrance to the channelized right-turn lane
- Limited width for right-turning cyclists sharing the channelized right-turn lane with automobiles
- Conflict between right-turning vehicles merging along the cross road and through bicyclists on the cross road along the merge lane end section

Chapter 3 provides techniques for addressing these conflicts, and Chapter 8 provides more details associated with specific signing and pavement marking treatments.

Potential for Wrong-way Movements

The crossover intersection has the potential for wrong-way movements, as well as path overlap as vehicles travel through the crossover curves. Designers should consider path alignment through the signal to position vehicles at the stop bar to aim vehicles to the receiving lane beyond the intersection and not rely solely on signing and pavement markings for guidance. Assuming Exhibit 4-6 is oriented east-west horizontally, it shows the eastbound left turns align directly with the opposing westbound throughs, which is undesirable.

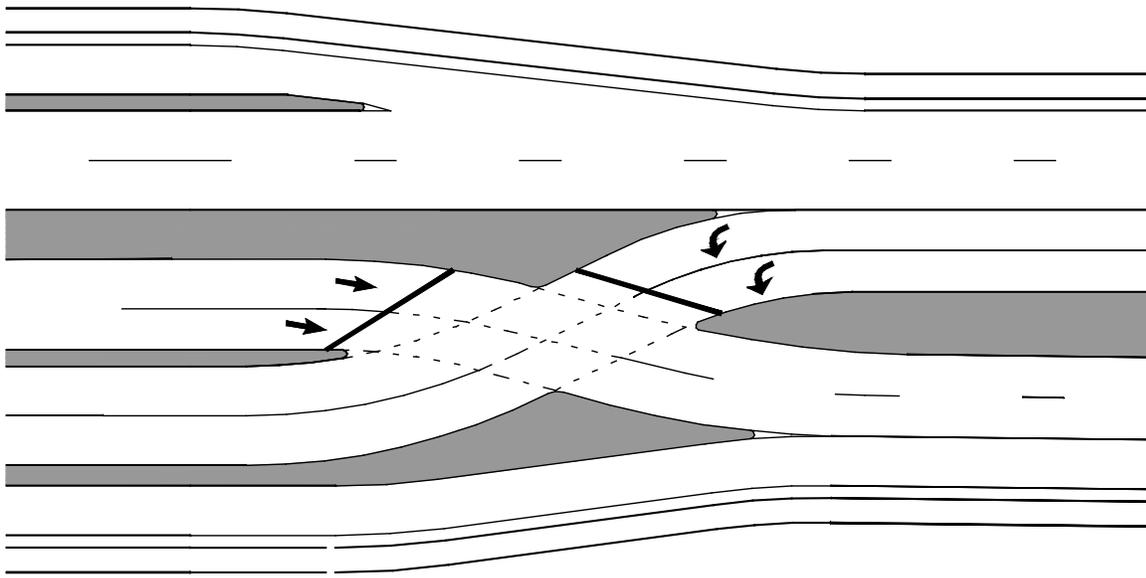


Exhibit 4-6. Undesirable crossover intersection layout.

Exhibit 4-7 shows the eastbound left turns are oriented away from the oncoming westbound lanes, which is desirable. This configuration provides a tangent alignment along through lanes in the area of the crossover intersection. Chapter 8 provides specific signing and pavement marking details to supplemental desirable geometry.

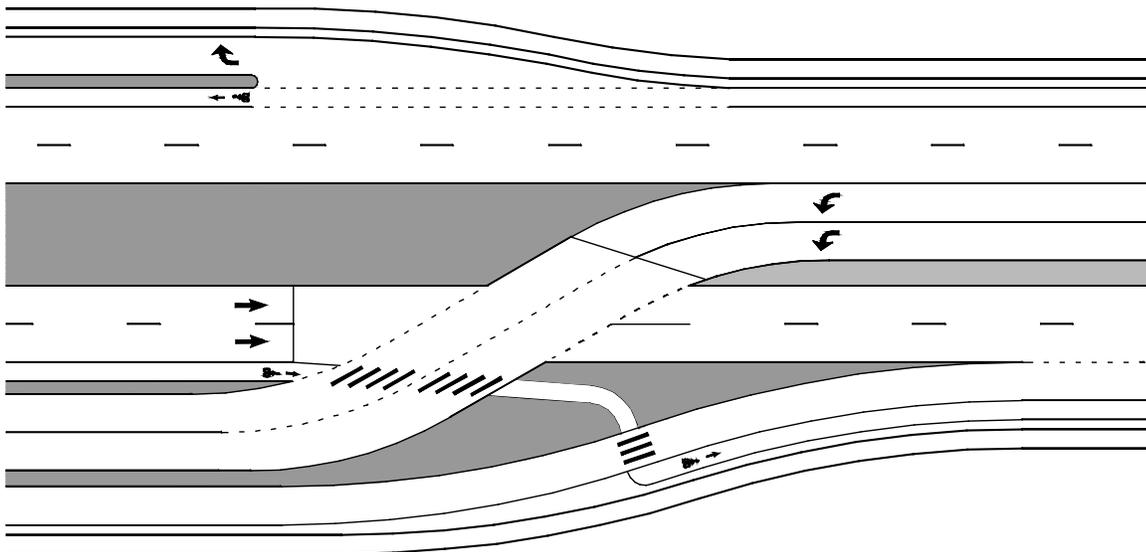


Exhibit 4-7. Desirable crossover intersection layout.

At the main intersection, as well as the crossover intersections, the road alignment of the through movements is a particular focus. Curvature (e.g., sharper than expected) through a signalized intersection may result in approaching vehicles not appropriately aligning and entering opposing left-turn lanes. Applying basic geometric principles to allow for appropriate curve lengths and tangents between curves results in appropriate natural paths through the intersections. Chapter 7 provides guidelines for developing a layout meeting overall basic street design principles.

INCIDENT RESPONSE CONSIDERATIONS

This section presents incident response considerations for DLT intersections.

Loss of Power to the Traffic Signals

Many agencies now require backup batteries and a natural gas generator in traffic signal systems in case of power failures. Given the unconventional geometry of a DLT intersection, there is potentially a greater benefit from installing a battery backup or generator than at a conventional intersection. For example, a DLT intersection in Baton Rouge, LA contains backup batteries and a natural gas generator for use in the event of power failure.⁽²⁵⁾

Intersection Blocked

There is potential for the crossover to be blocked during crashes or incidents where stoppage and subsequent queuing of one movement (either the left-turn crossover or the through vehicles) could block the other movement. These situations can be mitigated by constructing shoulders or wide lanes to move vehicles around the blockage, but these treatments may also lead to higher speeds. In addition, metering and signal coordination with upstream and downstream intersections minimizes the likelihood of blockages in non-crash situations.⁽²⁴⁾

The use of mountable curbs in the crossover area could help facilitate emergency vehicle access to the crossover lanes. Frontage roads could also provide access to channelized right-turn lanes.

Emergency Response

Emergency vehicle preemption (e.g., fire preemption) is provided for many signalized intersections. To minimize response time, an emergency response vehicle should be able to travel through all signalized intersections within the DLT configuration without stopping (completing a left turn, through movement, or right turn as illustrated in Exhibit 4-8). The signals would be coordinated to allow the progression when preempted, as shown in Exhibit 4-8.

Four-leg DLT intersections, while restricting direct left turns, do not install physical objects within the primary intersection (intersection of major and minor cross roads) that would physically block emergency vehicles from making direct left turns. Direct left turns at four-leg DLT intersections are denied exclusively by signing, signal indications, and pavement markings. Emergency vehicles using sirens and flashing lights as they approach a four-leg DLT intersection and desiring to turn left can make a direct left turn after verifying vehicles with conflicting movements have yielded the right-of-way. A direct left turn could be beneficial to emergency vehicles if the left-turn crossover lanes are blocked by queued traffic or disabled vehicles.

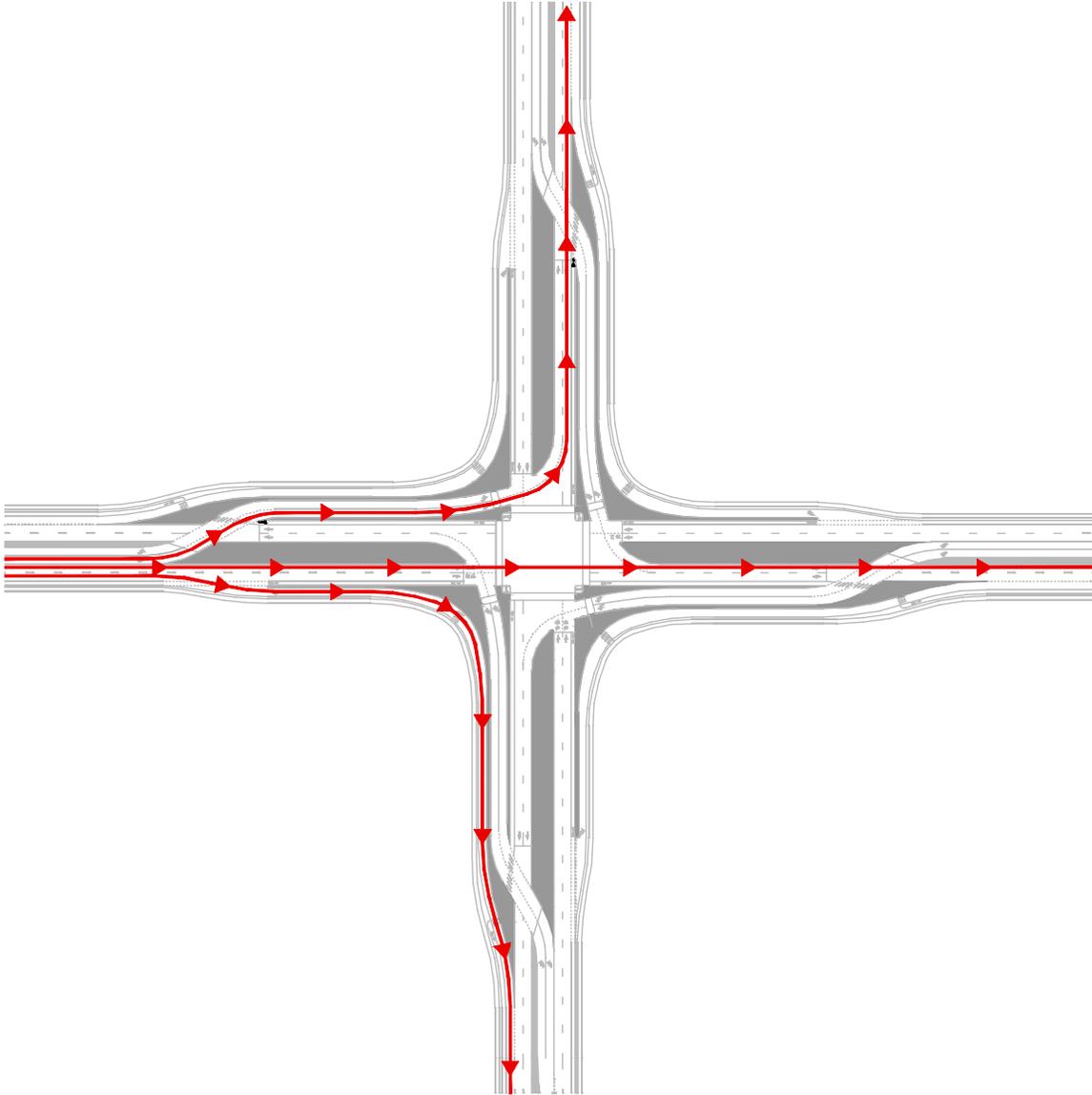


Exhibit 4-8. Emergency preemption movements on one approach of a DLT intersection.

SAFETY EVALUATION CONSIDERATIONS

Given the limited available data, safety at a DLT intersection should be evaluated by assessing conflict points and driver expectancy. There are no crash modification factors (CMFs) specific to DLT intersections.

CHAPTER 5— OPERATIONAL CHARACTERISTICS

This chapter provides information on the unique operational characteristics of DLT intersections and how they affect elements such as traffic signal phasing and coordination. The guidance presented here builds on existing DLT studies, which include operational performance studies, comparative performance studies, and simulation analysis. The chapter also provides guidance relating to design elements, such as driveways, that could affect the operational performance of DLT intersections. It is intended to help transportation professionals understand the unique operational characteristics of DLT intersections and prepare them for conducting operational analysis as described in Chapter 6.

OPERATIONAL PRINCIPLES

The DLT intersection is often implemented as a treatment to maximize throughput at an intersection. DLT configurations exhibit operational benefits specifically when a heavy left turn conflicts with a heavy through movement. The distinguishing feature of a DLT intersection is the left-turn crossover, which serves left turns at a signalized intersection upstream of the main intersection. The crossover intersection then carries the left turns to the cross street on the left side of the two-way traffic at the main intersection. This enables the left turns to move during the same signal phase as the through movement. Removing the left-turn movements from the main intersection reduces signal phases, which in turn leads to higher capacity for the intersection. Exhibit 5-1 illustrates concurrent movements for the east-west arterial at a conventional intersection and a DLT intersection. Concurrent movements for the north-south arterial are analogous.

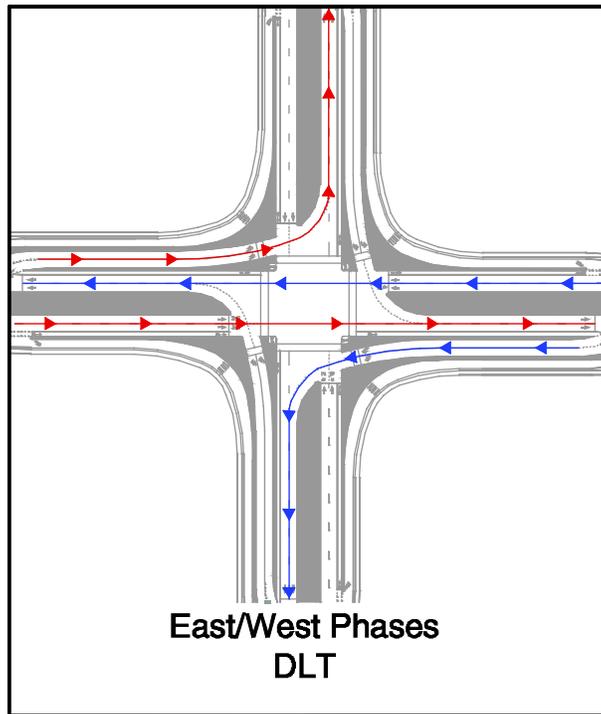
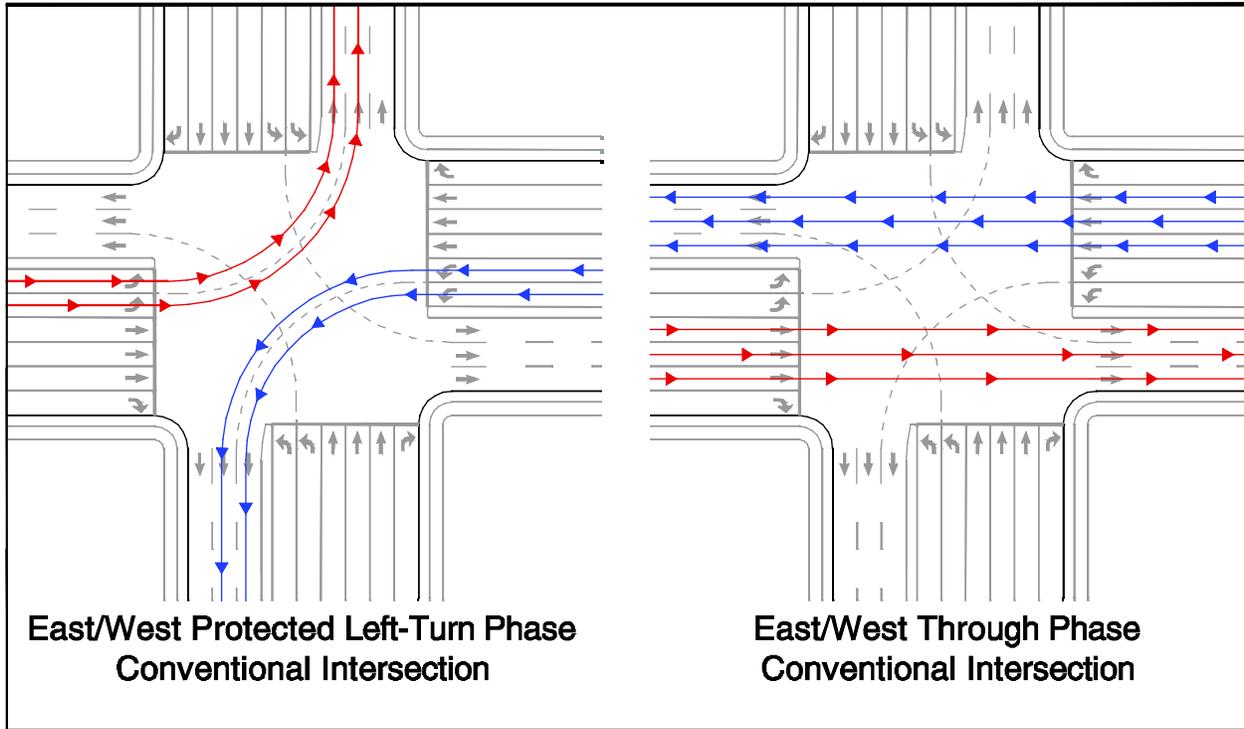


Exhibit 5-1. Concurrent movements for east-west arterial at conventional intersection and DLT intersection.

Traffic Signal Phasing

The MUTCD presents the current practice regarding traffic control devices, but the DLT intersection presents additional challenges regarding signal control not explicitly addressed in the MUTCD.⁽⁶⁾ A DLT configuration consists of a signalized intersection on one or more approaches along with a signal at the main intersection. Exhibit 5-2 shows the typical locations of signalized intersections within a DLT configuration; Intersection 1 represents the main intersection while Intersections 2 through 5 represents the crossover intersections. DLT intersections typically have shorter cycle lengths than similarly sized traditional intersections as a result of the reduced number of phases and the need to reduce queue lengths between the closely-spaced intersections.

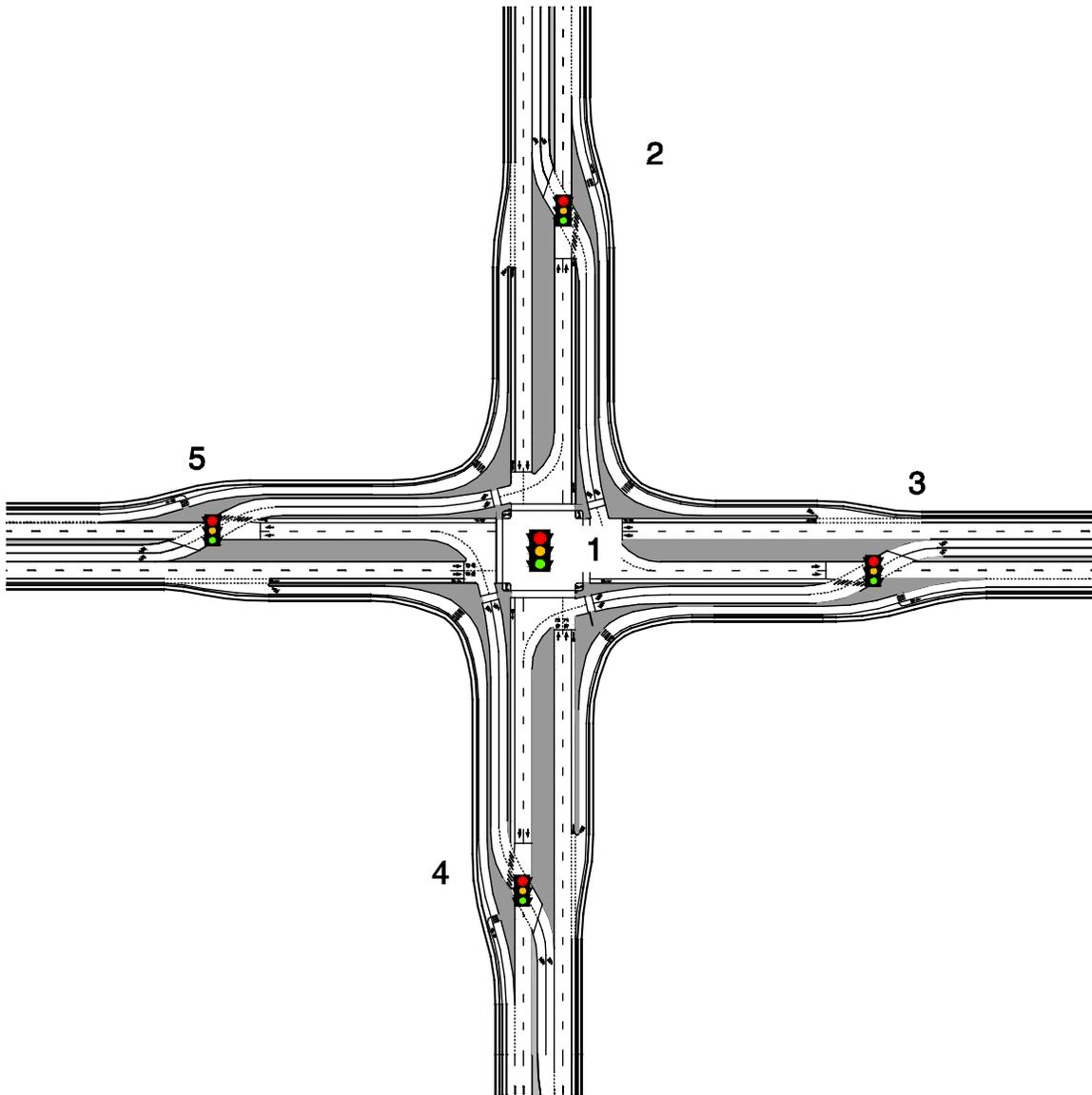


Exhibit 5-2. Typical DLT intersection signal locations.

The DLT intersection can consist of up to five signalized intersections depending on the number of crossovers. The five signals, as shown in Exhibit 5-2, can be operated either with separate

controllers or with a single controller. Coordination of the traffic signal controllers is necessary when multiple signal controllers are used to control each signalized intersection separately at a DLT intersection. Sample signal phasing for a DLT intersection where five separate signal controllers are used is depicted in Exhibit 5-3. This concept does not show the pedestrian movements in the diagram, but if pedestrian refuge islands are provided between the displaced left turns and through movements, as described in Chapter 3, pedestrian crossings are accommodated within the phasing shown.

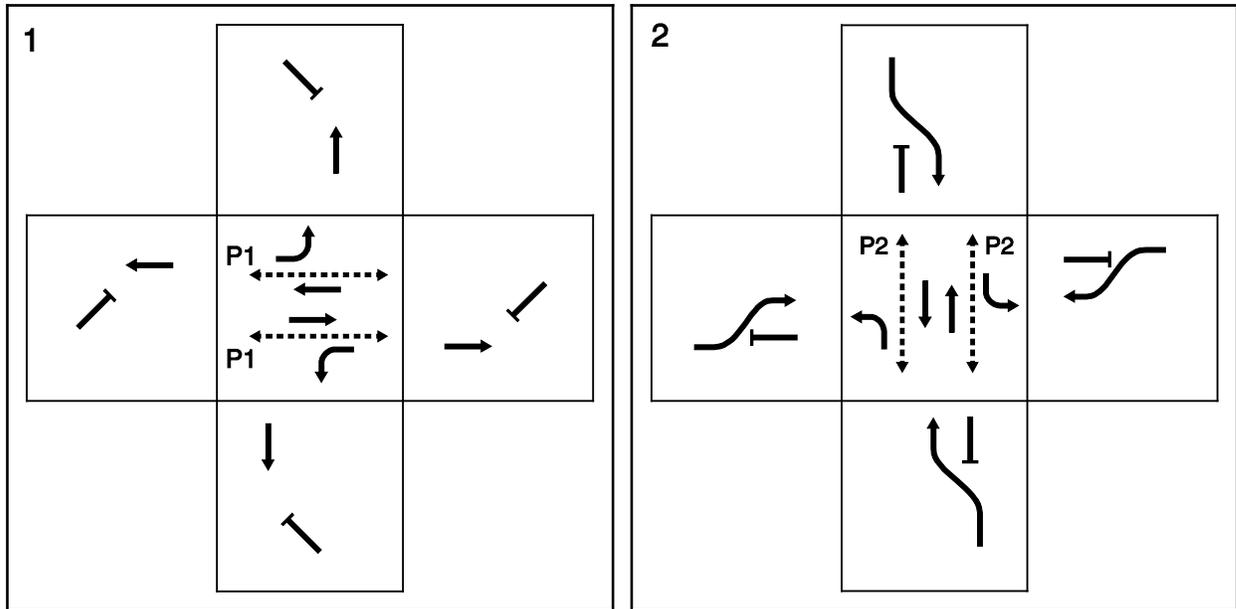


Exhibit 5-3. Two-phase signal phasing at five separately controlled signalized intersections within a DLT intersection.

Sample signal phasing for a DLT intersection where one signal controller is used is depicted in Exhibit 5-4. This illustrates that pedestrians are accommodated in a leading phase and the displaced left turns are accommodated after the pedestrian phases are completed.

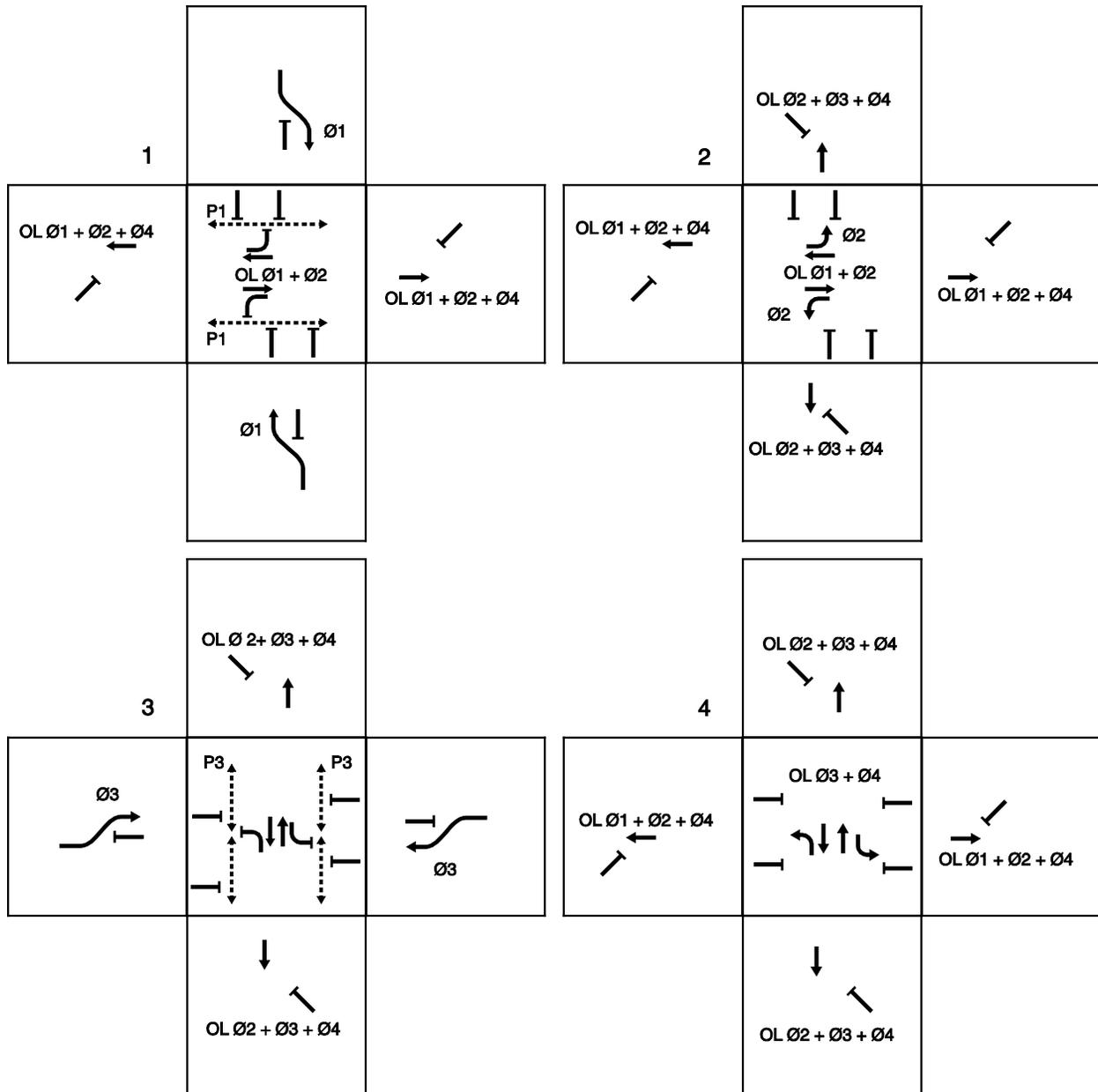


Exhibit 5-4. Signal phasing for a DLT intersection with a single controller.

Exhibit 5-5 shows a sample signal phasing scheme for a DLT intersection with displaced left turns only along the major street and conventional protected left turns along the side street.

Displaced Left Turn Informational Guide

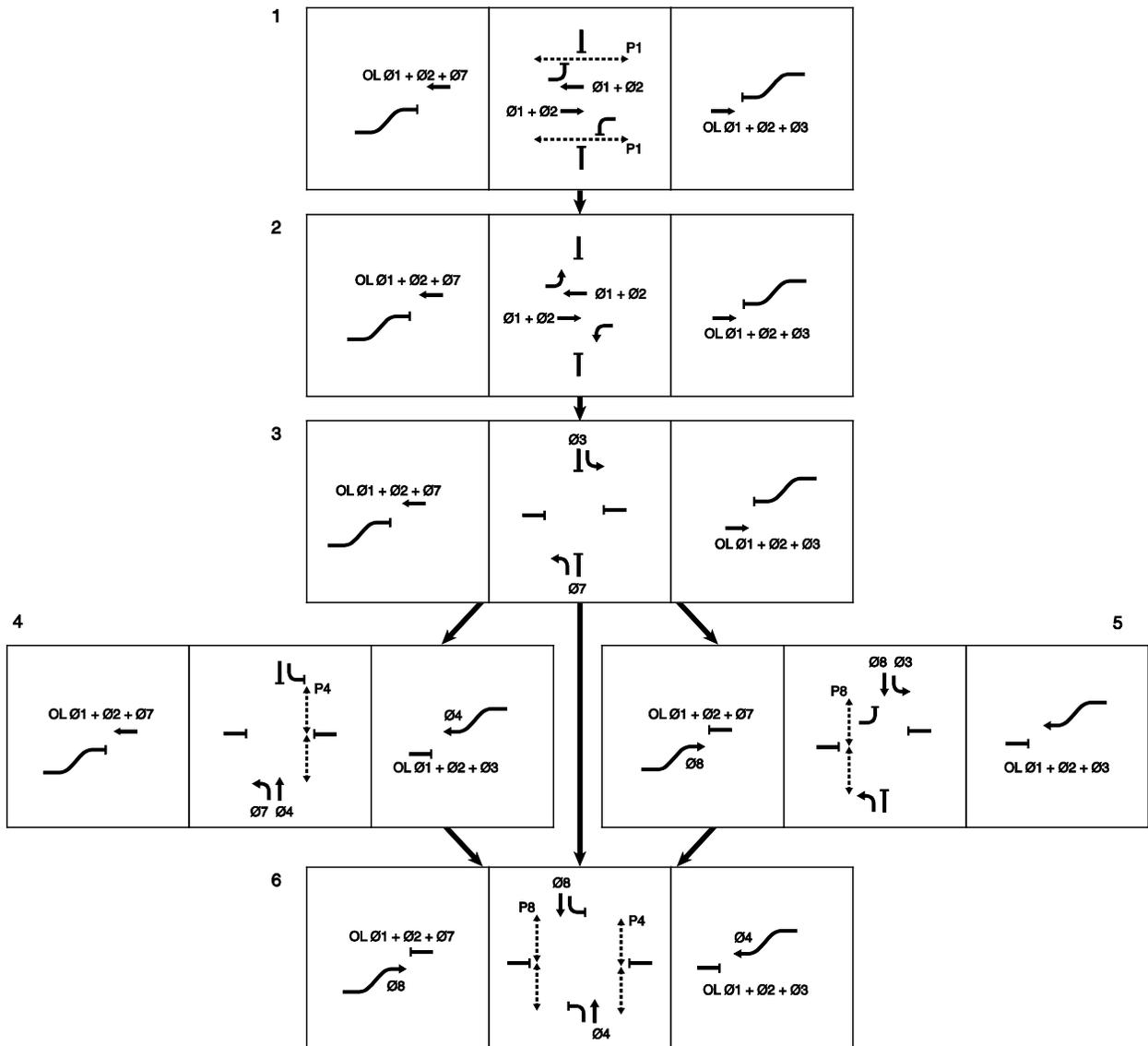


Exhibit 5-5. Signal phasing for a DLT intersection with major street displaced left turns with a single phase crossing for pedestrians.

Traffic Signal Coordination

The multiple signalized intersections contained within a DLT intersection are usually coordinated so certain movements at separate intersections essentially operate during the same phase. An example is illustrated in Exhibit 5-6:

- In Step 1, the left-turn crossover upstream of the main intersection may give green to crossover vehicles at the same time the minor street movements occur at the main intersection.
- By the time the crossover vehicles reach the main intersection, Step 2 (the next phase) will have begun, allowing the left turns to discharge at the main intersection.

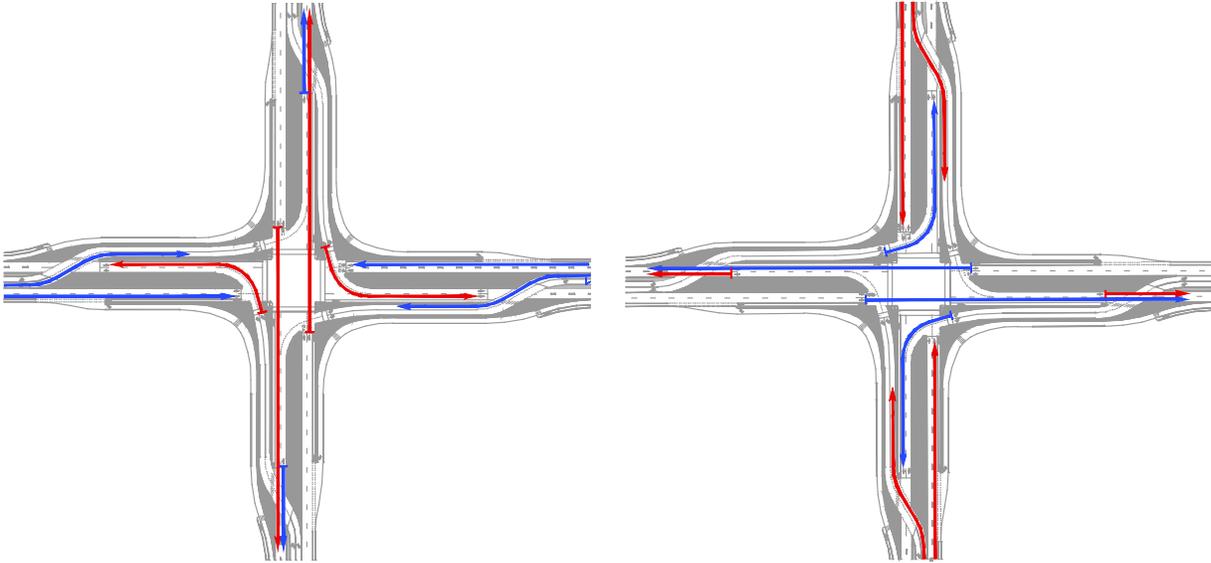


Exhibit 5-6. Typical signal coordination.

OPERATIONAL CONSIDERATIONS

DLT intersections are often used in locations where overall demand approaches the capacity of a conventional intersection form.

Access Management

Maintaining or providing access to homes and businesses near a DLT intersection can be accomplished by using frontage roads and other access management treatments; however, it can result in the following operational impacts:

- Weaving movements into and out of driveways
- A need for U-turns at the main intersection or adjacent intersections
- Driver confusion related to wayfinding

DLT intersection implementation typically restricts access to parcels situated in the quadrants of the main intersection. Access to these parcels can be accommodated via right-in/right-out configurations from the channelized right-turn lanes. The NCHRP Report 420 “Impacts of Access Management Techniques” discusses design, location, and spacing of driveways in general, and similar principles apply for DLT intersections.⁽²⁶⁾

U-turn movements are typically prohibited at the main intersection of a DLT intersection due to conflicts with other movements. To facilitate egress and easy movement of traffic from driveways in either direction of the approach, U-turn crossovers can be provided between the main intersection and the left-turn crossover. One such U-turn movement using a median opening—implemented in Baton Rouge, LA—is shown in Exhibit 5-7. Median width at the U-turn crossover is designed to accommodate the design vehicle making a U-turn.



Exhibit 5-7. Location of U-turn, frontage road, and driveway at DLT intersection in Baton Rouge, LA.⁽¹⁾

Since direct access to adjacent properties is restricted in a DLT configuration design, frontage roads can provide access to these properties. General features of frontage roads and their typical layouts are detailed in the AASHTO Green Book.⁽²⁾ The AASHTO Green Book provides guidance to maintain outer separation.

Chapter 10 of NCHRP Report 420 presents guidelines for one-way and two-way frontage roads and their key features.⁽²⁶⁾ Exhibit 5-7 shows the frontage road design at the DLT intersection in Baton Rouge, LA.

System-Wide Considerations

DLT intersections can be used in series with conventional intersections or other DLT intersections. The first corridor-wide installation of a DLT facility occurred on Bangerter Highway in Salt Lake City, UT. UDOT developed a corridor plan for the Bangerter Highway with eight DLT intersections and one DDI, as shown in Exhibit 5-8.⁽¹²⁾ The UDOT DLT guidelines address the Bangerter Highway corridor. These guidelines indicate several design elements that were incorporated into the initially constructed DLT intersections were refined in the construction of those that followed. Specifically, the cost of the first DLT intersection was especially high due to the right-of-way required to facilitate the channelized right turns. So, subsequent DLT intersections were constructed without these channelized right turns. The guidelines also indicate that signage and signal design have “evolved” with the development of subsequent DLT intersections in Utah.

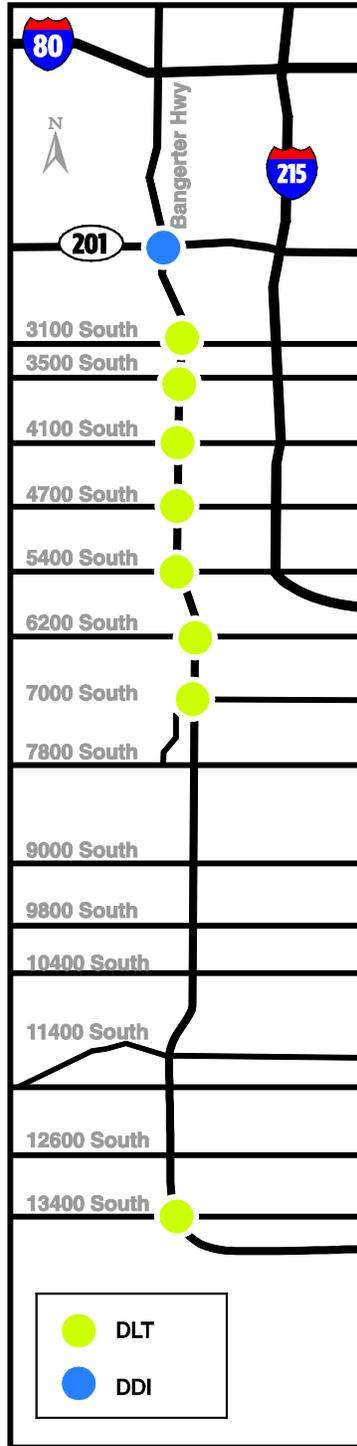


Exhibit 5-8. Bangerter Highway Corridor in Utah.⁽¹²⁾

COMPARATIVE PERFORMANCE STUDIES

Limited field studies of constructed DLT intersections have been completed to date, but it is possible to draw conclusions about the operational effects of DLT intersections simply based on

their design. In particular, the simultaneous movement of the left-turn and through traffic at DLT intersections promotes progression of traffic platoons on the arterial, increases vehicular throughput, and reduces travel time along a corridor.

Two-phase signals typically result in more efficient signal operations compared with multi-phase signals (e.g. the typical eight-phase signal) for accommodating full access movements due to the reduced lost time per cycle. Two-phase signals provide flexibility for progression along corridors and/or certain travel patterns, as well as relatively short cycle lengths depending on the pedestrian crossing distance. This reduced cycle length also leads to shorter queues on the intersection approaches, as well as within the DLT itself, given that it is made up of multiple signalized intersections.

According to the 1996 Traffic Control Systems Handbook, a DLT intersection has 60-percent more capacity than a similarly sized conventional intersection.⁽²⁷⁾ Another study compared the increased capacity associated with a grade separation with that of a DLT, showing similar results.

Simulation Model Studies

A significant amount of research on DLT intersections was produced by Reid and Hummer, who compared several alternative intersections in a simulation analysis of intersection operations.⁽¹⁰⁾ The authors concluded it was competitive with the other alternative intersection designs in terms of delay, queues, and number of stops. The authors also stated “the displaced left turn intersection may need the smallest amount of right-of-way of all the unconventional designs” examined.⁽¹⁰⁾

A sensitivity analysis using the microsimulation software VISSIM was performed as part of the research included in FHWA’s *Alternative Intersection Informational Report*.⁽²⁵⁾ Under four scenarios that varied the number of crossovers, lanes on the major street and minor street, and volumes on the major street and minor street, the analysis revealed the following results:

- For each case, the DLT form resulted in increased capacity, as well as decreased queues, delay, and number of stops, compared to a conventional intersection
- The benefits of the DLT intersection were more pronounced when traffic volumes increased
- The DLT configuration performed well regardless of the volume balance regarding left-turning, through, and right-turning vehicles

All cases had signal timings adjusted for pedestrian presence. In the absence of pedestrians, cycle lengths can be lowered resulting in average intersection delay in the range of 14 to 19 seconds/vehicle (s/veh) at low and medium traffic volumes for one of the cases. The details associated with this sensitivity study can be found in the appendices. The results are summarized below in Exhibit 5-9.

For each of the cases modeled, the DLT intersection consistently outperformed the conventional intersection with respect to vehicle throughput, vehicle delay, number of stops, and queue length.

The operational improvement of the DLT intersection over the conventional intersection was notable at relatively low traffic volumes, but greater benefits were achieved as traffic volumes increased. Reducing the number of cycle phases reduced vehicle delay and increased the intersection capacity.

Exhibit 5-9. Comparative simulation results.⁽²⁵⁾

Comparison Item	Percent decrease for DLT compared to conventional intersection	
	Four displaced left turns	Two displaced left turns
Intersection delay, with mainline flows balanced	10 to 90 %	36 to 39 %
Intersection delay, with mainline flows unbalanced	69 to 82 %	30 %
Number of stops, non-saturated conditions	15 to 30 %	
Queue length	34 to 88%	
Throughput, with mainline balanced flows	-16 to -30 %	-34 to -88%
Throughput, with mainline flows unbalanced	- 12 to -25 %	-10 to -14 %

Even with a single signal timing plan, the DLT intersection worked effectively for the combinations of traffic flows (low, medium, and heavy) studied. This is unique and can be useful for intersections that cannot implement multiple signal timing plans.

Regarding left-turn capacity, a 1974 study from the United Kingdom found the DLT intersection could increase capacity and decrease delay for right-turning traffic (or left-turning traffic in countries with a right-hand traffic convention).⁽²⁸⁾ A 1994 study concluded that under balanced volumes and similar lane configuration, the upstream crossover of a DLT intersection has approximately twice the left-turn capacity as a conventional intersection.⁽²⁹⁾

Approaches of a DLT intersection that have the left-turn crossovers cannot accommodate median breaks within a distance of approximately 600 to 700 feet of the main intersection depending on the design of the left-turn crossovers. Therefore, driveways in these areas need to be right-in/right-out only.

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CHAPTER 6— OPERATIONAL ANALYSIS

The previous chapter presented operational characteristics unique to DLT intersections. To support decisions regarding the choice and design of a DLT intersection there needs to be an appropriate level of traffic operations analysis corresponding to the stage of the project development process. The level of analysis needs to be consistent with the available data, and that data needs to support the applied analysis tools. Vehicular traffic operations coincide with multimodal considerations. Final intersection configurations and associated signal timing should be in balance with multimodal needs for each unique project context.

A DLT is a system of multiple signalized intersections. As such, an operational analysis needs to consider the effects of and relationship between the multiple signals.

Available data could include the following elements:

- Average daily traffic (ADT)
- Speed (posted, design, or 85th percentile)
- Weekday and weekend peak-hour turning movement counts
- Weekday and weekend off-peak turning movement counts
- Pedestrian volume at the intersection
- Bicycle volume at the intersection
- Proportion of the traffic stream composed of heavy vehicles

Measures of effectiveness are used to evaluate the operational efficiency of a particular design like the DLT intersection. The FHWA Traffic Analysis Toolbox has identified the following seven basic measures of effectiveness for vehicles:⁽³⁰⁾

- **Travel time:** average time spent by vehicles traversing a facility, including control delay, in seconds or minutes per vehicle
- **Speed:** rate of motion (expressed in distance per unit of time)
- **Delay:** additional travel time experienced by travelers at speeds less than the free-flow (posted) speed (expressed in seconds or minutes)
- **Queues:** length of queued vehicles waiting to be served by the system (expressed in distance or number of vehicles)
- **Stops:** number of stops experienced by the section and/or corridor (based on a minimum travel speed threshold)

- **Density:** number of vehicles on a street segment averaged over space (usually expressed in vehicles per mile or vehicles per mile per lane)
- **Travel time variance:** a quantification of the unexpected non-recurring delay associated with excess travel demand (can be expressed in several ways)

The final two measures, density and travel time variance, are less applicable to an intersection treatment than an uninterrupted flow facility, but may still be considered during the operational analysis. While average speed and travel time apply to the DLT intersection much like they would to a conventional intersection (as long as the analysis area includes the entire configuration), the delay and stops performance measures must be carefully aggregated over the multiple signalized intersections contained within intersection. The most difficult performance measure to incorporate into DLT intersection analysis is queuing. This is because the short spacing created between the intersections within the DLT intersection may cause queue spillback if the signalized intersections are not properly coordinated. Individual performance measures such as queues, stops, and delay across multiple intersections of a typical vehicle progressed through the intersection provides more meaningful comparisons versus simply adding or averaging the performance measures from each intersection.

OPERATIONAL ANALYSIS TOOL OVERVIEW

According to FHWA's Traffic Analysis Toolbox, several tools are available to analyze traffic operations at intersections, including the following:⁽³⁰⁾

- Planning Level Analysis (such as critical lane volume and CAP-X)
- Highway Capacity Manual (HCM) Analysis
- Microsimulation Analysis

One major factor distinguishing these three types of analysis is the time required to evaluate each scenario. A planning level analysis may take less than one hour to perform; an HCM analysis for one scenario could take two to four hours. Microsimulation requires considerably more time—anywhere from eight to 16 hours depending on the level of calibration involved. Planning-level tools are useful in the initial feasibility analysis and to conduct a high-level comparison of the approximate number of lanes for a DLT intersection. An operational analysis using a deterministic method, such as the HCM, is useful to perform a more detailed peak-hour performance analysis, and to estimate performance measures like delay, travel time, and queue lengths. The operational analysis may provide insight on additional geometric design and signal timing details.

The nature of a DLT intersection, especially the closely spaced and coordinated signals, can be difficult to evaluate in full detail in a deterministic tool and can also be evaluated with microsimulation.

Exhibit 6-1 provides a summary of available analysis techniques for DLT intersections.

Exhibit 6-1. DLT analysis techniques.

Available Techniques		
Planning	Highway Capacity Manual	Microscopic simulation
Available using critical lane analysis and CAP-X	Difficult to perform now for motor vehicles; can analyze crossing pedestrians and bicycles. DLT-specific HCM procedure under development	Can be performed for motor vehicles, pedestrians, and bicycles with most simulation packages

PLANNING LEVEL ANALYSIS

Planning-level tools and methods are useful in the early stages of a project when the DLT configuration is being considered as one of several options for an intersection improvement alternative. Planning-level tools and methods provide high-level analysis, typically providing no greater detail than volume-to-capacity (v/c) ratios and/or level of service (LOS) computations. Travel time, delay, queue lengths, signal timings, and specific geometric data are typically not inputs nor outputs of planning-level tools. In general, planning-level analysis results are useful for feasibility and high-level design features but are not directly tied to actual operational performance or operational model results.

FHWA has developed the CAP-X planning tool to conduct capacity analysis for planning of alternative intersections.⁽³¹⁾ “It is a tool that can be used to evaluate selected types of innovative or alternative junction designs (8 intersections, 5 interchanges, and 3 roundabouts) using given peak hourly traffic counts.” Exhibit 6-2 is a screen capture from the spreadsheet that is downloadable from the Transportation Systems Institute website, *A Federal Highway Administration Project in partnership with the Transportation Systems Institute at the University of Central Florida.*⁽³¹⁾

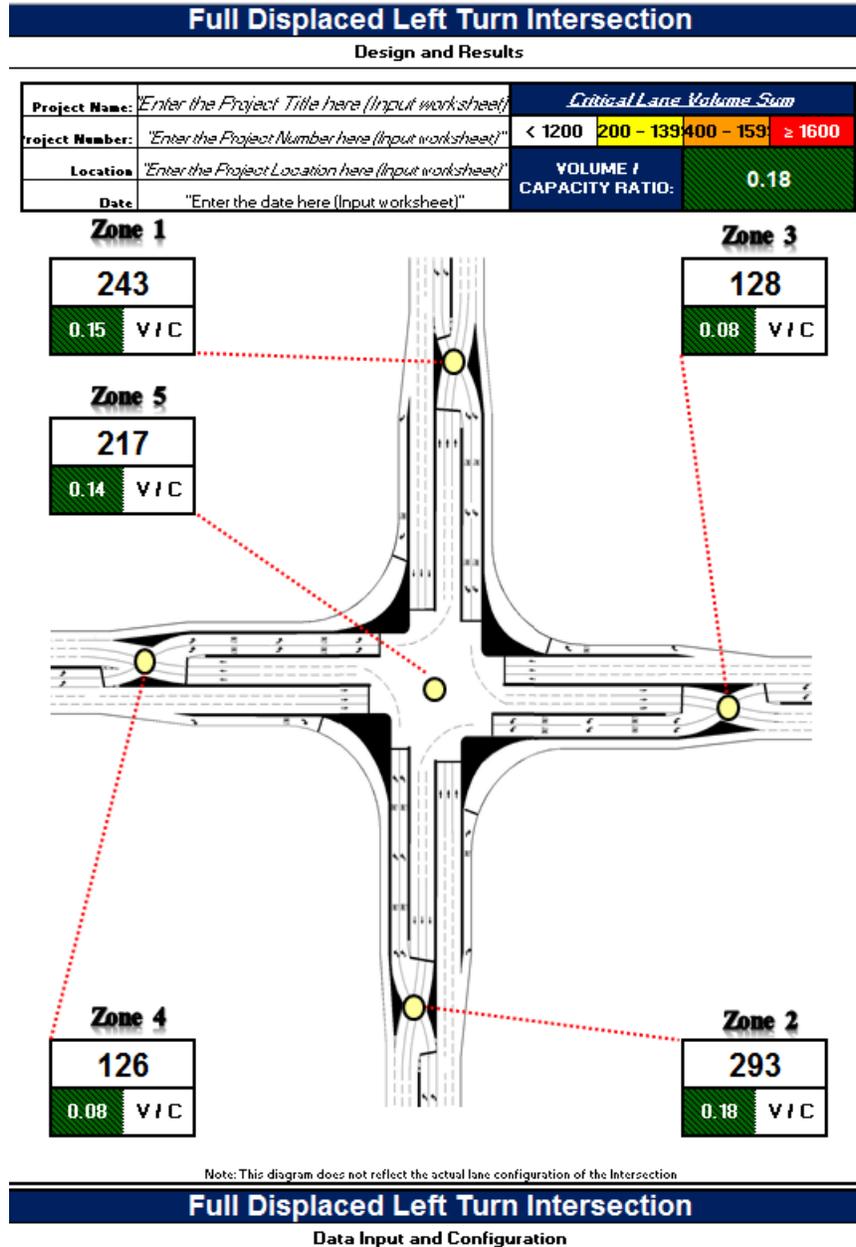


Exhibit 6-2. CAP-X Planning Level Tool Screen Capture.⁽³¹⁾

The critical lane volume methodology is a high-level analysis method that considers traffic volumes, number and assignment of lanes, and anticipated number of signal phases at each intersection. Each intersection within the DLT configuration is analyzed independently. While the advantage of critical lane volume is its ease of use and limited input data, this type of analysis does not account for some elements of traffic operations such as queues between closely-spaced intersections.

- If all the signals at the DLT intersection are controlled from the same controller, then this form of analysis can incorporate signal *coordination* in the sense that some movements at different intersections move at the same time.

- The critical lane volume cannot incorporate signal *progression* if separate controllers are used and different offsets are allowed.

HIGHWAY CAPACITY MANUAL (HCM) ANALYSIS

Analytical methods and deterministic models to establish highway capacity, vehicular delay, and other performance measures are required for a more detailed analysis. The *Highway Capacity Manual*, as well as Highway Capacity Software and other types of deterministic software available from private vendors, can be used to perform this level of analysis.⁽⁵⁾ These tools use deterministic methods derived through analytical equations. An HCM procedure specifically for DLT intersections is under development by FHWA. The procedure will be included in an update of the 2010 HCM scheduled for completion in 2015.

Operational analysis methods provide further insight into the operational effects of geometric design and signal timing elements of a DLT intersection compared to planning-level analysis methods. Advantages of the operational-level analysis approach in the HCM include the ability to balance operational detail with reasonable data input needs and analysis resource requirements. The HCM method provides more detailed output in the form of delays, travel time, and queue estimates than the planning-level method, while allowing for more customization and consideration of geometric variability and signal timing details. At the same time, its methods are typically applied more quickly than a more resource-intensive simulation analysis. Another key advantage of the HCM over simulation analysis is that the deterministic analysis framework offers consistency in performance estimation across analysts and interchange options. The HCM is generally regarded as the benchmark for operational performance estimation, and its equations and Level of Service (LOS) stratification form the basis of comparison with other tools.

Disadvantages of the current HCM include a limited scope of applicable geometry and lack of focus on network and system effects, including the interaction of the crossover intersections with the main crossing intersection. Other operational characteristics of DLT intersections not adequately handled by existing HCM methodologies include:

- The potential for queuing to spill back from the main intersection to the crossover intersections, or vice versa
- The arrival and departure of vehicles between the crossover and main intersection (signal coordination)
- The impact of transit stops within the boundary of the DLT intersection
- Estimation of pedestrian or bicycle level of service

The current HCM analysis models analyze each intersection independently. It is not possible to cumulatively analyze the travel time and delay associated with left-turning movements that are made through a series of intersections. Vehicles are not “tracked” through the series of intersections, and thus the net impact to movement delay and travel time is not readily comparable to conventional intersection operations. The DLT-specific procedure under development for the update of the 2010 HCM will include “tracking” of vehicles and net impacts.

While the HCM has limitations, as discussed above, it does provide the consistency that agencies need for evaluating alternatives. The HCM is an international reference manual overseen by an independent committee of experts in the field, and thus is often the basis for policy decisions and LOS thresholds for intersection selection.

When performing HCM analysis with existing procedures such as the signalized intersection procedure, the saturation flow rate for the left turns at the crossover intersections may need to be adjusted based on the turning radius (which would make the left-turn factor greater than the default value since this movement can occur at higher speeds than traditional left turns). While turning radii may increase theoretical saturation flow rates, the saturation flow rates selected should also account for driver hesitancy based on unfamiliarity with this intersection form.

MICROSIMULATION ANALYSIS

Microsimulation is the most detailed and data-intensive analysis that could be conducted for evaluating the traffic operations of a DLT intersection. There are multiple microsimulation tools, and some are more effective than others. Because these tools require an extensive amount of analyst time and data that is not always available for intersection projects, these tools need to be applied consistent with the amount and type of data available, as well as specific project needs.

Advantages of microsimulation models include flexible customization and configuration of geometry, signal timing, and other operational parameters. However, the greatest advantage is that microsimulation models can output “system” measures of effectiveness for DLT intersections so that overall movement delay, travel times, and number of stops can be readily compared to conventional or other unconventional intersection designs. The ability to evaluate closely-spaced intersections is also a critical part of the DLT intersection. Analytical methods such as those contained in the current HCM can be used separately at each intersection, but become significantly more complicated when multiple intersections are evaluated at once. The DLT-specific procedure under development for the update of the 2010 HCM will provide some “system” measures of effectiveness.

Disadvantages of microsimulation models include the time; budget; data required for input and proper calibration; and knowledge of how to properly choose, set-up, run, validate, and obtain results. Another limitation of simulation is the need to calibrate and validate the effort, as well as the potential implications of failing to do so. The analyst needs to understand the many unique operational attributes of the DLT including saturation flow rate, speed profiles, lost time, and gap acceptance (for new movements such as U-turns) and know how to replicate those in simulation. There may also be variability in the results of DLT microsimulation evaluations performed by different analysts.

CHAPTER 7— GEOMETRIC DESIGN

This chapter describes the typical DLT intersection design approach and provides guidance for geometric features. It requires input from the multimodal considerations (Chapter 3), safety assessment (Chapter 4), and traffic operational analysis (Chapters 5 and 6). The guidance in this chapter is intended to supplement national resources on intersections that apply basic design principles.

DESIGN APPROACH

Developing the geometric layout for an intersection configuration requires considering the relationship and interaction of safety, operations, and design. In addition, it requires understanding the trade-offs of the physical, environmental, or right-of-way constraints for the proposed DLT when local conditions preclude ideal DLT intersection layouts. As with any intersection form under consideration, undesirable geometry cannot necessarily be mitigated by signing and pavement markings. The overarching goal is to provide geometry that serves various users and meets their expectations. This includes clear and defined channelization that is supplemented with signing and pavement markings. Exhibit 7-1 highlights the characteristic features of a DLT intersection.

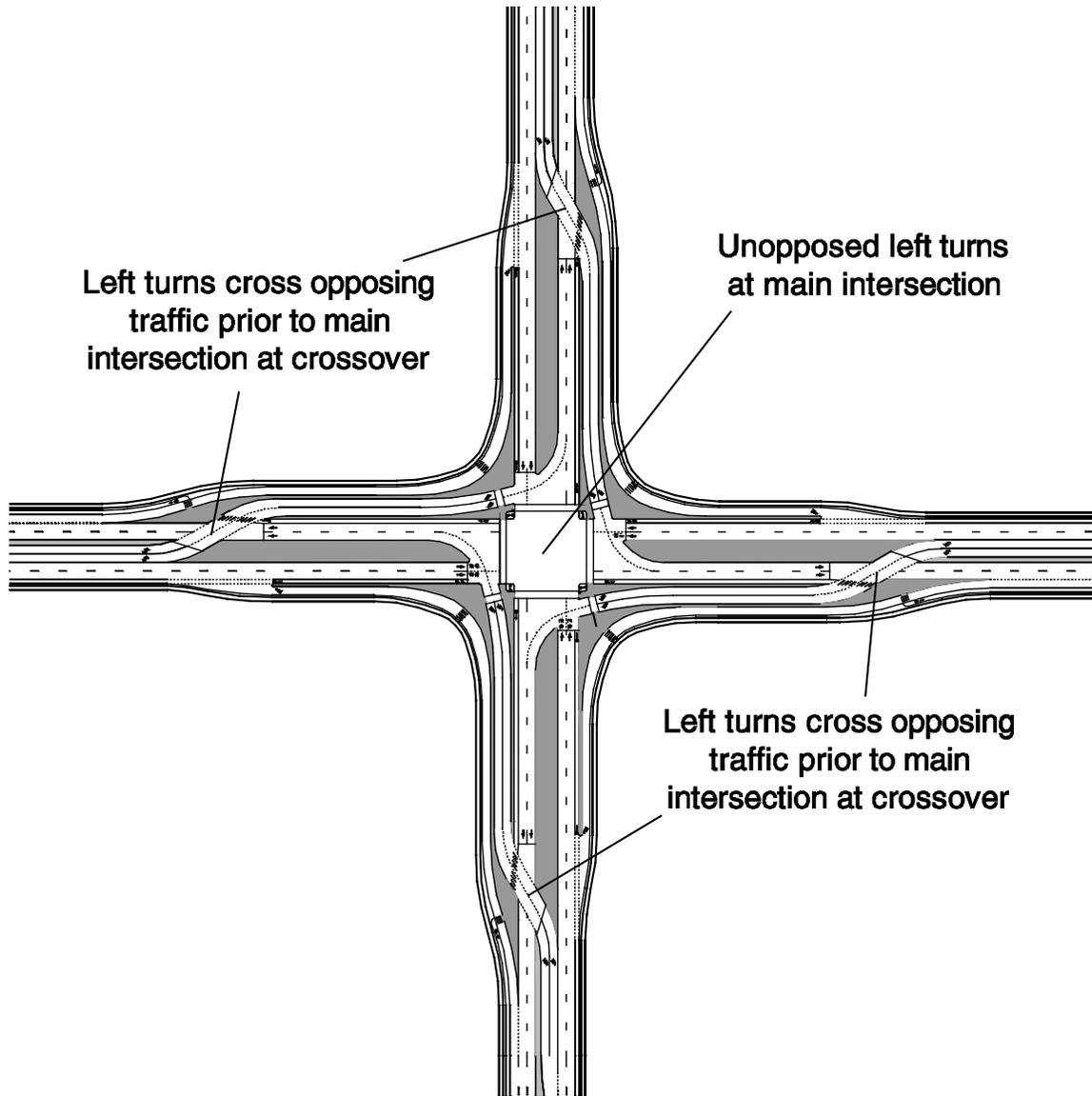


Exhibit 7-1. DLT characteristics.

GEOMETRIC DESIGN PARAMETERS/PRINCIPLES

The same basic geometric design parameters for a conventional intersection apply when developing the geometry for a DLT intersection, including:

- Developing turn pockets (i.e., adding left- and right-turn lanes)
- Merging right-turn bypass lane with cross street through lane or designing it as an add lane
- Setting the curb lines and stop bar locations at intersections using turning templates associated with single and/or dual turning movements

The DLT intersection form has unique geometric design features at the following locations:

Main Intersection

- The objective is to provide appropriate turning paths for the displaced left turns and consider how they interact with the pedestrian crosswalks.
- The vehicle paths for the displaced left turns through the main intersection will delineate the curb lines and stop bar locations and determine the width of the overall intersection, as shown in Exhibit 7-2.

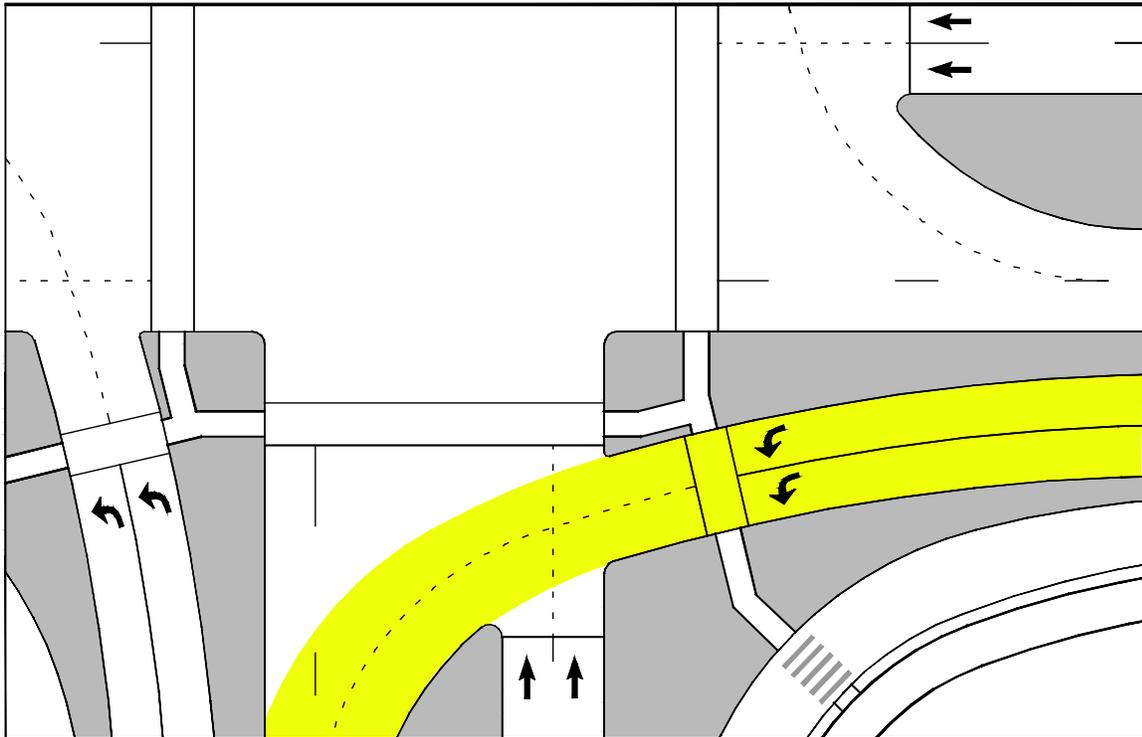


Exhibit 7-2. Left-turn maneuvers.

Crossover Intersection

- The objective is to provide a smooth alignment for the through traffic at the crossover intersections and not introduce back-to-back reverse curves along the travel paths.
- The goal is to align the left turns at the stop bar with the receiving lanes (for the displaced left turn pockets) to reflect desirable vehicle path alignment to minimize path overlap, as illustrated in Exhibit 7-3.

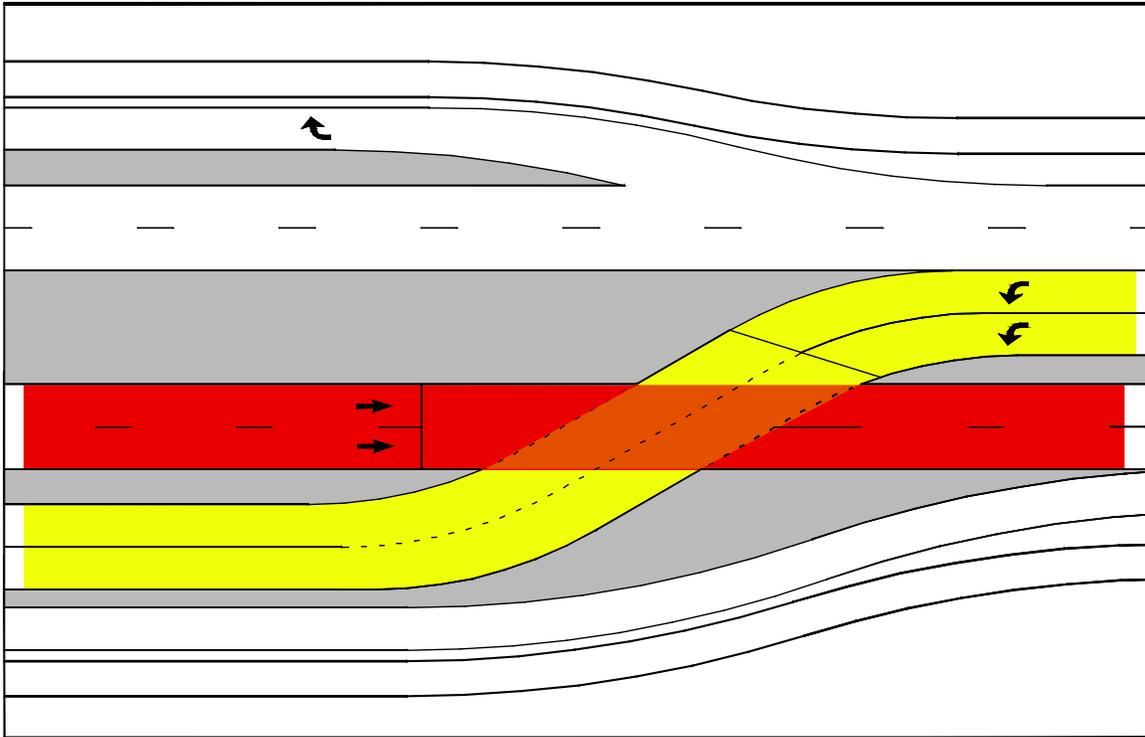


Exhibit 7-3. Crossover intersection geometry.

- There are two ways to accommodate the geometry where the right-turn bypass lane joins the cross road through lanes:
 - Provide an add lane with a downstream lane merge, as shown in Exhibit 7-4
 - Signalize the movement and operate it as part of the crossover signal, as shown in Exhibit 7-5

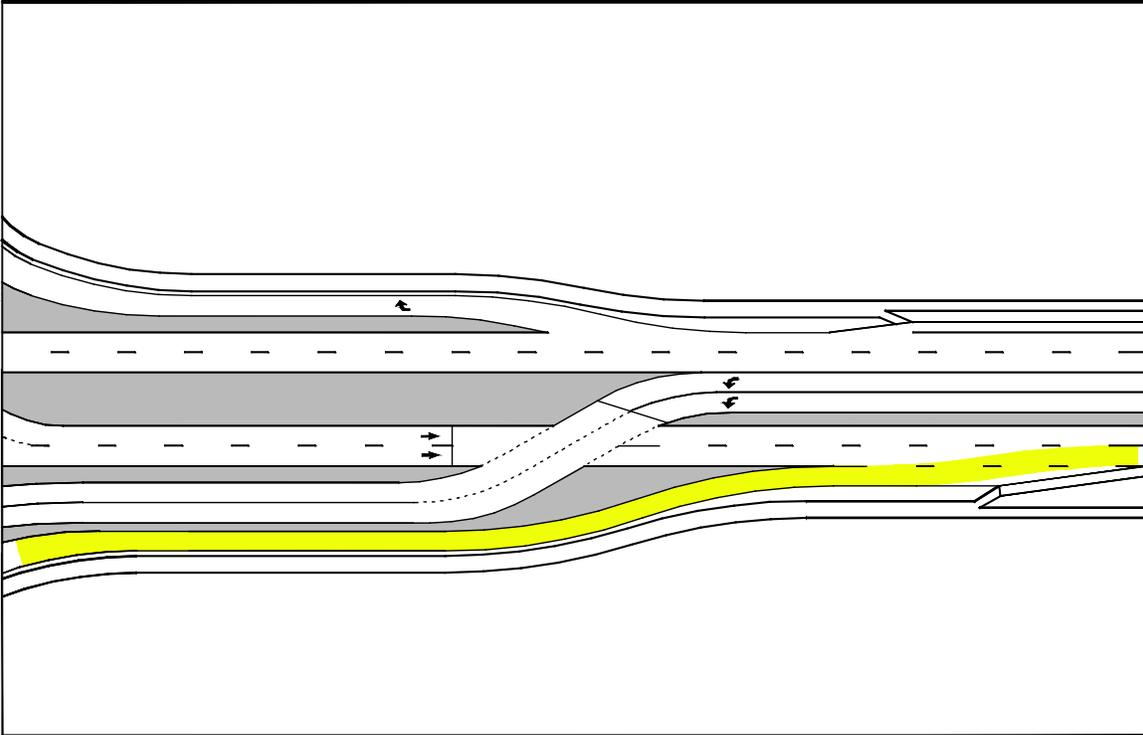


Exhibit 7-4. Add lane with a downstream lane merge.

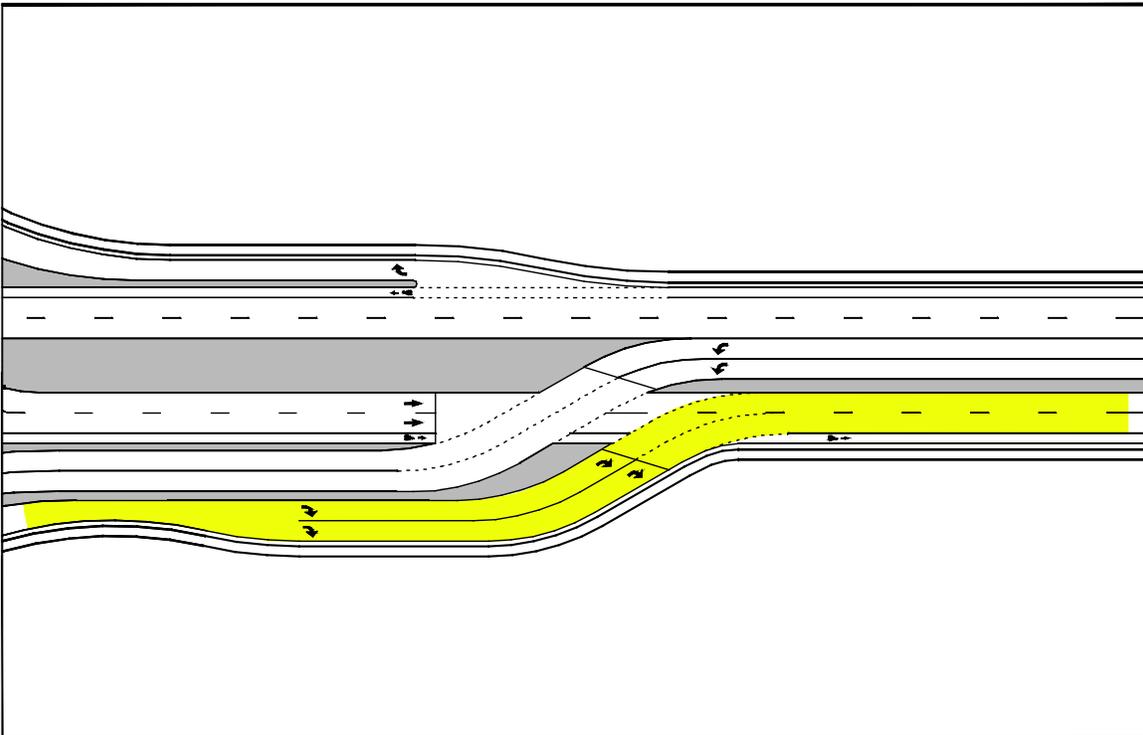


Exhibit 7-5. Signalized right turn.

RANGE OF DLT INTERSECTION CONFIGURATIONS

While a DLT intersection can have up to four crossovers at a four-leg intersection or up to two crossovers at a three-leg intersection, most of the DLT intersections in the United States have one or two crossovers. While most existing DLT intersections contain channelized right turns, some have been built without channelized right turns. Channelized right turns reduce auto-to-auto conflict points and provide more mobility for right turns, but they require additional right-of-way and create additional exposure for crossing movements.

Exhibits 7-6 through 7-10 show various DLT configurations:

- Four-legged DLT intersection with four displaced lefts
 - With channelized right turns
 - Without channelized right turns
- Four-legged DLT intersection with major street displaced lefts and channelized right turns
 - With channelized right turns
 - Without channelized right turns
- Three-legged DLT intersection with major street displaced left
- Three-legged DLT intersection with minor street displaced left

A list of specific existing or planned DLT sites is shown in the Appendix.



Exhibit 7-6. Four-legged DLT intersection with four displaced left turns and without channelized right turns (West Valley City, UT).⁽¹⁾



Exhibit 7-7. Four-legged DLT intersection with major street displaced left turns and without channelized right turns (West Valley City, UT).⁽¹⁾

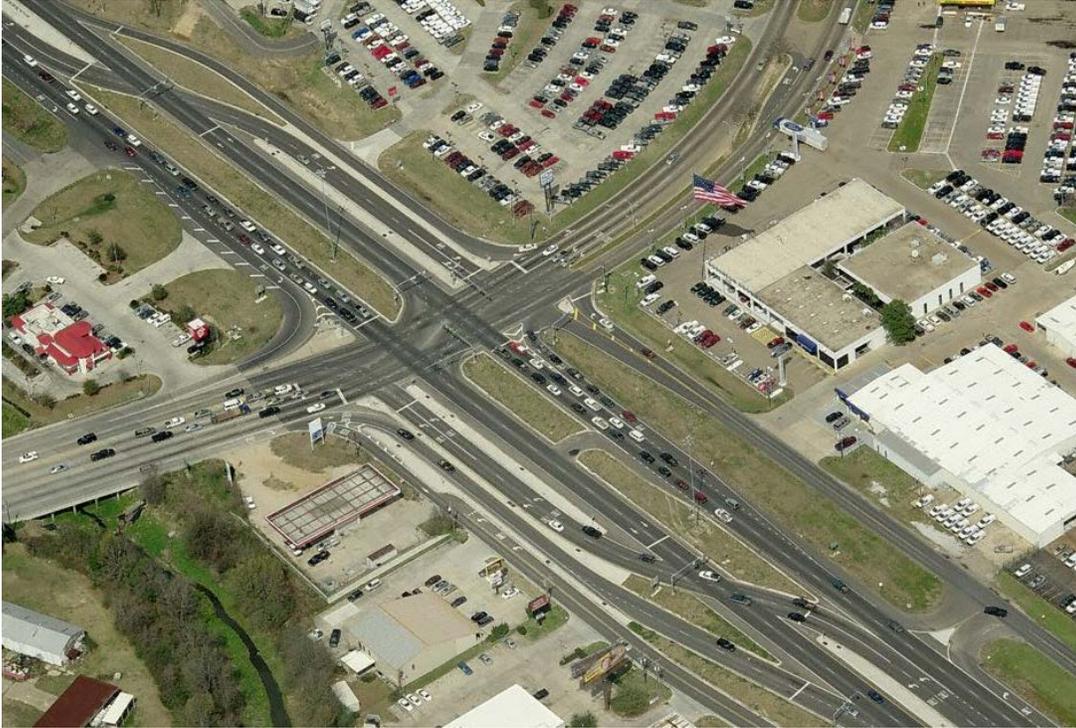


Exhibit 7-8. Four-legged DLT intersection with major street displaced left turns and channelized right turns (Baton Rouge, LA).⁽¹⁾



Exhibit 7-9. Three-legged DLT intersection with major street displaced left turn (Shirley, NY).⁽¹⁾



Exhibit 7-10. Three-legged DLT intersection with minor street displaced left turn (Accokeek, MD).⁽¹⁾

OPERATIONAL EFFECTS OF GEOMETRIC DESIGN

This section addresses the operational effects of geometric design on safety performance, traffic operations, and quality of service for pedestrians and bicyclists.

Crossover Intersection

The following are considerations of the crossover intersection design:

- The traffic operations typically establishes the initial clearance time for a traffic signal. At the crossover intersection, the intersection angle and associated intersection geometry refine the clearance interval for the traffic signal. As with any intersection design, the skew angle increases exposure for users within the conflict areas. Pedestrian crossings are not accommodated at the crossover intersection.
- Entrance to the left-turn pockets for the crossover intersection is farther in advance of a conventional intersection, which may be unexpected for unfamiliar drivers. Appropriate signing that communicates with approaching drivers to position themselves in the correct lane needs will help drivers complete their path through the DLT intersection.
- Carroll and Lahusen developed a deterministic model to minimize DLT intersection delay based on the geometric characteristics of the intersection.⁽¹¹⁾ The authors found that

for each DLT crossover, the offset length determines the maximum signal phase length that can be provided for the left-turn crossover.

- NCHRP Synthesis 225, “Left-Turn Treatments at Intersections – A Synthesis of Highway Practice” describes several design features for DLT intersections including channelizing islands, overhead lane controls, and raised pavement markers for lane delineation and traffic flow separation.⁽³²⁾

Right-Turn Bypass Lanes

Similar to conventional intersections, the following elements need to be considered when designing right-turn bypass lanes if implemented at DLT intersections:

- The geometry at the pedestrian crossing in the 90-degree turn minimizes the speed difference with pedestrians at the crosswalk.
- Stopping sight distance for the approaching motorists and sight distances for the pedestrians approaching the potential oncoming automobiles should be clear of obstructions and provide sufficient visibility for various users.
- The location of the weaving/merging segment (where the free-flow right turn rejoins the through traffic exiting the intersection) in relation to the next decision point downstream of the intersection needs to be evaluated to minimize weaving beyond the intersection. It may be necessary to signalize the right turns as part of the crossover signal to eliminate a potential downstream weaving/merging segment.
- Driveways within the weaving/merging areas need to be avoided to minimize unexpected deceleration and unexpected maneuvers.

Exhibit 7-11 shows two designs for the channelized right turns.

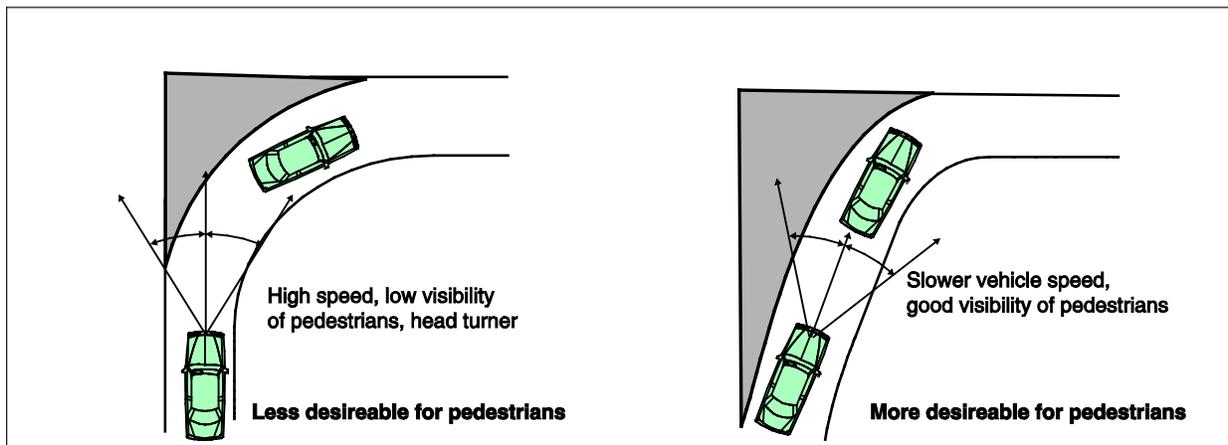


Exhibit 7-11. Types of channelized turns.⁽²²⁾

As discussed in Chapter 3, similar attention needs to be given to bicyclists at the following conflict areas:

- The start of the right-turn lane if bicyclists are continuing through the intersection
- The free-flow right turn where bicyclists traditionally do not have bicycle lanes
- The merge point of the right turn beyond the crossover intersection on the cross street when merging across the bicycle lane along the cross street
- Left turns where bicycles may either function as a pedestrian or make a “Copenhagen-style” left turn

Through Movement

Most street facilities are typically designed according to a specific design speed. The overall goal is to provide tangent/smooth alignments for the through movements throughout the DLT configuration. A designer may consider some deflection for the through movements while considering the potential trade-offs such as introducing potential wrong-way movements. If introducing deflection for through movements, the designer needs to consider the effect the S-curves may have on travel speed (e.g., speed differential), possible vehicle overtracking their striped travel paths, and driver expectation of encountering non-tangent alignments.

DESIGN GUIDANCE

This section provides guidelines by highlighting key dimensional elements when developing the layout of a DLT intersection.

Right-of-Way Requirements

A DLT intersection has a larger footprint compared to conventional and other alternative intersections. Exhibits 7-12 and 7-13 illustrate the estimated footprint for a DLT intersection compared to a conventional intersection. Shaded portions of the figure show where the DLT footprint is beyond that of a conventional intersection. Exhibit 7-12 shows a tangent alignment for through movements at the crossover intersections, while Exhibit 7-13 illustrates the undesirable deflections at the crossover intersections.

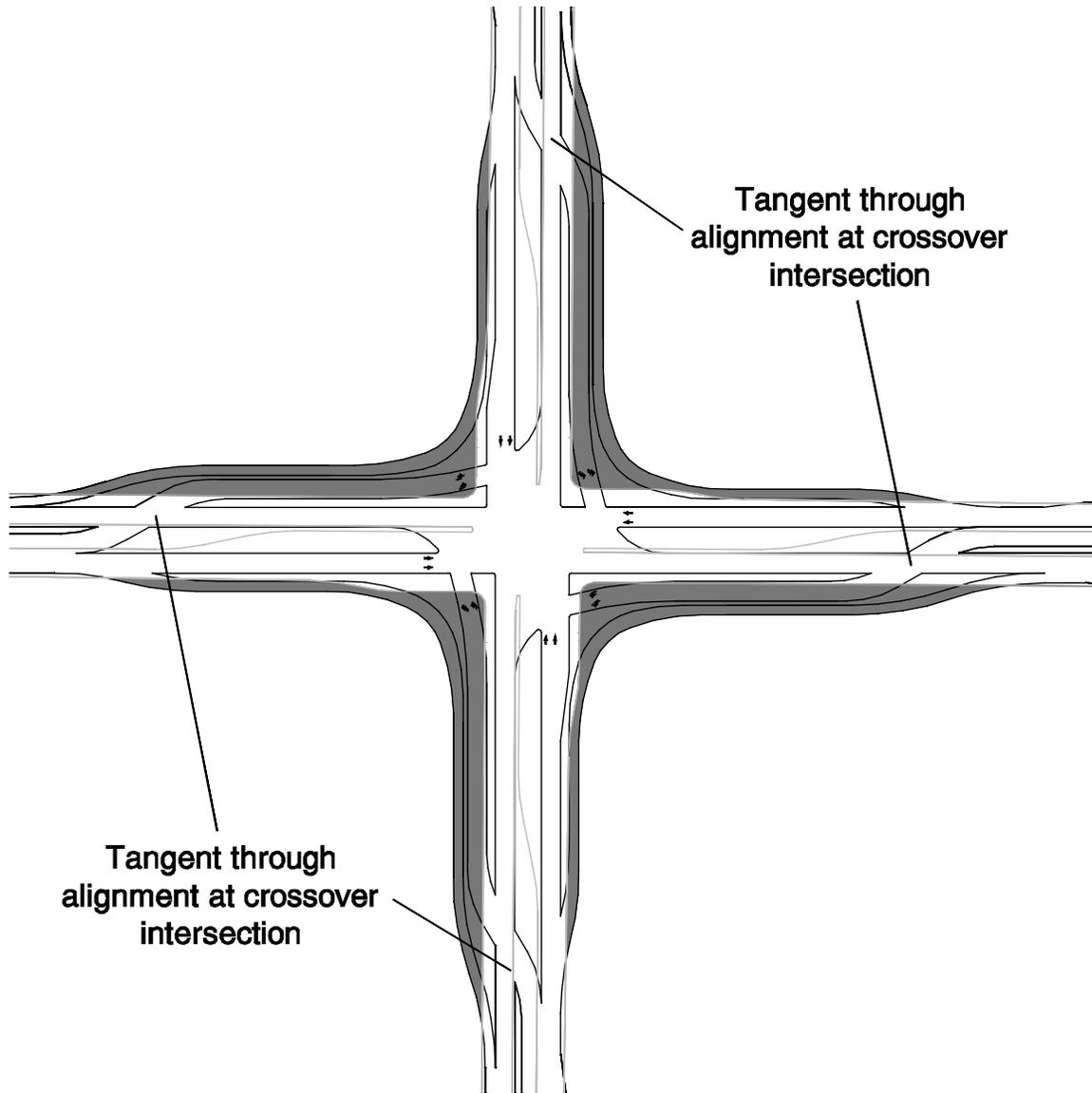


Exhibit 7-12. Footprint comparison of a DLT intersection with tangent through alignments versus a conventional intersection.

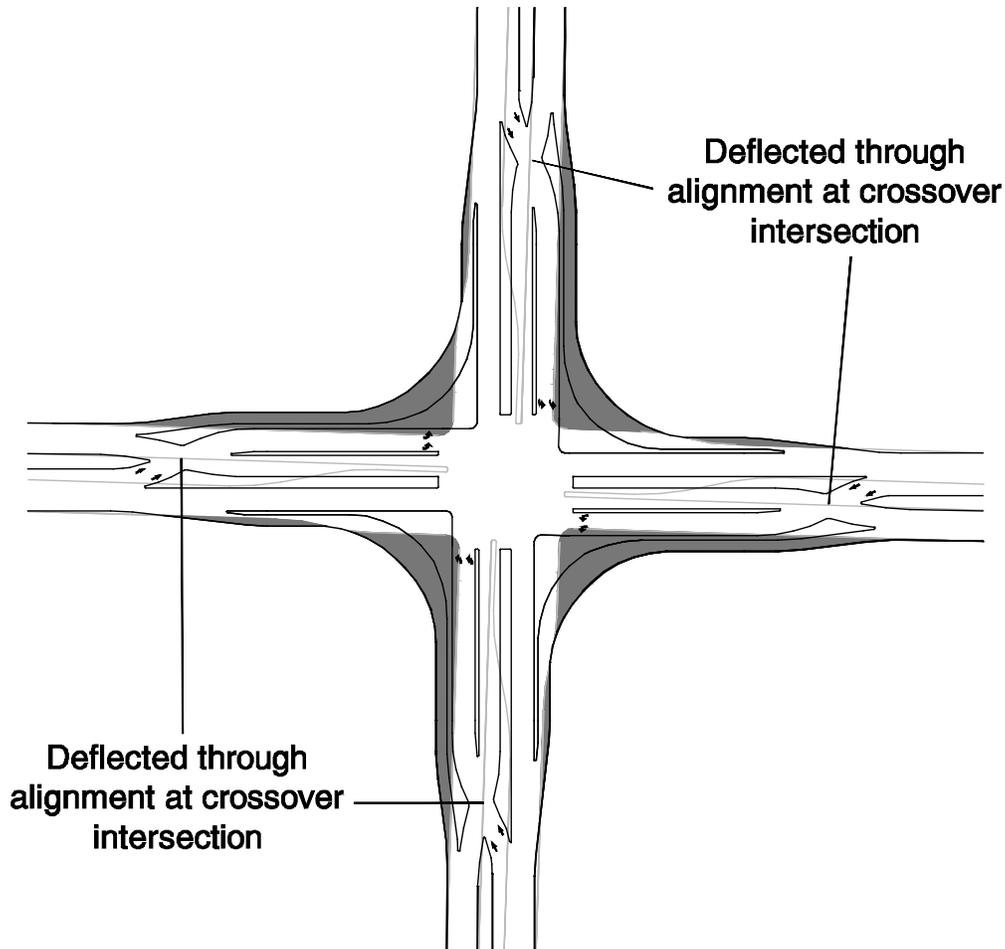


Exhibit 7-13. Footprint comparison of a DLT intersection with deflected through alignments versus a conventional intersection.

The right-of-way footprint may affect agency decisions on whether to construct this type of intersection. This may be of particular focus within an urban environment or other areas where right-of-way may be expensive or difficult to obtain. Access to parcels located in the quadrants of the intersection might be restricted and U-turns are difficult to accommodate in the DLT configuration.

While a DLT intersection requires more right-of-way than a conventional intersection, it typically requires less than an interchange or partial grade-separation and also provides more access. Median width can be reduced to mitigate the right-of-way requirements, but all median widths need to be sufficient to facilitate sign placement, provide pedestrian refuges, and provide appropriate geometry at the crossover intersections.

Median width design guidance can be found in the AASHTO Green Book.⁽⁴⁾ Installing post-mounted signs within the medians needs to be considered for safe and effective channelization of traffic. Offsets for signs should be in accordance with the MUTCD.⁽⁶⁾ While the median needs to be adequately wide to make room for left-turn lanes at the crossover (with some buffer distance

to achieve an angle for the crossover itself), medians exceeding this width can be counterproductive for the following reasons:

- It increases walking distances for pedestrians at the main intersection. This can result in correspondingly longer pedestrian clearance intervals, which can be counterproductive to the efficient signal operation.
- It results in a wider intersection footprint, which can lead to longer yellow and all-red clearance times for the intersection and consequently longer cycle lengths.

Deflecting the through movements at the crossover intersections may be a way to decrease the right-of-way footprint in the vicinity of the crossover. The median can be narrowed using transition curves based on guidance from the AASHTO Green Book. Similarly, minimum turning radius criteria for heavy or conventional design vehicles and shoulder placement can be obtained from the AASHTO Green Book and applied as appropriate.

Lane Widths

Lane widths are typically wider through turning roadways than on tangent sections. This applies to the DLT crossover intersections when accommodating turning paths for the design vehicle.

The following factors can be considered when evaluating the trade-offs of providing narrow lanes: facility type (e.g., intersection or segment), functional classification (principal arterial), number of lanes, travel speed, presence of transit buses, percent of truck traffic, and area type (e.g., urban, rural). With this information, the overall effect of a cross-section change can be established.

Design Vehicle

The design vehicle at a DLT intersection should be consistent with the design vehicle of the surrounding street network. The transportation professional should work with the local agencies to establish the appropriate design vehicle, particularly at locations where there are multilane movements. For example, a designer can design for a 30-foot single-unit truck (SU-30) and a school bus to complete the dual turns side-by-side. However, a 67-foot tractor-trailer truck (WB-67) would be accommodated by using both lanes (if that is a legal maneuver within the given jurisdiction).

The curves associated with the left-turn movements at the crossover intersection have relatively large radii, and over-tracking into the adjacent lane can be addressed by adjusting the curb lines. Exhibit 7-14 shows side-by-side maneuvers, and Exhibit 7-15 shows semi-truck maneuvers through the crossover intersection.

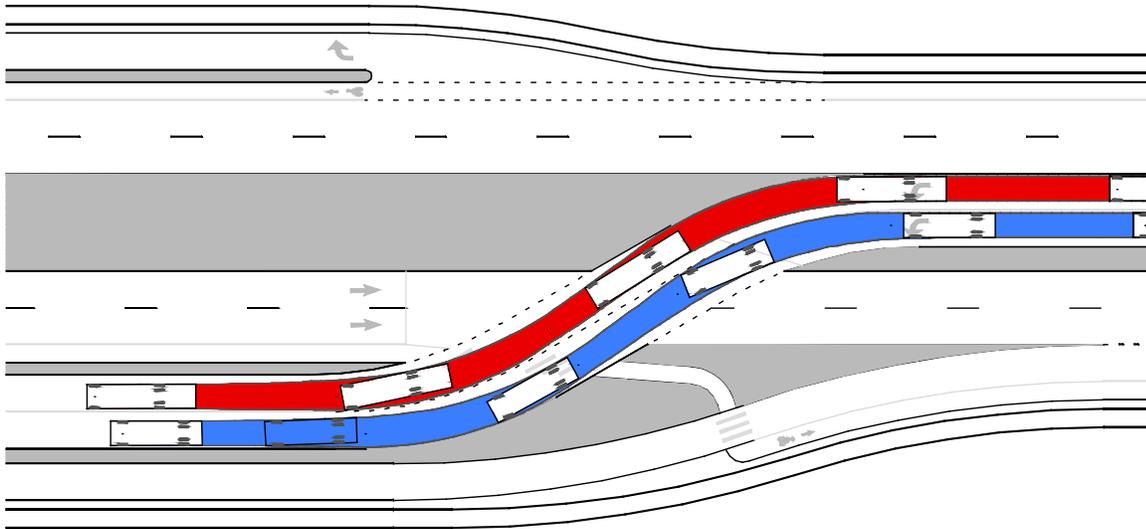


Exhibit 7-14. Side-by-side maneuvers at crossover intersection.

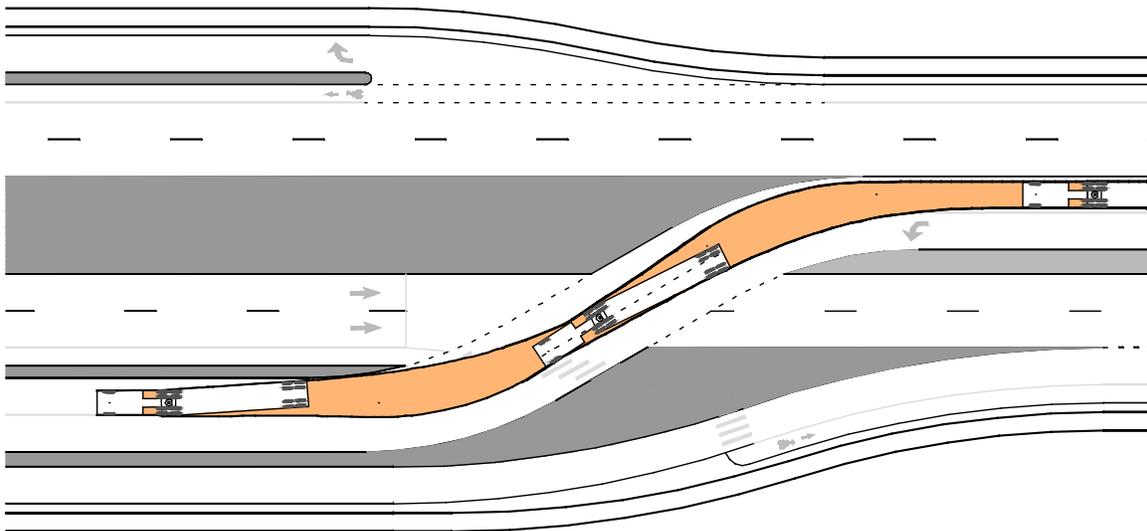


Exhibit 7-15. Semi-truck maneuvers at crossover intersection.

The design vehicle for the left turns at the main intersection will determine the stop bar locations and set the curb lines for the pedestrian refuge islands. Exhibit 7-16 shows the side-by-side left turns at the main intersection, and Exhibit 7-17 shows semi-truck maneuvers through the main intersection.

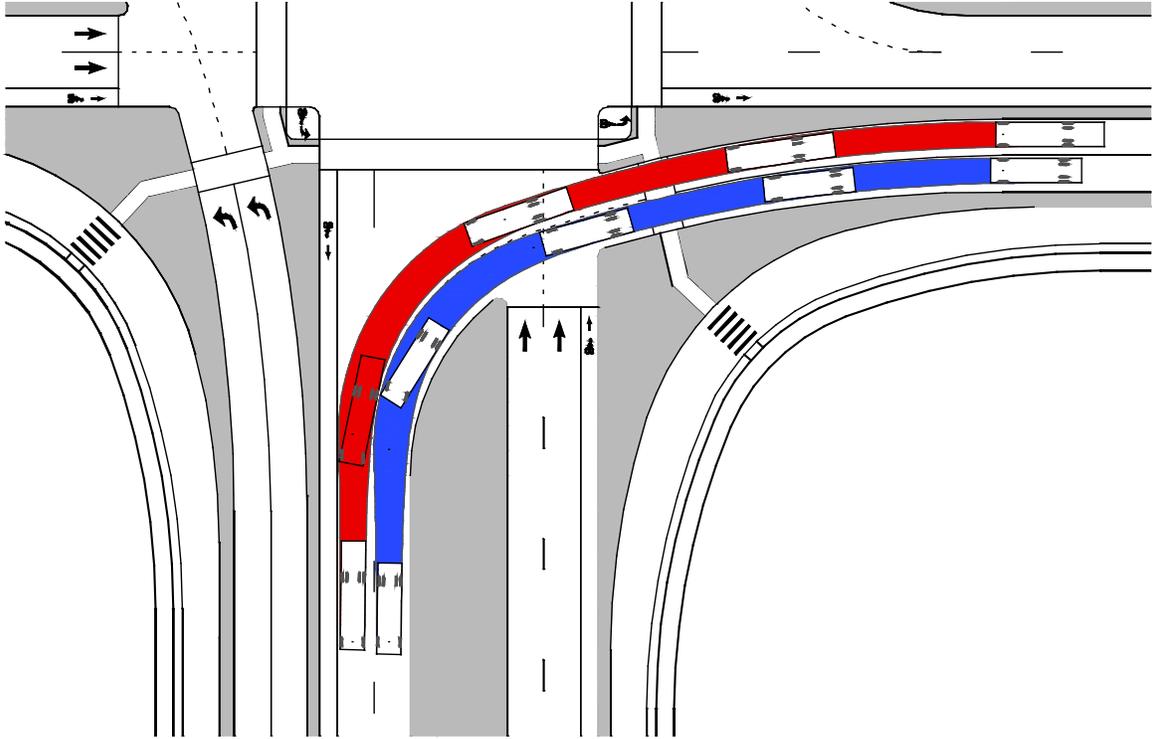


Exhibit 7-16. Side-by-side left turns at main intersection.

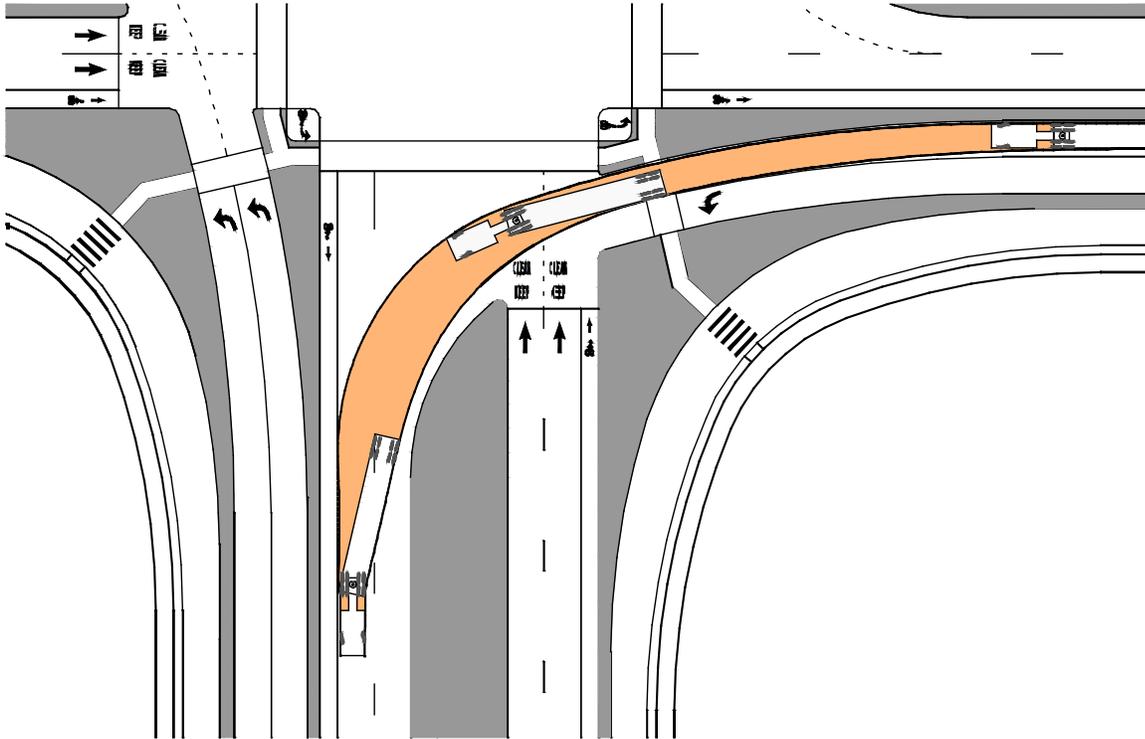


Exhibit 7-17. Semi-truck maneuver at main intersection.

Another consideration for designers is cross slopes (i.e., super-elevation) at the crossover intersection. For normal crowned facilities, the left-turning vehicle will transition from a 2-percent slope to the outside over to a 2-percent slope to the other side of the road (total rollover of 4-percent) through S-curves. For trucks with unique loads this may create instability or load shifting. The cross section design may be coordinated with local agencies to refine the design to meet defined project needs. In addition to cross slope, intersections that are not situated on level terrain may contribute to possible rollovers.

Crossover Intersection Spacing

The spacing between the main intersection and each upstream crossover intersection generally ranges from 300 to 500 feet (see Exhibit 7-18). It is not always possible to stay within these ranges, and there are trade-offs to be considered. For example, spacing of less than 300 feet may result in queue spillback and reduce the ability to clear queues through a single signal cycle. For an intersection spacing of more than 500 feet, it may be more difficult to coordinate DLT signal operations. The distance between the main intersection and the crossovers greatly affects the range of possible signal timing strategies that allow for coordination between movements. Research indicates intersection spacing influences the phase time that can be allocated to the left-turn crossover. ⁽²⁸⁾ In general, a DLT intersection approach with higher left-turn demand should have longer spacing between the main intersection and the crossover on that approach. Higher design speeds also necessitate greater spacing between intersections.

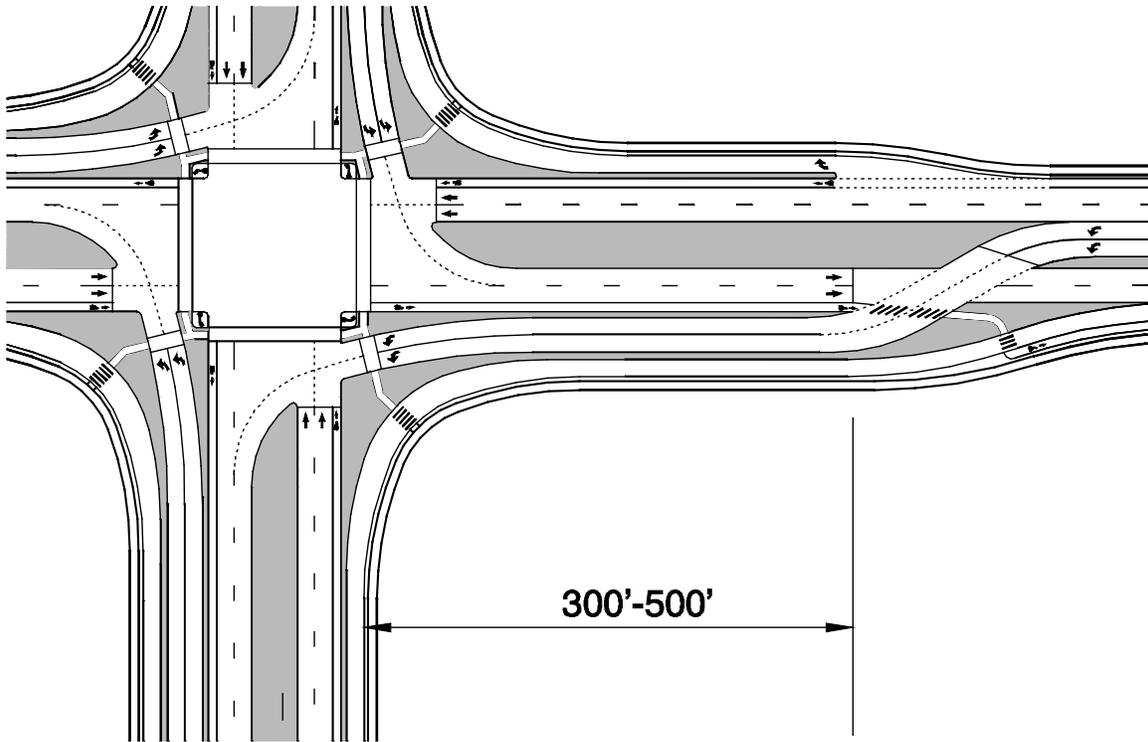


Exhibit 7-18. Typical intersection spacing.

Pedestrians and Bicycles

Chapter 3 provides guidelines to accommodate pedestrians and bicyclists at DLT intersections. As for conventional intersection design, ADA guidelines provide guidance for designing crosswalks, pedestrian ramps, and sidewalks, which applies to both pedestrian and shared-use pedestrian/bicycle paths.⁽¹⁷⁾

One unique feature for designing for bicyclists at a DLT intersection is providing a bicycle box in the far-side pedestrian island for bicyclists to complete a left turn through the main intersection. Exhibit 7-19 illustrates a layout for a modified pedestrian island to accommodate a bicycle box.

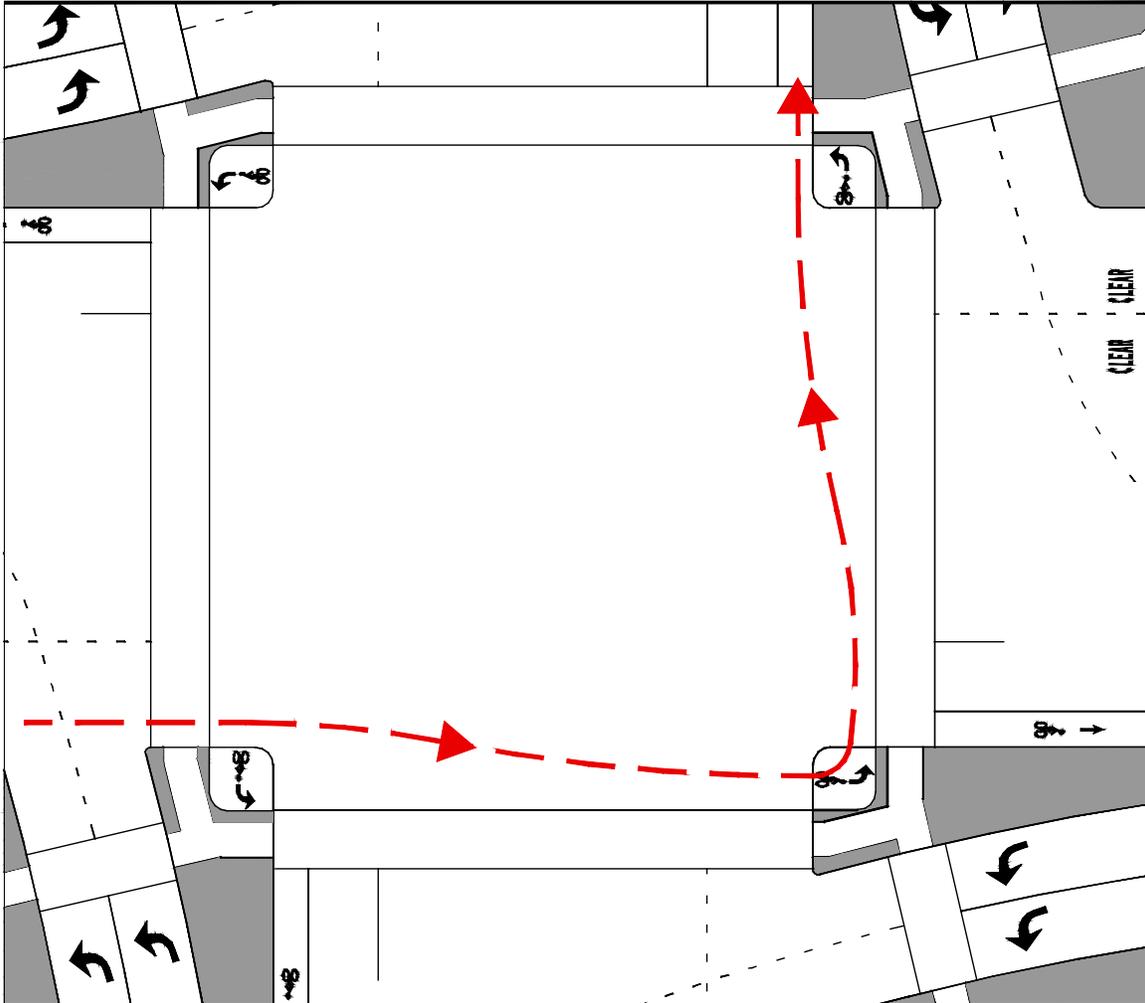


Exhibit 7-19. Bicycle box for left turn.

Transit

As discussed in Chapter 3, transit buses can be accommodated by stopping in travel lanes or by providing bus pullout areas in strategic locations within the DLT configuration. Local transit agencies have design guidelines for bus pullouts. A typical bus pullout has 10:1 tapers in and out of a 40-foot long, 10-foot wide bus stop. Special consideration needs to be given to bicycle lanes and pedestrian amenities at bus stops.

CHAPTER 8— SIGNAL, SIGNING, MARKING, AND LIGHTING

This chapter presents information for designing and placing traffic control devices at DLT intersections, including traffic signals, signs, pavement markings, and intersection lighting. The unique features of the DLT, such as the width of the intersection and unconventional geometry, result in additional considerations with respect to signal head placement, number of signal heads, additional lighting and signs, and pavement markings. The guidance in this chapter supplements the national resources on intersection design highlighted in previous chapters, including the MUTCD, as well as local agency design standards and policies.⁽⁶⁾

DESIGN PRINCIPLES AND APPROACH

Traffic signal design, signing, pavement marking, and lighting design at a DLT intersection can be different from conventional intersections, particularly related to the crossover intersections and the turning movement restrictions at the main intersection. For auto users, the following treatments need to be emphasized at DLT intersections:

- Position signal heads above the receiving lanes at the crossover intersections to provide guidance through the intersection
- Provide wrong-way signage and pavement markings to warn drivers of prohibited movements
- Consider overhead and post-mounted signing to guide drivers
- Use pavement markings and overhead lane use signs to supplement other guidance methods
- Provide lane extension striping to help guide motorists through the main and crossover intersections
- Provide appropriate lighting at conflict points (i.e., main and crossover intersection) within the DLT configuration to emphasize the presence of various users

SIGNALS

Chapter 5 provides operational characteristics for potential signal phasing, timing, and progression.

Working with the local agency's maintenance department, the designer can locate the controller based on the following considerations:

- Proximity to power source
- Place equipment outside vision triangles
- Provide maintenance vehicle access and parking

The controller is typically located where it has the least exposure (reducing the chance it will be hit), or appropriate protection is provided.

Exhibit 8-1 is a schematic of possible signal pole and mast arm locations for a DLT intersection. Section 4D of the MUTCD provides national guidance for traffic control signal features, including placement of overhead signal heads. One possible set of locations for pedestrian push-buttons is depicted in Exhibit 8-1, and more information can be found in Section 4E.08 of the MUTCD.⁽⁶⁾ An alternative signal design is a span-wire signal that is often considered when the expense of a mast arm becomes relatively high.

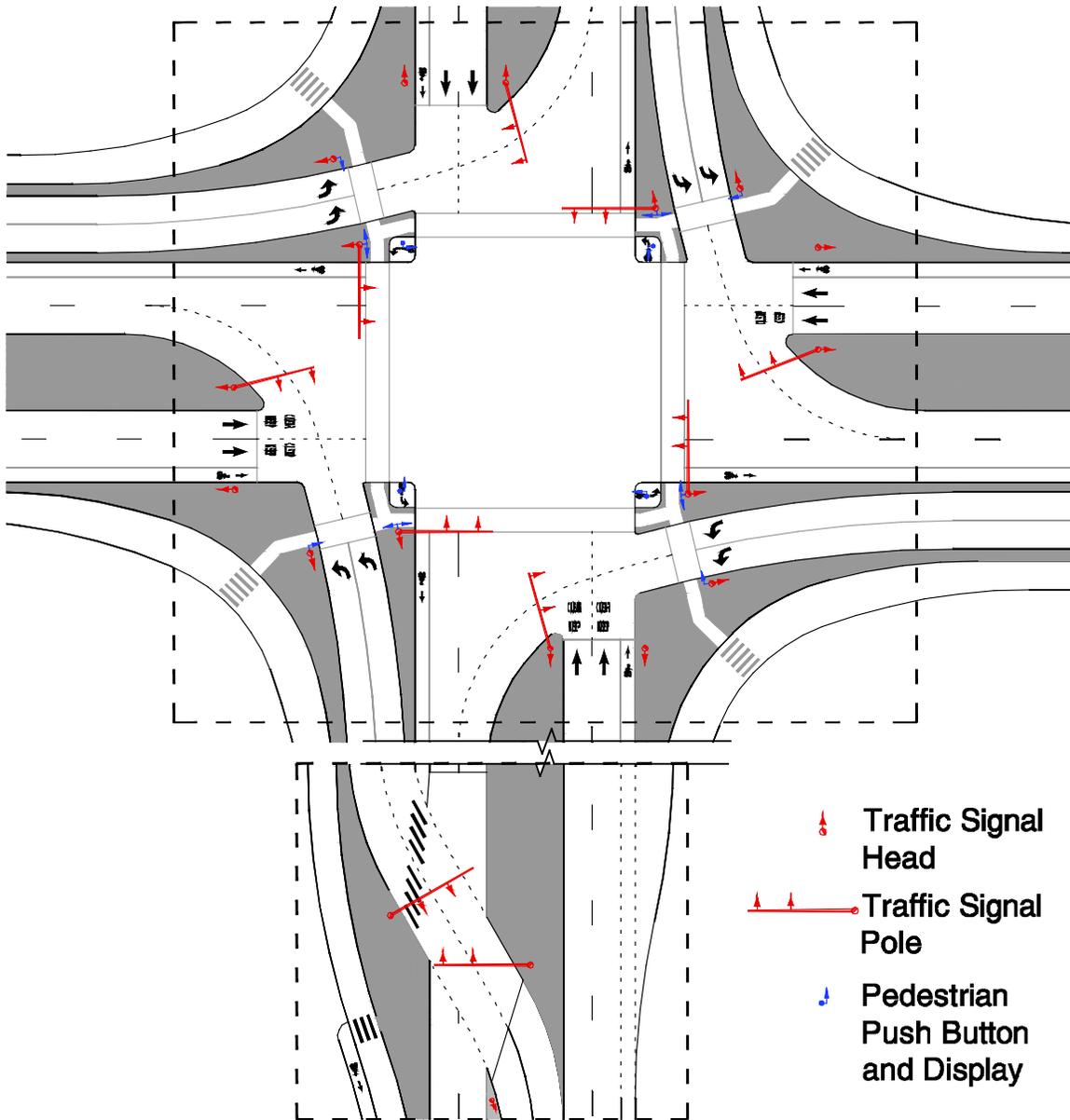


Exhibit 8-1. Possible signal pole and mast arm locations for a DLT intersection.

The DLT intersection can consist of up to five signalized intersections depending on the number of crossovers. The five signals can be operated either with separate controllers or with a single controller. Coordination of the traffic signal controllers is necessary when multiple signal controllers are used at a DLT intersection to control each signalized intersection separately. The advantages of single- and multiple-controller signal systems are described below.

Advantages of multiple controllers include:

- If one controller fails, the other intersections of the DLT can still function
- Programming phases and signal timing is simpler to install and maintain
- Installations require shorter wire lengths (signal conductor wire/detector wire runs to local controller only)
- Easier for signal maintenance in that each cabinet will likely be placed with visibility provided to the signal heads it controls

Advantages of a single controller include:

- The system requires fewer cabinets and controllers to purchase, install, and maintain
- Interconnection is not required to keep signals coordinated
- Only one controller is required to program and maintain
- There is a single service point for power
- There are fewer components to fail
- Vehicle detection may be easier to configure

Signal control at a DLT intersection may be operated in a fully-actuated mode to minimize delay. Detectors can be installed to cover all of the crossovers, the minor street approaches, and the major street approaches. Detector actuation would depend on the type of operation. Exhibits 8-2 and 8-3 show the possible detector locations and associated phases for multiple controllers and a single controller for a DLT intersection, respectively.

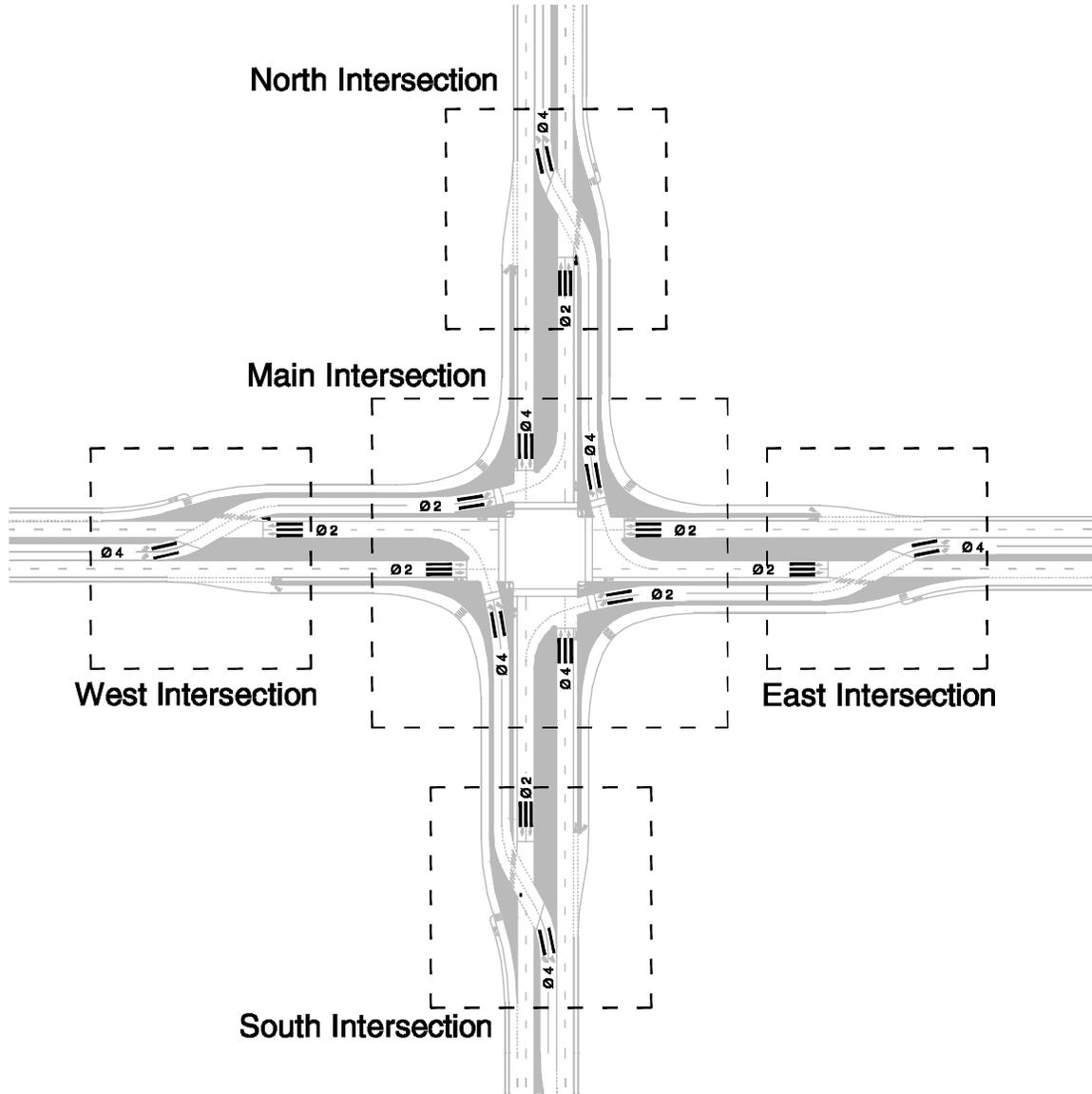


Exhibit 8-2. Possible detector placement locations for a DLT intersection with five separate controllers.

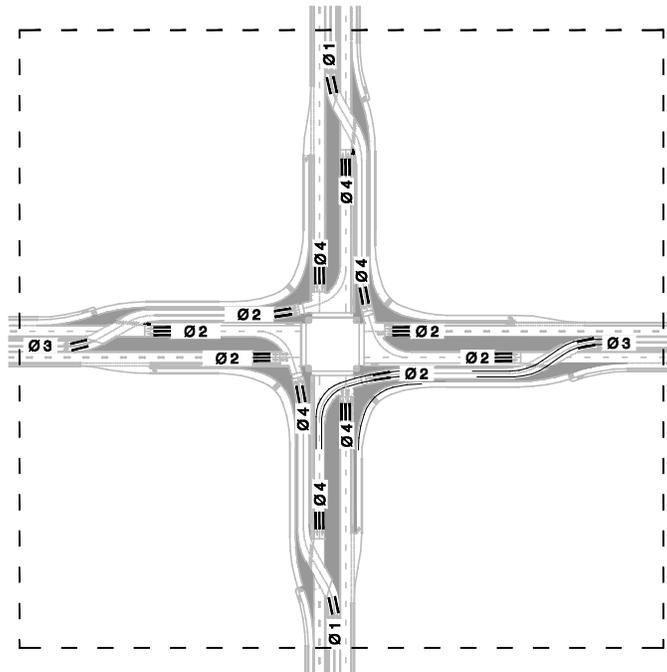


Exhibit 8-3. Possible detector placement locations for a DLT intersection with a single controller.

An angular arrow signal display as shown in Exhibit 8-4 for the left-turn traffic at the crossover intersection could help guide motorists through the crossover intersection.

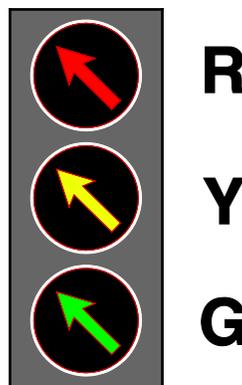


Exhibit 8-4. Angular arrow signal display.

Crosswalks at the channelized right-turning streets will require installing some form of accessible signalized treatment. This can be in the form of a RRFB, pedestrian hybrid beacon, or fully-signalized crossing (which can then be controlled by an adjacent controller within the DLT intersection so vehicular movements are coordinated). The pushbuttons for pedestrians to cross the

major legs of the main intersection may be located on the channelizing islands, which also serve as pedestrian refuges. These pushbutton locations should meet ADA guidelines and be consistent with Section 4E.08 of MUTCD, which also provides more information on the appropriate location and type of pedestrian signal heads.⁽⁶⁾

SIGNING

As for conventional intersections, signing supports a motorist in making decisions at appropriate locations to select and navigate movements through the DLT configuration. The advance diverging points associated with a DLT intersection can lead to wayfinding signage becoming more cumbersome and costly than what is typically provided at a conventional intersection. Decision points occur well in advance of the main intersection and may not meet driver expectancy to turn left at an intersection prior to the cross street. Left-turn crossover intersections and driver actions must be communicated well in advance for motorists to get in the appropriate position when arriving at the decision point. Example signing and pavement marking plans can be found in the Appendix.

New reference material is available from the TRB paper, “Evaluation of Signs and Markings for Partial Continuous Flow Intersection”⁽³³⁾. In a driver simulator study, Inman found advance signing of the DLT crossover intersection was critical to ensuring drivers did not miss the crossover completely. The study could not determine a significant difference between dual ground-mounted signage of the crossover and overhead-mounted signage. From the TRB paper, Exhibit 8-5 provides a visual perspective of the progression of overhead signage from a driver simulator approach of the crossover intersection.



Exhibit 8-5. Progression of overhead signs for the DLT crossover intersection.⁽³³⁾

Exhibit 8-6 shows typical guide signage along one of the intersection approaches to be provided at a DLT intersection, and Exhibit 8-7 illustrates example regulatory and warning signs in the vicinity of the intersection.

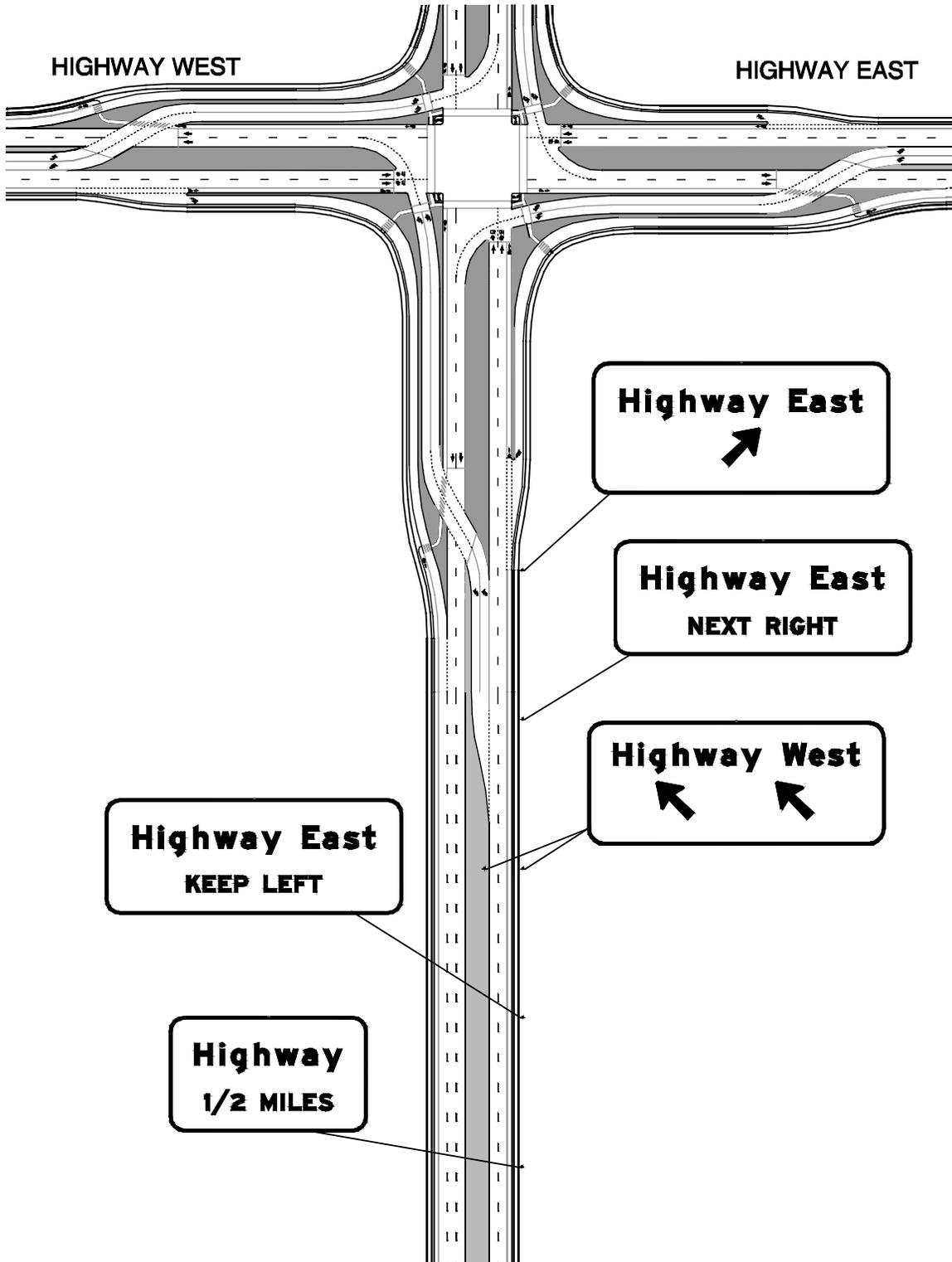


Exhibit 8-6. Example guide signing along an intersection approach for a DLT intersection.

PAVEMENT MARKINGS

Pavement markings supplement intersection geometric design and signage. Visibility of the pavement marking can be influenced by weather conditions (especially snow). Part 3 in the MUTCD provides national guidance for consistent pavement markings throughout the United States.⁽⁶⁾ Striping approaches should be consistent with the local agency's design guidelines.

A driver simulator study found the words “KEEP CLEAR” as pavement markings beyond the minor street stop bar effectively prevented stop bar overrun.⁽³³⁾ Section 3B.17 of the MUTCD provides guidance on placing these symbols.⁽⁶⁾ Exhibit 8-8 provides a visual perspective of the pavement markings at the main intersection from the driver simulator approaching along the minor approach.⁽³³⁾ The study did not use “STOP HERE ON RED” signage or nearside signals, but suggested those messages may be equally effective treatments.



Exhibit 8-8. High treatment on minor street approach.⁽³³⁾

Exhibit 8-9 shows pavement markings along one of the intersection approaches to be provided at a DLT intersection.

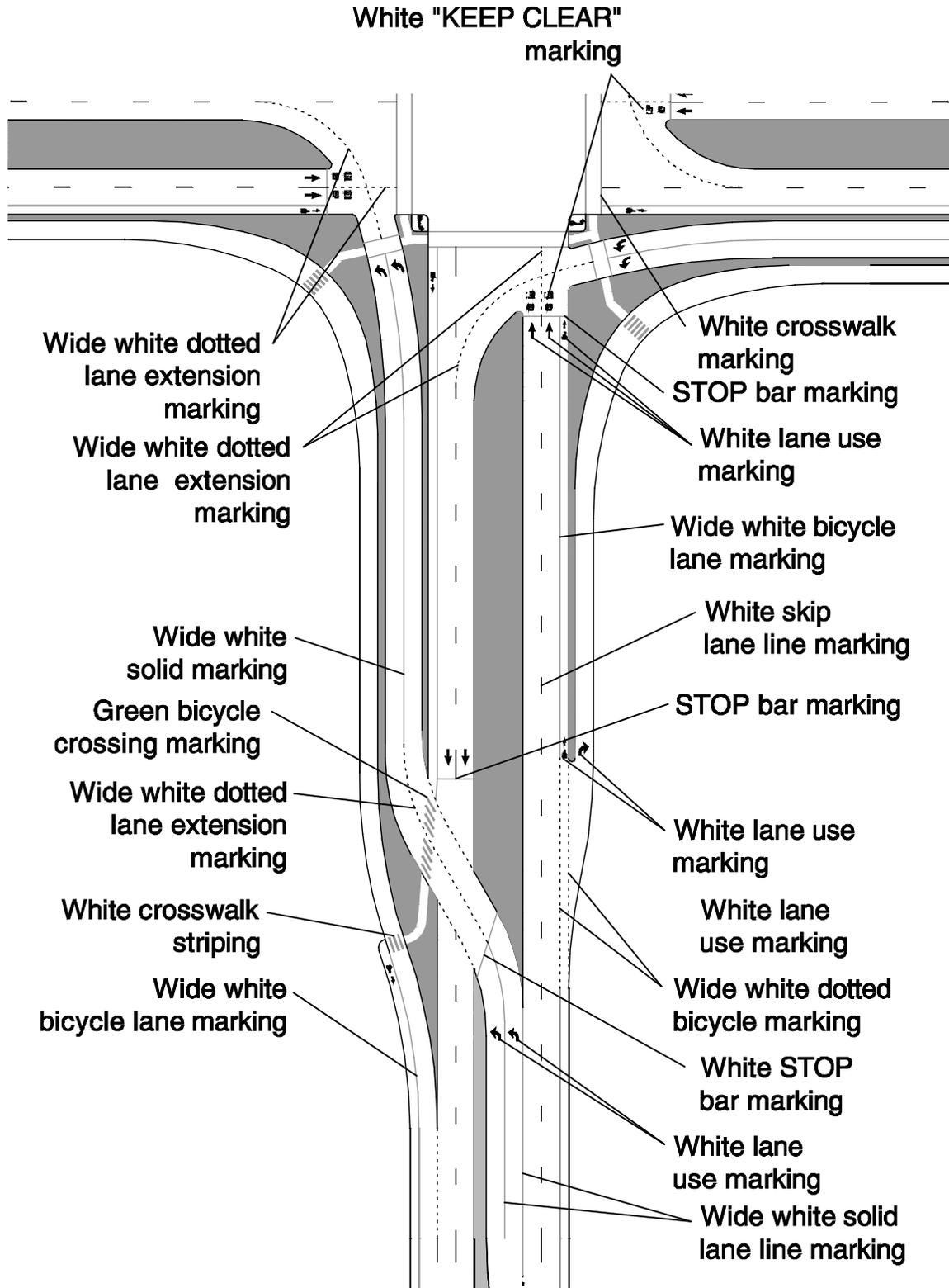


Exhibit 8-9. Pavement markings along an intersection approach for a DLT intersection.

LIGHTING

Lighting standards and specifications outlined in AASHTO's *Roadway Lighting Design Guide*, FHWA's *Lighting Handbook*, and the Illuminating Engineering Society of North America (IESNA) publications including *American National Standard Practice for Roadway Lighting* can be used to determine optimal lighting for DLT intersections.^(34, 35, 36)

Based on the national lighting guidance, agencies establish street lighting design guidelines along their facilities that are based on the road functional classification and pedestrian conflict area classifications. Intersection lighting is typically 1.5 times the street lighting along the approaches, or the street lighting of the two crossing streets are added together to determine the lighting guidelines for the intersection.

For the DLT intersection, it is desirable to light the main and crossover intersection according to the determined intersection light levels. Depending on the intersection spacing, the light levels for the road segments between the intersections may be reduced to the street segment light levels. If there is no lighting along the approaches, then transition lighting coming from dark into light and vice versa may enhance the user experience and performance. Even with sufficient lighting provided for the overall intersection, additional supplemental lighting could be added in the median to illuminate the pedestrian refuge area.

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CHAPTER 9— CONSTRUCTION AND MAINTENANCE

Constructing a DLT intersection follows a pattern that might be similar as conventional intersections with the overall goal to maintain non-motorized and motorized traffic while providing a safe work environment. The context of the project location will inform the staging and sequencing of construction. DLT construction costs may be higher compared to conventional intersections given the more extensive street layout (more pavement and curbs) and the need for increased traffic control devices (potentially up to five signals). The guidance in this chapter supplements the national resources on construction and maintenance, including the MUTCD, as well as local agency design standards and policies.

CONSTRUCTION

Utah, Colorado, Missouri, Mississippi, Louisiana, Ohio, Maryland, New Jersey, and New York have constructed DLT intersections. These agencies could serve as resources for construction planning guidance. As with any new type of street construction, additional communication and coordination with construction contractors may streamline project implementation. Understanding lessons learned from agencies having developed DLT intersections may reduce construction delays.

The considerations and objectives of constructing a DLT intersection are similar to those of a conventional intersection. In each case, primary considerations include maintaining traffic for each user and protecting workers and users during construction. A DLT intersection may be associated with reconstructing an existing intersection. If so, some considerations include local access, building up to four new intersections on the crossing streets, and adding new streets between the crossover intersections and the main intersection. When constructing a new DLT intersection, scenarios might include adding a new intersection to an existing street or adding the DLT intersection as part of a new street network. In these cases, some considerations include where to locate future accesses and creating frontage roads to accommodate accesses within the future DLT intersection influence area.

Construction Staging

The following are potential options for constructing a DLT:

- Close the entire intersection
- Close one cross road at a time
- Accommodate all movements/users during construction

It may be appropriate in some cases to close the entire intersection. Information gathered during public outreach activities can help inform construction approaches. The general public may be willing to accept more disruption (congestion, temporary road, or access closures) over a shorter construction period compared to less disruption over a longer period. In some situations, depending on the type of adjacent land uses, full access might need to be provided at all times. There may be ways to close the cross roads one at a time to simplify the movements at the main

intersection. There are trade-offs when selecting the most appropriate approach, and the solution depends on the context of the environment, such as where the project is located and the potential impact on the community and intersection users. In general, it may be helpful to avoid using new pavement for movements that will change in the final stage to avoid “training” drivers twice.

Operational analyses considering the immediate and surrounding street network can help inform and guide project decision making as to the approach of staging sequencing for intersection and street construction. Understanding stakeholder needs and the surrounding land use context combined with an assessment of street network operations can help inform the optimal approach to potential road segment closures and/or temporary lane closures during certain time periods.

Construction sequences for converting a traditional four-leg intersection to a DLT intersection in Baton Rouge, LA—as well as a DLT intersection in Salt Lake City, UT—can be found in the Appendix. Each project used three general construction phases and accommodated various movements (left turn, through, and right turn for each approach) at the overall intersection. The three general phases used were as follows:

- Phase I – Build outside first (see Exhibit 9-1)
 - Construct right-turn bypass lanes and displaced left-turn lanes along the streets
 - Install a temporary traffic signal (if needed) at the main intersection for Phase II operations
 - Maintain traffic under existing signal operations at the main intersection

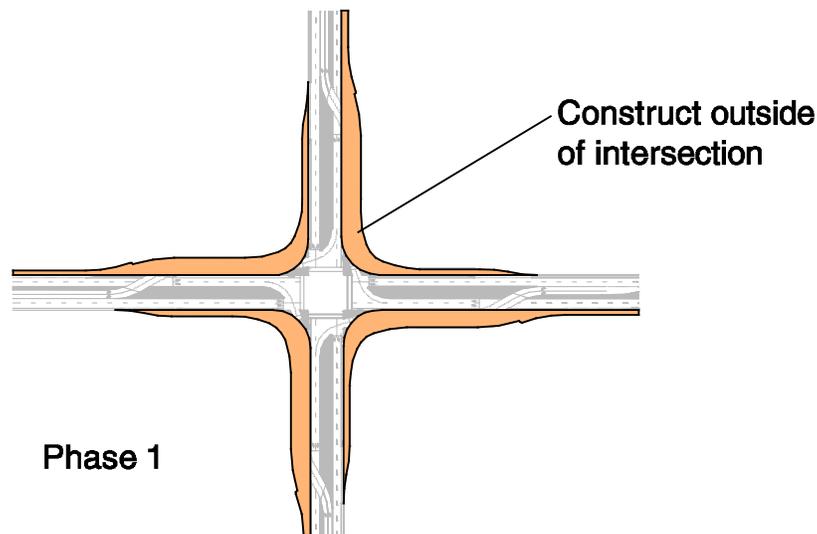


Exhibit 9-1. Phase I construction.

- Phase II – Construct major pedestrian islands (see Exhibit 9-2)

- Divert right turns to the newly constructed right-turn bypass lanes while maintaining other movements
- Construct major street left-turn lanes at the crossover intersections and the new traffic signals
- Construct major pedestrian islands and a new traffic signal at the main intersection

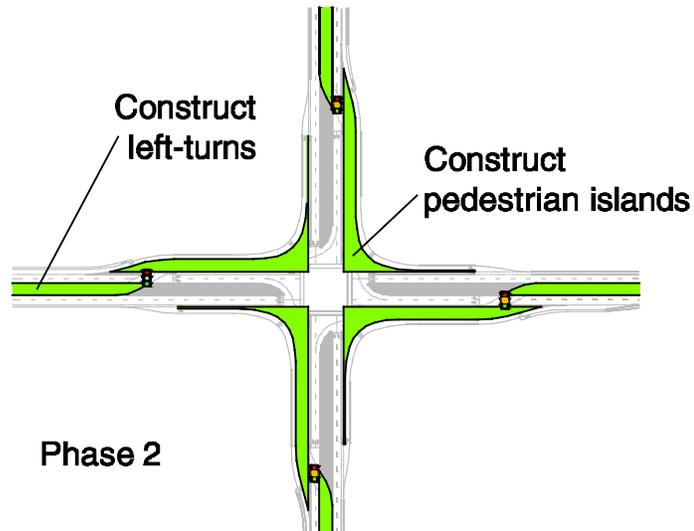


Exhibit 9-2. Phase II construction.

- Phase III – Direct traffic to ultimate configuration and finish medians (see Exhibit 9-3)
 - Direct traffic to the ultimate travel pattern
 - Construct medians along the major streets
 - Finalize the street lighting installation, permanent signing, and pavement markings

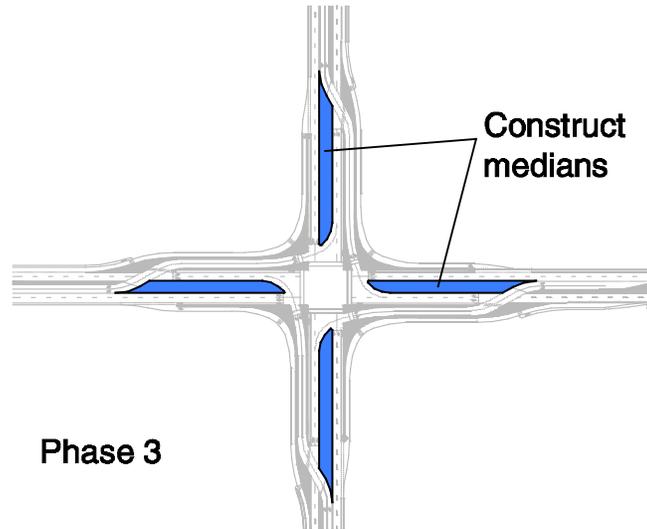


Exhibit 9-3. Phase III construction.

Work Zone Traffic Control

Part 6 of the MUTCD provides guidance regarding temporary signal, signing, and pavement marking needs during construction and temporary street and intersection configurations.⁽⁶⁾ MUTCD principles and applications for conventional intersections and streets would apply to constructing a DLT intersection.

A DLT intersection construction project may need more specialized work zone traffic control compared to conventional intersection construction, especially when informing users of the sequence of construction activities. The objective is to maintain the existing intersection operations with all the movements as long as possible at the main intersection (Phases 1 and 2). Installing the guide signs prior to switching the traffic to the final DLT intersection configuration (Phase 3) to help users navigate through the new travel pattern. Portable Changeable Message Signs (PCMSs) can be placed prior to the traffic switchover to inform the public in advance of the change; the message then needs to be adjusted to notify the users of the new pattern in place.

COSTS

The construction cost of a DLT intersection is likely to be higher than a conventional intersection primarily because of increased footprint and associated additional right-of-way requirements.⁽²⁵⁾ The costs for right-of-way and new signal control (the DLT intersection requires one to four additional signal-controlled intersections compared to a conventional intersection) will increase the cost of a DLT intersection beyond that of a conventional intersection. However, considering a grade separation may be an alternative option for a high volume intersection, the DLT may be more cost effective and produce similar operational benefits.

Total project costs of DLT intersections depend on many project-specific factors, such as project context, public outreach, adjacent businesses, right-of-way, as well as the engineering and

construction costs. The cost of three completed DLT intersection projects are provided below to give a potential range of costs. Exhibit 9-4 provides a summary of the three DLT intersections.

Exhibit 9-4. Summary of costs associated with DLT intersections.

Location	Open to Traffic	Cost	Image
Airline Highway / Siegen Lane intersection Baton Rouge, Louisiana¹	2006	Construction cost was approx. \$4.4 million (including \$1 million for the frontage road) ²	
Bangerter Highway / 3500 South intersection Salt Lake City, Utah	2007	Total project cost of \$7.5 million ³	
Route 30 / Summit Drive intersection Fenton, Missouri	2007	Total construction cost of \$4.5 million ²	

¹ Constructing left-turn crossovers and a frontage road; widening the existing street and channelization work (no right-of-way needed)

² Cost represents the construction bid price of the project only

³ Cost includes all costs associated with the project (e.g., planning/environmental, engineering, and right-of-way)

MAINTENANCE

Street maintenance of a DLT intersection is similar to a conventional intersection. However, there are more raised medians separating movements compared to conventional intersections. Repairs along any of these medians (i.e., raised islands) will likely require temporarily closing an adjacent lane. Closures occurring during off-peak periods may minimize traffic disruptions. This process could follow the appropriate work zone guidelines, as for all conventional intersections.

Maintaining signals, signing, pavement markings, and lighting is similar to conventional intersections. The following DLT intersection design features may limit intersection maintenance, as discussed in more detail in Chapters 7 and 8:

- Locate traffic signal controllers and signal and street lighting poles with sufficient horizontal clearance to reduce the potential of being hit.
- Consider backup battery systems for the traffic signals to allow the intersection to continue to operate during a power outage.
- Use agency-preferred signing material as established during the design phase of a project.
- Place signs to provide clearance between edge-of-signs and face-of-curbs.
- Use agency-preferred pavement marking material as established during the design phase of the project. Where there are “lane line extension” pavement markings through the intersection to guide movements (i.e. dual turning movement), place the skip striping according to the through movement wheel paths.

Snow Removal

Consistent for all types of intersections, snow removal strategies focus on systematically pushing snow to the outside of the street. The DLT intersection has several medians and end treatments that delineate curb locations (i.e., surface mounted delineators) will support snow management efforts. Snowplow operators will need to become familiar with the DLT configuration and develop a sequence for plowing the different travel paths. Through lanes are typically plowed as part of a corridor, and plowing the major street left-turn lanes is similar to a conventional left-turn lane. The displaced left-turn lanes will need to be plowed after the through lanes and then the right-turn bypass lanes will likely be plowed last.

LAW ENFORCEMENT NEEDS

There are unique law enforcement needs at a DLT intersection. Through traffic at a DLT operates no differently from a conventional intersection and drivers need to stay within their respective through lanes. However, right- and left-turning traffic—depending on the DLT intersection configuration—may be exposed to potential wrong-way movements as discussed and addressed in Chapters 4 and 8.

Enforcement during the periods after the DLT intersections are initially opened to traffic could help drivers become familiar with intended operations and help reduce illegal maneuvers. As the novelty effect of the new intersection operations subside, the need for extra enforcement will likely diminish.

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Appendix A CATALOG OF ALL KNOWN INSTALLATIONS IN THE UNITED STATES

Exhibit A-1 presents location information for all known installations of DLT intersections in the United States.

Exhibit A-1. Known installations of DLT intersections in the United States

Intersection	Location	# Cross-overs	Built	Image
MD 210 at MD 228	Accokeek, MD	1	2000	
US 61/Airline Hwy at Siegen Ln	Baton Rouge, LA	2	2006	
US 61/Sgt Prentiss Dr at US 84/US 425/Junkin Dr	Natchez, MS	1	2010	
UT 154/Bangerter Hwy at UT 173/5400 S	West Valley City, UT	2	2007	

Displaced Left Turn Informational Guide

Intersection	Location	# Cross-overs	Built	Image
UT 154/Bangerter Hwy at 4700 S	West Valley City, UT	2	2007	
UT 154/Bangerter Hwy at 4100 S	West Valley City, UT	4	2007	
UT 154/Bangerter Hwy at US 171/3500 S	West Valley City, UT	2	2007	
UT 154/Bangerter Hwy at US 171/3100 S	West Valley City, UT	2	2007	

Displaced Left Turn Informational Guide

Intersection	Location	# Cross-overs	Built	Image
William Floyd Pkwy at Dowling College	Shirley, NY	1	1996	
NJ 168 at Nicholson Rd	Haddon Township, NJ	1	pre- 1995	
MO 30 at Summit Rd/Gravois Bluffs Blvd	Fenton, MO	2	2007	
OH 741 at Austin Blvd	Miami Township, OH	2	2010	
US 167 at Camellia Blvd	Lafayette, LA	2	2011	

Displaced Left Turn Informational Guide

Intersection	Location	# Cross-overs	Built	Image
US 34/Eisenhower Blvd at Madison Ave	Loveland, CO	2	2011	
UT 265/University Pkwy at Sandhill Rd	Orem, UT	2	2012	
Bennion Blvd at UT 68/Redwood Rd	Salt Lake County, UT	2	2011	
UT 173/5400 S at UT 68/Redwood Rd	Salt Lake County, UT	2	2011	

Appendix B SUPPLEMENTAL OPERATIONAL AND SAFETY DETAILS

VISSIM[®], a microscopic traffic simulation software, was used to gain insights into the operational performance of a DLT intersection in comparison to conventional intersections. Four intersection geometric scenarios of DLT intersections and conventional intersections were simulated. Exhibit B-1 shows the geometric design configurations of the cases simulated. The lane configurations and geometric features for the DLT intersection and conventional intersections on the approaches of the major road and the minor road are identical for each case. These four geometric cases with three major road directional splits were simulated under three sets of traffic volumes: low, medium, and high. The major and minor road splits were set at 50 percent each for all simulation cases. Therefore, a total of 16 unique sets of simulation conditions were developed for the DLT intersection, and an equal number of unique VISSIM[®] simulations were developed for comparable conventional intersections (see Exhibit B-2). The VISSIM[®] simulation network was one mile in length on the major and minor road approaches for the cases simulated. The base case simulations assume no pedestrian activity at the intersection. In addition to the use of typical VISSIM[®] defaults, the following constants were maintained for each simulation:

- Optimum fixed signal timing determined using Synchro[®]
- Yellow times determined using Institute of Transportation Engineers (ITE) policy
- All-red times determined using ITE policy
- A total of 5 percent heavy vehicles on all legs
- A total of 350-foot left-turn bay lengths upstream of the displaced crossover junction
- A total of 325-foot left-turn bay lengths downstream of the displaced crossover junction
- A network size of 0.5 mile in each direction from the main intersection
- Single right-turn bays on the mainline
- Right-turn-on-red allowed at each signal, no left-turn-on-red allowed
- A signal at each displaced left-turn crossover
- A 40-foot median width on mainline
- Undivided side street
- A 45 miles per hour (mi/h) desired speed on mainline
- A 25 mi/h desired speed on side street

- Saturation headway of approximately 1,900 vehicles per hour per lane (veh/h/lane)
- No bus stops
- Seeding time of 30 minutes for the simulations
- Running period of 60 minutes for the simulations

The four cases modeled are as follows:

1. Intersection of a six-lane major road and a six-lane minor road with four corresponding DLTs (one on each approach)
2. Intersection of a six-lane major road and a four-lane minor road with only two opposing DLTs (one on each approach of the major road)
3. Intersection of a six-lane major road and a four-lane minor T-leg with the DLTs on the major road
4. Intersection of a four-lane major road and a four-lane minor road with only two opposing DLTs (one on each approach of the major road)

Exhibit B-1. Geometric design configuration for VISSIM[®] simulation.

Geometric Design Cases	Approach Configuration					
	Major Road			Minor Road		
	DLT intersection and Conventional Intersection					
	Through Lanes	Left-Turn Lanes	Right-Turn Lanes	Through Lanes	Left-Turn Lanes	Right-Turn Lanes
A	3	2	1	3	2	1
B	3	2	1	2	1	1
C	3	2	1	2	2	1
D	2	1	1	2	1	1

Displaced Left Turn Informational Guide

Exhibit B-2. Volumes for Geometric design configuration for VISSIM® simulation—full DLT intersection.

Geometric Cases	Turning Movement Set (veh/h)	Major Road Approach 1 Volume* (veh/h)	Major Road Approach 2 Volume* (veh/h)	Total Minor Road Volume** (veh/h)	Major Road Approach 1 Volume/Total Major Road Volume (veh/h)	Total Minor Road Volume/Total Intersection Volume (veh/h)	
A	Three-lane major road, two left-turn lanes on major road, and three-lane minor road approaches	1	1,000	1,000	1,000	0.50	0.33
		2	1,750	1,750	1,500	0.50	0.30
		3	2,500	2,500	2,000	0.50	0.29
		4	3,500	3,500	7,000	0.50	0.50
		5	3,500	1,500	7,000	0.70	0.58
B	Three-lane major road, two left-turn lanes on major road, and two-lane minor road approaches	1	750	750	500	0.50	0.25
		2	1,500	1,500	1,500	0.50	0.33
		3	2,750	2,750	3,500	0.50	0.39
		4	3,000	3,000	4,000	0.50	0.40
		5	3,000	1,286	4,000	0.70	0.48
C	Three-lane major road, one left-turn lane on major road, and two-lane minor road approaches	1	1,000	1,000	500	0.50	0.20
		2	1,750	1,750	2,000	0.50	0.36
		3	2,500	2,500	3,000	0.50	0.38
		4	2,500	1,071	3,000	0.70	0.46
D	Three-lane major road, two left-turn lanes on major road, and two-lane minor road approaches	1	750	750	500	0.50	0.25
		2	1,500	1,500	1,500	0.50	0.33
		3	2,500	2,500	1,500	0.50	0.23
		4	3,000	3,000	4,000	0.50	0.40
		5	3,000	1,286	4,000	0.70	0.48

veh/h vehicles per hour

* A constant right-turn volume of 300 has been used and is excluded from the major road volumes shown.

** Both minor road approaches have the same volumes.

Case A Simulation

The DLT intersection simulated for this design case had three through lanes: two left-turn lanes and one right-turn lane per approach for all four approaches. The DLT lane before the main intersection had a length of 325 feet, the right-turn bay had a length of 250 feet, and the left-turn

bay before the separation of the displaced left-turn had a length of 350 feet. All acceleration lanes for right-turning vehicles were 300 feet. The median separating the opposing through lanes was 10 feet wide, the median separating the through lanes from the displaced left-turn lanes was 10 feet wide, and the median separating the through lanes from the right-turn lane was 6 feet wide. The comparable conventional intersection had similar geometric features and dimensions as the DLT intersection described above on all four approaches.

The traffic flows on the approaches of the DLT intersection were randomly generated. A large number of cases modeled had directional flows to replicate peak hour directional flows at intersections. The total cycle length for all scenarios was 70 seconds. The ranges in traffic volumes used for each approach by movement were as follows:

- Left-turn movement: 100–750 veh/h
- Through traffic movement: 300–2,650 veh/h
- Right-turn movement: 50–350 veh/h

The results for the full DLT intersection are summarized in Exhibit B-3. In addition, a partial DLT intersection was also evaluated. The results are shown in Exhibit B-4.

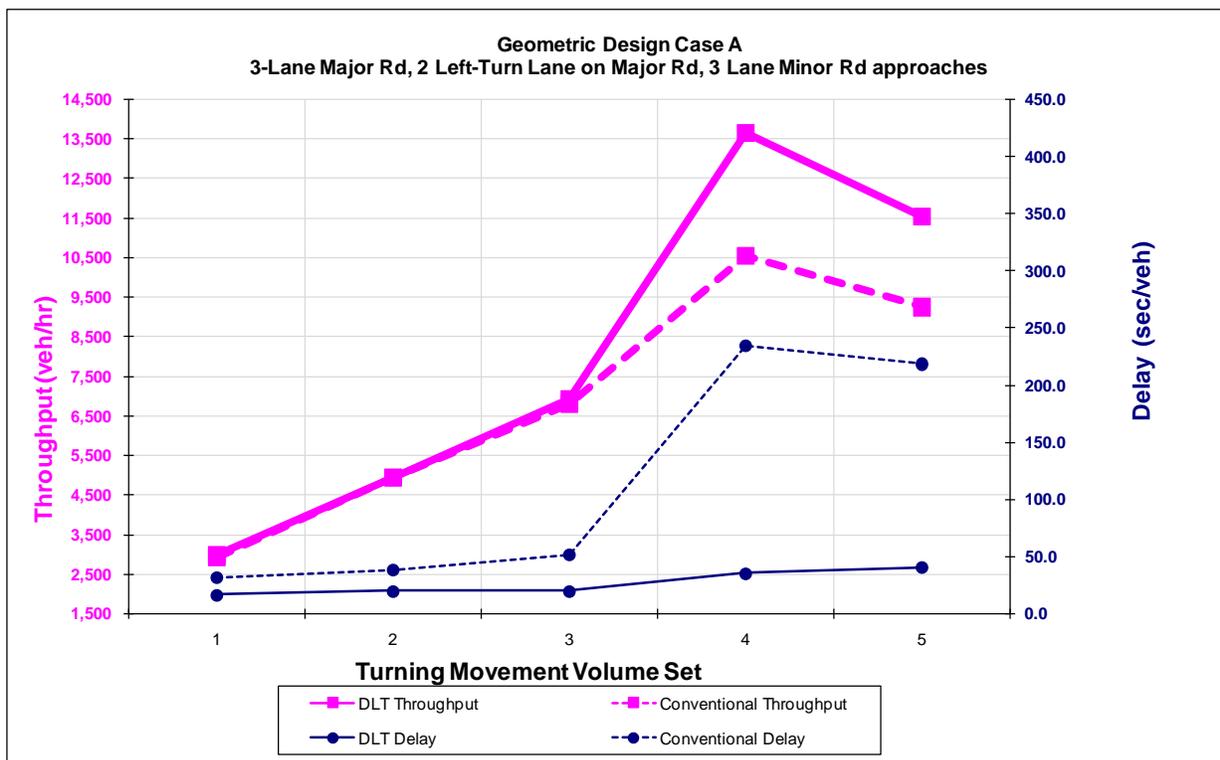


Exhibit B-3. Graph. Throughput and delay comparisons for geometric design case A—full DLT intersection.

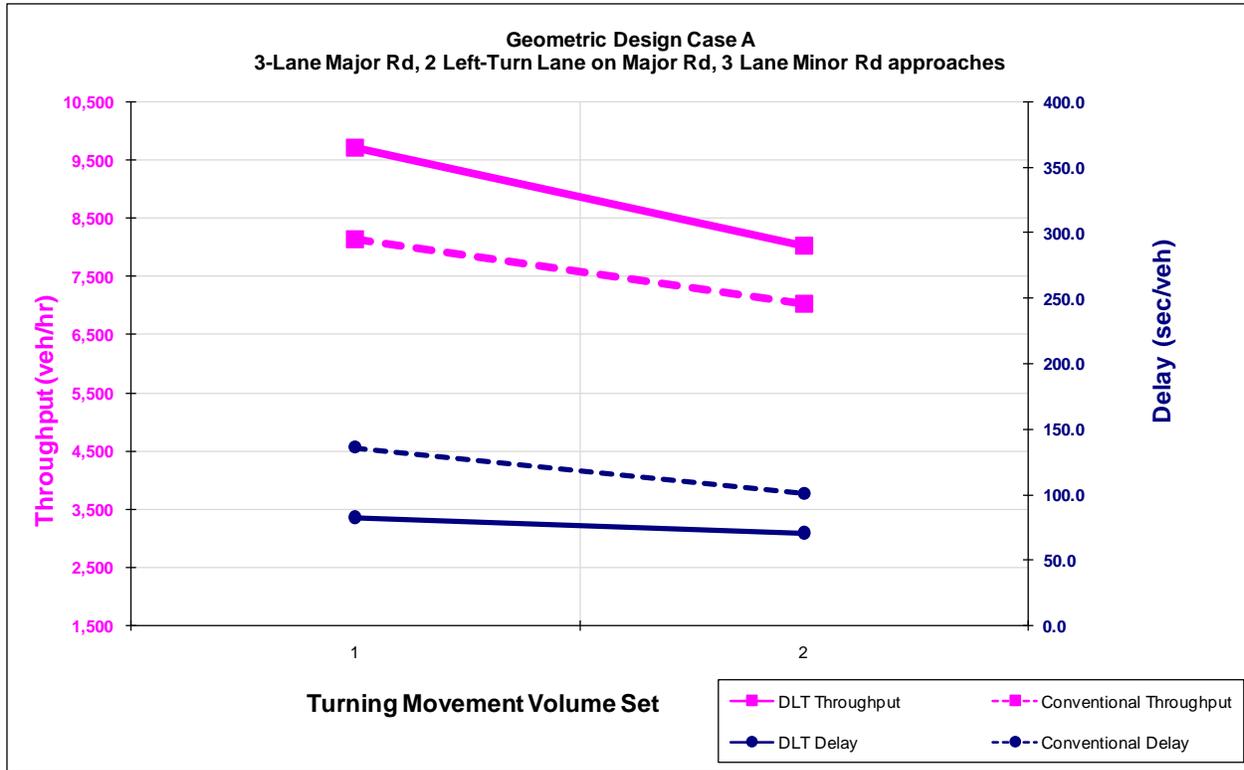


Exhibit B-4. Graph. Throughput and delay comparisons for partial DLT intersection geometric design case A.

Case B Simulation

The intersection had three through lanes, two-left-turn lanes, and one right-turn lane per approach for the two major road approaches. The displaced left-turn lane before the main intersection had a length of 325 feet, the right-turn bay had a length of 275 feet, and the left-turn bay before the separation of the displaced left-turn had a length of 350 feet. The acceleration lanes for the right-turning vehicles were 300 feet. The two minor road approaches were configured as a conventional geometric design with two through lanes: one left-turn lane, and one right-turn lane. For the minor road approaches, the length of the right-turn bay was 3 feet, and the left-turn bay was 350 ft. The median separating the opposing through lanes was 10 feet wide, the median separating the through lanes from the displaced left-turn lanes was 10 feet wide, and the median separating the through lanes from the right-turn lane was 6 feet wide. The comparable conventional intersection had similar geometric features and dimensions as the DLT intersection described above on all four approaches.

The traffic flows on all the approaches were randomly generated. A large number of cases modeled had directional flows to replicate peak hour directional flows at intersections. The cycle length used for all scenarios was 80 seconds.

The ranges of traffic volumes used for each approach by movement were as follows:

- Major road left turns: 100–700 veh/h

- Major road through traffic: 300–2,200 veh/h
- Major road right turns: 50–350 veh/h
- Minor road left turns: 50–200 veh/h
- Minor road through traffic: 50–1,200 veh/h
- Minor road right turns: 50–250 veh/h

The results for a full DLT intersection for case B are shown in Exhibit B-5. The results for a partial DLT intersection for case B are shown in Exhibit B-6.

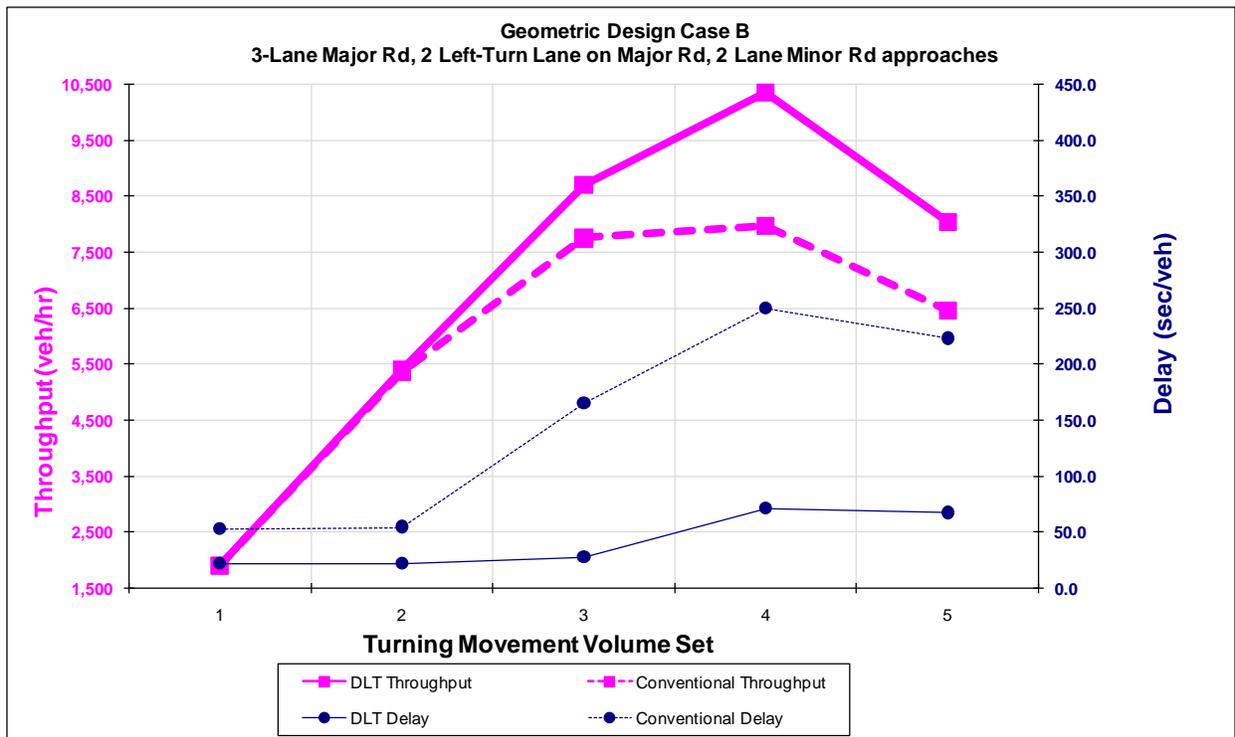


Exhibit B-5. Graph. Throughput and delay comparisons for geometric design case B—full DLT intersection.

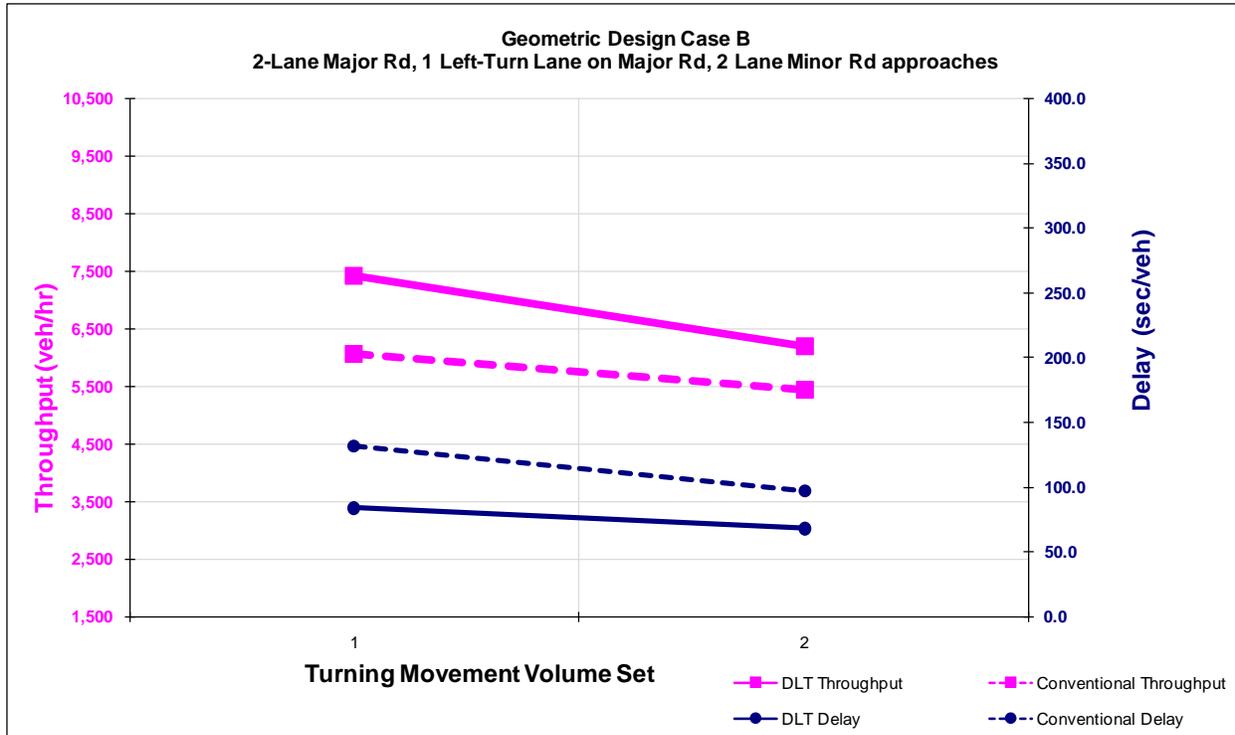


Exhibit B-6. Graph. Throughput and delay comparisons for partial DLT intersection geometric design case B.

Case C Simulation

Case C modeled a T-intersection. There were three through lanes per direction on the major road with DLT lanes on one major road approach and one right-turn lane on the other major road approach. The minor road approach had two left-turn lanes and one right-turn lane. The DLT lane before the main intersection had a length of 325 feet, the right-turn bay on the major road had a length of 300 feet, and the left-turn bay before the separation of the displaced left-turn had a length of 350 feet. The acceleration lane for the right-turning vehicles was 300 feet. The minor road approach had a conventional geometric design with two left-turn lanes and one right-turn lane. The length of the left-turn bay on the minor approach was 350 feet. The median separating the opposing through lanes was 10 feet wide, and the median separating the through lanes from the right-turn lane was 6 feet wide. The geometry can be further improved if a separate acceleration lane is provided for the right-turning vehicles from the main road. The comparable conventional intersection had similar geometric features and dimensions as the DLT intersection described above on all three approaches.

The traffic flows on all approaches were randomly generated. A large number of cases modeled had directional flows to replicate peak hour directional flows at intersections. The cycle length for all scenarios was 70 seconds.

The ranges of traffic volumes used for each approach by movement were as follows:

- Major road left turns: 50–750 veh/h

- Major road through traffic: 300–2,650 veh/h
- Major road right turns: 50–350 veh/h
- Minor road left turns: 100–1,450 veh/h
- Minor road right turns: 50–750 veh/h

The results are shown in Exhibit B-7.

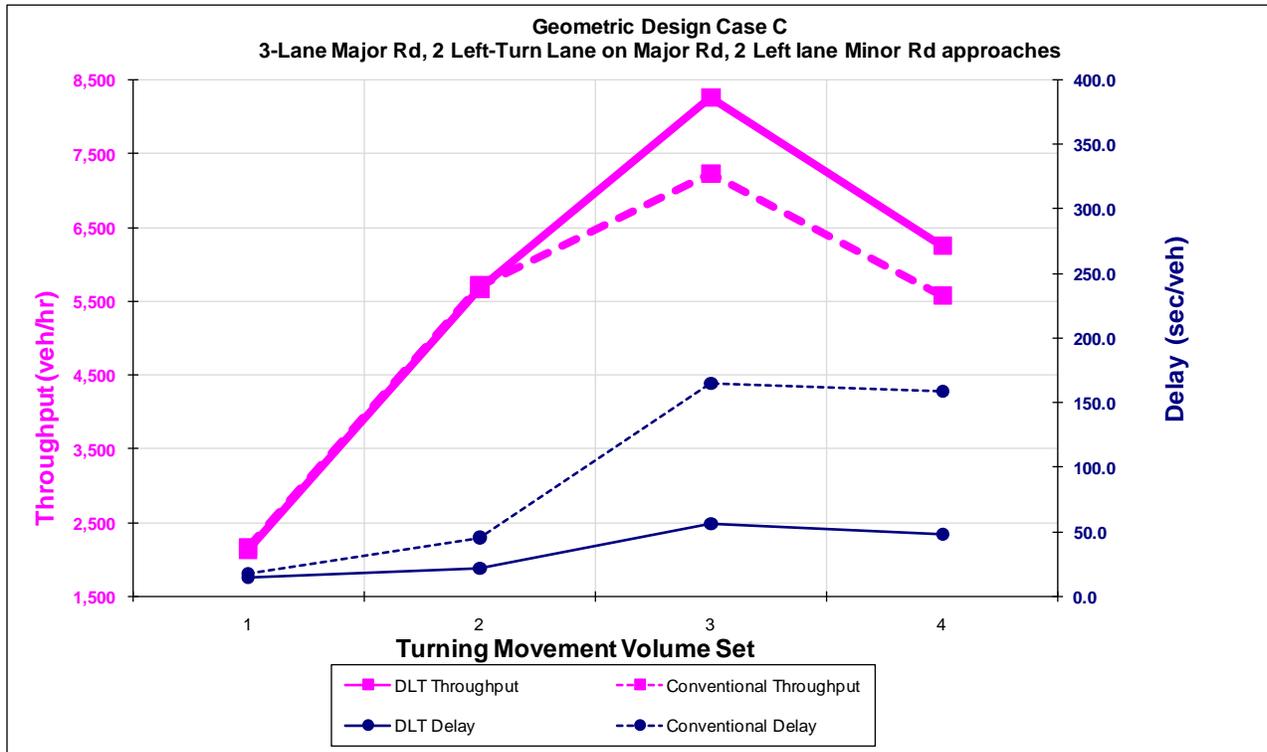


Exhibit B-7 Graph. Throughput and delay comparisons for geometric design case C.

Case D Simulation

The intersection model had two through lanes, one-left-turn lane, and one right-turn lane per approach for the two major roads. The DLT lane before the main intersection had a length of 325 feet; the right-turn bay had a length of 275 feet; and the left-turn bay before the separation of the displaced left-turn had a length of 350 feet. The acceleration lanes for the right-turning vehicles were 300 feet. The two minor road approaches had a conventional geometric design with two through lanes: one left-turn lane and one right-turn lane. For the minor road approaches, the length of the right-turn bay was 300 feet, and the left-turn bay was 350 feet. The median separating the opposing through lanes was 10 feet wide, the median separating the through lanes from the displaced left-turn lane was 10 feet wide, and the median separating the through lanes from the right-turn lane was 6 feet wide. The comparable conventional intersection had similar

geometric features and dimensions as the DLT intersection described above on all four approaches.

The traffic flows on all the approaches were randomly generated. A large number of cases modeled had directional flows to replicate peak hour directional flows at intersections. The cycle length used for all scenarios was 80 seconds.

The ranges of traffic volumes used for each approach by movement were as follows:

- Major road left turns: 100–350 veh/h
- Major road through traffic: 300–1,500 veh/h
- Major road right turns: 50–350 veh/h
- Minor road left turns: 50–200 veh/h
- Minor road through traffic: 50–1,200 veh/h
- Minor road right turns: 50–250 veh/h

The results are shown in Exhibit B-8.

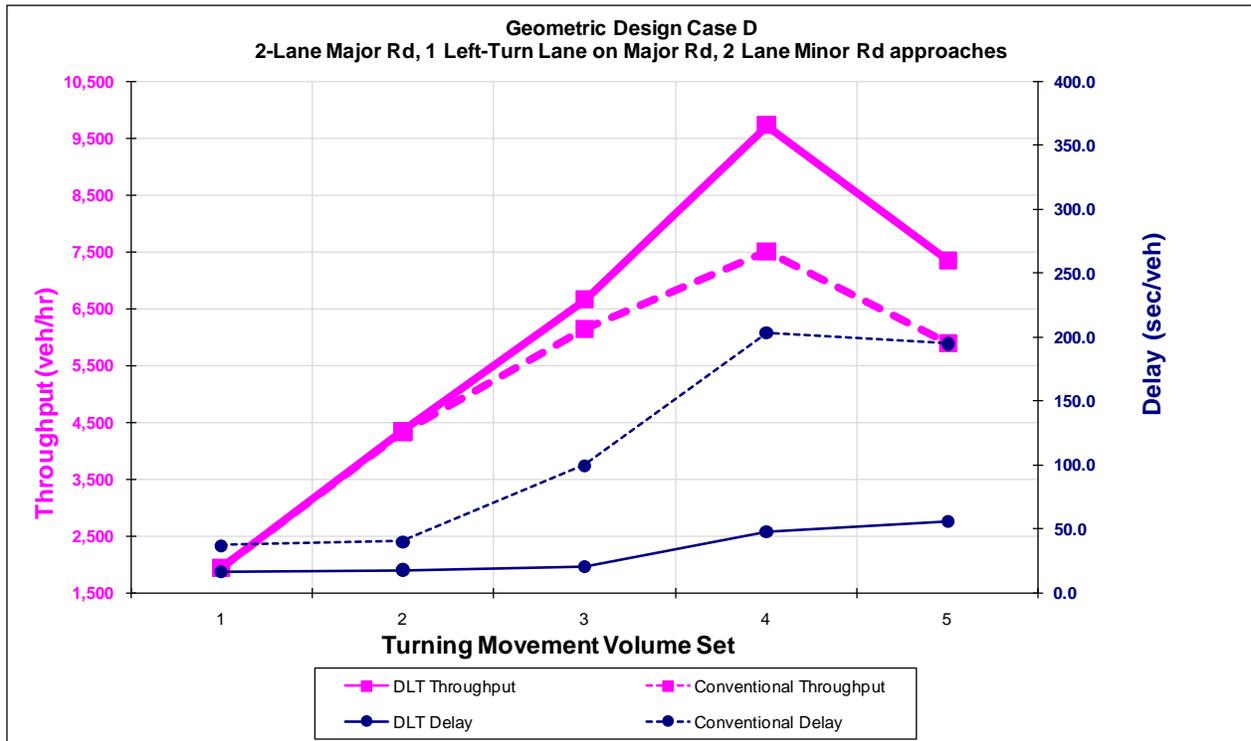


Exhibit B-8. Graph. Throughput and delay comparisons for geometric design case D.

Discussion of Simulation Results

For each of the cases modeled, the DLT intersection consistently outperformed the conventional intersection with respect to vehicle throughput, vehicle delay, number of stops, and queue length. The average vehicle delay and queue estimation models can help traffic engineers and planners compare the DLT intersection with other types of intersections to measure suitability of application, especially when traffic congestion at the intersection is a serious problem. The results of the operational analysis are summarized below.

The operational improvement of the DLT intersection over the conventional intersection was notable even at relatively low traffic volumes, but greater benefits were achieved with the DLT intersection design as traffic volumes increase. The reduction in number of phases for those approaches with the DLT intersection significantly reduced vehicle delay and increased the capacity of the intersection considerably. In addition, the percent reduction in average intersection delay for a DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are balanced as follows:

- Case A: 48–85 percent
- Case B: 58–71 percent
- Case C: 19–90 percent
- Case D: 54–78 percent

The percent reduction in average intersection delay for a DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are unbalanced as follows:

- Case A: 82 percent
- Case B: 70 percent
- Case C: 69 percent
- Case D: 72 percent

The percent reduction in average intersection delay for the partial DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are balanced as follows:

- Case A: 39 percent
- Case B: 36 percent

The percent reduction in average intersection delay for the partial DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are unbalanced as follows:

- Case A: 30 percent
- Case B: 30 percent

The percent reduction in the average number of stops for the DLT intersection compared to a conventional intersection is 15–30 percent for nonsaturated traffic flows at the conventional intersection and 85–95 percent for saturated traffic flow conditions at the conventional intersection.

The percent reduction in average intersection queue length for a DLT intersection compared to a conventional intersection is shown for each simulated case as follows:

- Case A: 62–88 percent
- Case B: 66–88 percent
- Case C: 34–82 percent
- Case D: 64–86 percent

The percent increase in throughput of the intersection for a DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are balanced as follows:

- Case A: 30 percent
- Case B: 30 percent
- Case C: 16 percent
- Case D: 30 percent

The percent increase in throughput of the intersection for a DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are unbalanced as follows:

- Case A: 25 percent
- Case B: 25 percent
- Case C: 12 percent
- Case D: 25 percent

The percent increase in throughput of the intersection for the partial DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are balanced as follows:

- Case A: 20 percent
- Case B: 20 percent

The percent increase in throughput of the intersection for a partial DLT intersection compared to a conventional intersection is shown for each simulated case when mainline flows are unbalanced as follows:

- Case A: 14 percent
- Case B: 10 percent

It is important to note that all cases had signal timings adjusted for pedestrian presence. In the absence of pedestrians, cycle lengths can be lowered resulting in average intersection delay in the range of 14–19 s/veh at low and medium traffic volumes for case A.

Even with a single signal timing, the DLT intersection works effectively for all combinations of traffic flows (low, medium, and heavy). This is unique and can be useful for intersections that cannot implement multiple signal timing plans.

Appendix C **MARKETING AND OUTREACH MATERIALS**

This appendix provides some examples of DLT Public Outreach Material Examples.

FHWA has created alternative intersection and interchange informational videos and video case studies, which can be viewed on the FHWA YouTube channel (<https://www.youtube.com/user/USDOTFHWA>).

In addition, FHWA has developed alternative intersection brochures that can be found on the FHWA website (<http://safety.fhwa.dot.gov>). An example of the displaced left turn intersection brochure is shown below.

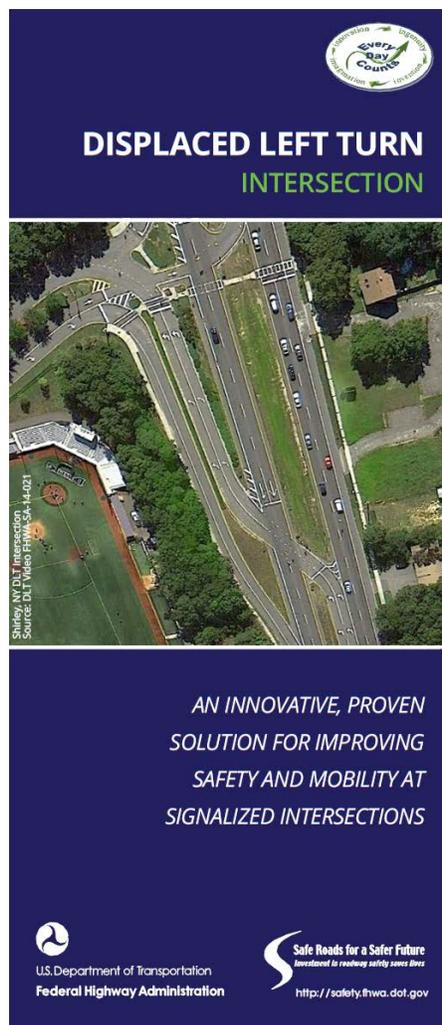


Exhibit C-1. FHWA Displaced Left Turn Intersection Brochure.

Several examples from state and local agencies are provided below, although various others are available online for additional information and guidance.

Educational Videos

Several agencies have developed educational videos as part their outreach with DLTs. Examples weblinks are provided below for access to these videos.

- UDOT DLT - <http://www.youtube.com/watch?v=oVI3Ledw7mc>
- UDOT DLT Tutorial - http://www.youtube.com/watch?v=_dB25GPPdeU
- UDOT DLT Interactive Map - http://i15core.utah.gov/flash/interchange_diagrams/universityparkway/
- MoDOT DLT - <http://www.modot.org/stlouis/links/ContinuousFlowIntersections2.htm>
- CDOT DLT - http://www.coloradodot.info/projects/us160_us550durangocfi/video.html

Brochures and Fact Sheets

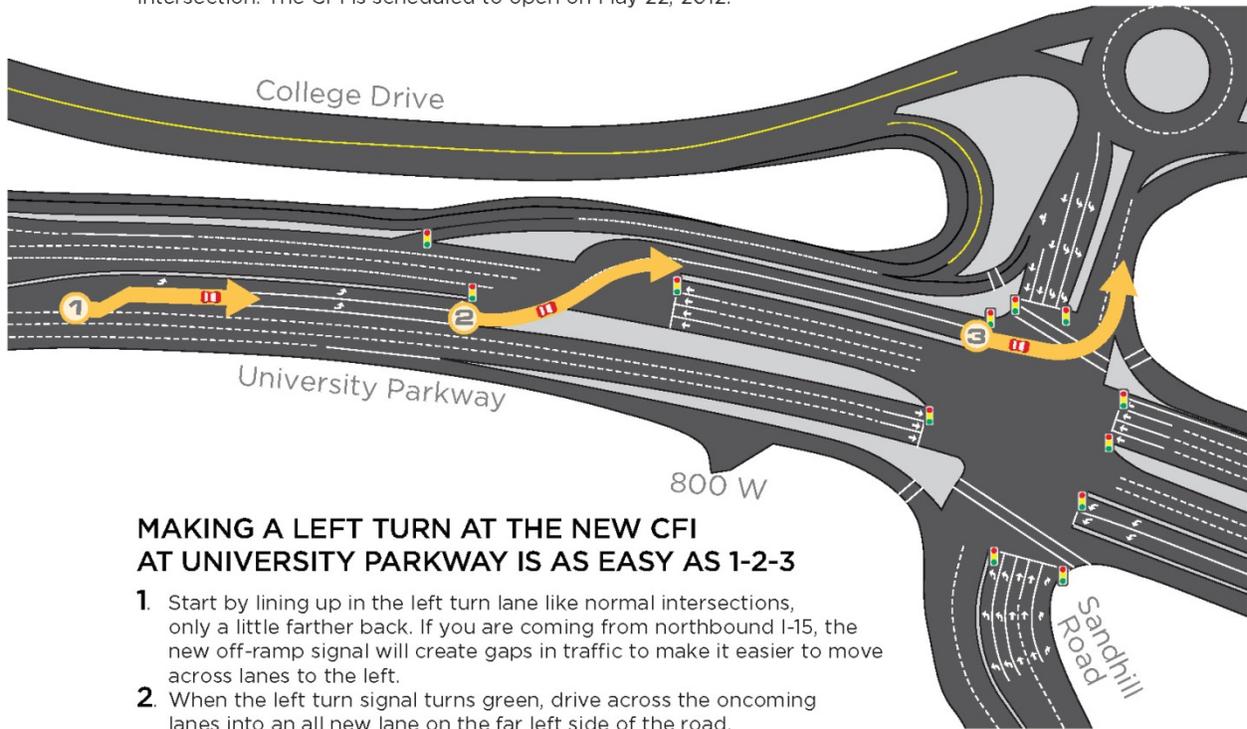
- Exhibit C-2 illustrates a fact sheet on how to navigate a DLT from the I-15 CORE project in Utah County, UT.
- Exhibit C-3 illustrates a project website for the CDOT US 160/US 550 Durango DLT intersection in Durango, CO.
- Exhibit C-4 illustrates a graphical illustration of the CDOT US 160/US 550 Durango DLT intersection in Durango, CO.
- Exhibit C-5 illustrates a fact sheet of a DLT project with TxDOT.
- Exhibit C-6 illustrates page one of a two-page brochure for a DLT project in Illinois.
- Exhibit C-7 illustrates page two of a two-page brochure for a DLT project in Illinois.



GO WITH THE FLOW

HOW TO NAVIGATE A CONTINUOUS FLOW INTERSECTION (CFI)

As part of the I-15 Corridor Expansion (I-15 CORE), UDOT is redesigning the intersection at University Parkway and Sandhill Road. This new Continuous Flow Intersection (CFI) is the first of its kind in Utah County and will increase the number of vehicles that can move through the intersection. The CFI is scheduled to open on May 22, 2012.



MAKING A LEFT TURN AT THE NEW CFI AT UNIVERSITY PARKWAY IS AS EASY AS 1-2-3

1. Start by lining up in the left turn lane like normal intersections, only a little farther back. If you are coming from northbound I-15, the new off-ramp signal will create gaps in traffic to make it easier to move across lanes to the left.
2. When the left turn signal turns green, drive across the oncoming lanes into an all new lane on the far left side of the road.
3. Another left turn signal will then tell you when you can go ahead and make your left turn.

GOING STRAIGHT:	RIGHT TURNS:	LEFT TURNS (onto University Parkway):
Proceed as you normally would, but watch for another light just past the intersection. It's possible to encounter a red light here, which allows left-turning cars to cross in front of you.	Be sure to yield to traffic, cyclists and pedestrians. Make your turn, merge with traffic and keep on going.	Proceed just like a normal intersection, but watch for another light just past the intersection. You may see a red light here, which allows left-turning cars to cross in front of you.

Hotline 1.888.i15core (415.2673) | Email i15core@utah.gov | Website udot.utah.gov/i15core A UDOT Project

Exhibit C-2. Fact sheet on how to navigate a DLT from the I-15 CORE project in Utah County, UT.

Displaced Left Turn Informational Guide

US 160/US 550 Durango Continuous Flow Intersection

The Colorado Department of Transportation (CDOT) began work on its first Continuous Flow Intersection (CFI) project on Monday, March 17, 2014, at the US 160/550 west intersection in Durango. The CFI is a proven and promising approach to reducing congestion and increasing safety at high-traffic intersections, based on other CFIs constructed nationwide.

A CFI effectively removes a left turn movement from an intersection by re-configuring the highway to allow vehicles to cross to the left side of the highway in advance of the intersection, allowing for longer green times for southbound and eastbound movements. Vehicles traveling northbound on US 550 (from Walmart, for example) turning left onto westbound US 160 (to Cortez) will utilize a new signal to turn in advance of the current stoplight, cross southbound traffic to a new separated cross southbound traffic to a new separated lane, and complete their turn onto US 160 from the new lane.

The total construction cost of the CFI is estimated at \$6.1 million; the work was contracted to Concrete Works of Colorado.

Please see specific project details posted to the NEIS link at left.

Project Schedule & Anticipated Travel Impacts: The work is expected to last through mid-August 2014. Single lane closures Monday through Friday during day- and nighttime hours are possible. No weekend work is currently anticipated. More information about travel impacts will be sent to those signing up for updates and posted on this project web site or check CDOT's weekly lane closure report here and click on SW Colorado.

Sign up for project updates: The best way to stay up to date on project progress, traffic impacts and more is to sign up for email and/or wireless (text) alerts. Click on the green cell phone icon in the upper right hand corner of this page and choose "US 160/550 Durango" under the "projects" list.

Graphic provided courtesy of the Durango Herald.

Exhibit C-3. Project website for the CDOT US 160/US 550 Durango DLT intersection in Durango, CO.

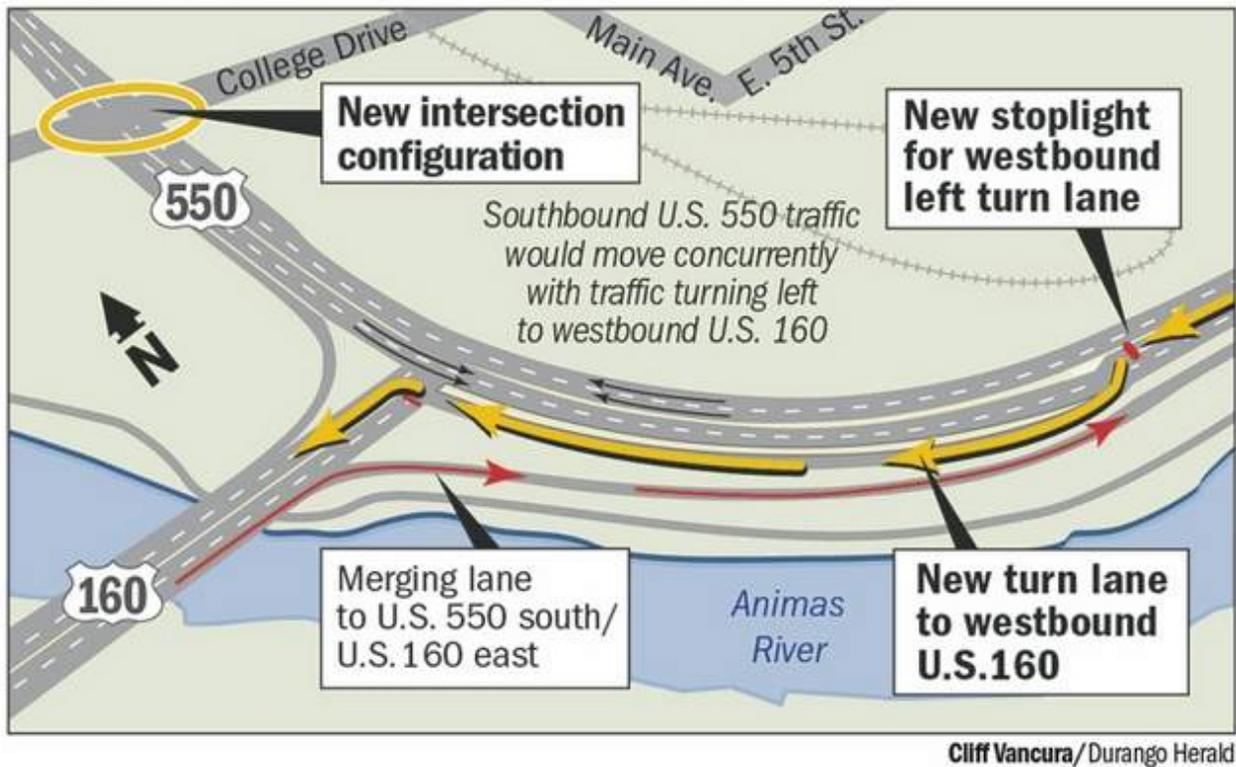


Exhibit C-4. Graphical illustration of navigating the DLT for the CDOT US 160/US 550 Durango DLT intersection in Durango, CO.



**Continuous Flow Intersections
FACT SHEET**

Continuous Flow Intersections

A continuous flow intersection, or CFI, is a new, innovative intersection that allows vehicles to travel more efficiently through an intersection. A CFI enhances safety and increases traffic flow through intersections by allowing left-turning traffic and thru-traffic to move simultaneously.

Traditional intersections have left-turning traffic in the middle of the road, so thru-traffic must wait for those vehicles to turn. A CFI shifts left-turning traffic to the outside edges of the road, which allows thru-traffic to move through the middle of an intersection and left-turning traffic to move simultaneously along the outside edges of the intersection.

Driving in a Continuous Flow Intersection

Existing CFI's have proven easy for drivers to understand and navigate. If turning left, mid-block traffic signals allow drivers to shift to the left side of the road to prepare for the left-turn movement. Drivers move through the mid-block traffic signal to the far left side of the road, and then make their left-turn at the main intersection. After proceeding through the intersection, left-turning traffic then returns to driving on the right side of the road.

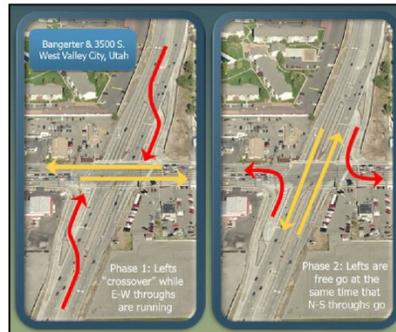
Thru-traffic proceeds as it would in a typical intersection. Right-turning traffic uses the right lane or a right-turn lane, like a typical intersection. In some cases, CFI's do not allow right turns on red.



Advantages of a Continuous Flow Intersection

A CFI enhances safety and mobility by reducing potential crash points at intersections, and by allowing more cars to move through an intersection. Because a CFI allows for more efficient movement, this type of intersection can reduce delays and travel time. Other benefits of CFI's include:

- Enhanced safety because of fewer potential crash points
- Improved travel time
- Allows more vehicles to pass through an intersection
- Low cost improvement
- Less right-of-way needed than adding lanes
- Quicker and cheaper to implement, compared with building overpasses or underpasses



Contact Information

For further information, please contact:
Kelli Reyna
Public Information Officer
TxDOT Austin Office
512-832-7060
Kelli.Reyna@txdot.gov

BENEFITS OF CFI

EFFICIENT TRAFFIC FLOW

- Reduced number of traffic signal phases, delay times, and queue lengths
- Improved level of service at the intersection
- Relief to entire system by reducing overall network delay
- Provides for more continuous movements

SAFETY IMPROVEMENTS

- Eliminates the conflict between left-turning and oncoming traffic at the MAIN Intersection
- Fewer conflict points
- Potential to decrease congestion-related collisions as a result of reduced "stop-n-go" conditions
- Clear lines of sight

REDUCTION IN POLLUTION & FUEL USE

- Reduced congestion and delay associated with the CFI results in less fuel consumption and fewer vehicle emissions

SMALLER DESIGN FOOTPRINT

- Less right-of-way required than a grade-separated alternative

COST SAVINGS

- Less costly than grade-separated alternatives

COMMUNITY BENEFITS

- More aesthetically pleasing than a grade-separated alternative



Any questions or comments regarding the Continuous Flow Intersection being evaluated as part of the Randall Road Improvements Study may be directed to:

Joseph R. Korpalski, Jr., PE
 Director of Transportation/County Engineer
 McHenry County Division of Transportation
 16111 Nelson Road
 Woodstock, Illinois 60098
 Phone: 815.334.4960
 Fax: 815.334.4989



www.randallroad.info

Randall Road Improvements Study

CONTINUOUS FLOW INTERSECTIONS

What You Need To Know



Two-Leg CFI at Siegen Lane & US61/Airline Highway in Baton Rouge, LA
(Source: Google Maps, 2008)



www.randallroad.info

Exhibit C-6. Page one of a two-page brochure for a DLT project in Illinois.

INTRODUCTION

The McHenry County Division of Transportation is studying improvements to Randall Road between County Line Road and Ackman Road. The Purpose & Need for the Study is to identify a transportation system improvement that will enhance mobility and local access while addressing safety issues, community values, and minimizing environmental impacts within the Study Area.

The Study includes evaluating improvements to the corridor and several intersections. One major intersection that requires improvements is the Randall Road and Algonquin Road Intersection. The Preferred Alternative for this intersection is a **Two-Leg Continuous Flow Intersection (CFI)**.

ABOUT RANDALL ROAD...

The corridor extends 3.5 miles along Randall Road through Crystal Lake, Lake in the Hills, and Algonquin, IL. The existing conditions of the corridor include:

- Randall Road: Four-lane undivided highway
- 11 intersections along corridor
- Major intersection at Randall Road and Algonquin Road.

Following an extensive alternatives analysis process that included meetings with stakeholders and the public, a **Preferred Alternative** was identified:

- Widen Randall Road to a 6-lane divided roadway
- Implement a **Two-Leg Continuous Flow Intersection** at the Randall Road at Algonquin Road Intersection
- Improvements to other intersections including a Continuous Green T Traffic Signal at the Randall Road at Village Road Intersection
- Access modifications to improve traffic flow and safety

DESCRIPTION

Continuous Flow Intersections (CFI) are a type of intersection that allows left-turning and through traffic to complete their movements simultaneously. This is achieved by having left-turning vehicles cross over oncoming traffic several hundred feet before the MAIN Intersection Traffic Signal. Three individual traffic signals are required: 2 MID-BLOCK Traffic Signals & 1 MAIN Intersection Traffic Signal.

Continuous Flow Intersections have gained support as an Alternative to a traditional signalized intersection and grade-separated intersections. Over 40 CFIs have been constructed worldwide, with a few in the U.S. and the majority in Mexico. Within the U.S., the State Departments of Transportation in New Jersey, Maryland, Louisiana, Utah, and Missouri have constructed CFIs. Ohio, Arkansas, and Texas are currently evaluating CFIs.

FEATURES

MAIN Intersection Traffic Signal - - - - -

- Left-turning and through movements operate simultaneously
- Through traffic does not have to stop for turning vehicles at the MAIN Intersection Traffic Signal

MID-BLOCK Traffic Signals - - - - -

- Used to cross left-turning traffic over to the opposite side of oncoming traffic

LEFT TURN Bays - - - - -

- Situated at the MID-BLOCK & MAIN Intersection Traffic Signals

NAVIGATING A CFI



Source: Utah Department of Transportation

THROUGH Movement:

- Separated from left & right turn lanes using concrete barriers or traffic island
- Does not stop for left-turning vehicles at MAIN Intersection Traffic Signal
- Through traffic proceeds into intersection at the same time as opposing left turning traffic without stopping



Source: Utah Department of Transportation

LEFT TURNS:

- Wait several hundred feet behind the MAIN Intersection Traffic Signal at the MID-BLOCK Traffic Signal
- Left-turning vehicles cross over oncoming traffic and hold in the left turn bay
- Left-turning vehicles can complete their turn onto the cross street upon green light



Source: Utah Department of Transportation

RIGHT TURNS:

- Enter right turn bays and complete turning maneuver into a designated acceleration lane
- Designated acceleration lanes merge with cross street traffic upstream of the MID-BLOCK Traffic Signal

Exhibit C-7. Page two of a two-page brochure for a DLT project in Illinois.

Appendix D SUPPLEMENTAL CONSTRUCTION AND DESIGN DETAILS

This appendix presents construction sequencing options for consideration during the construction of DLT intersections. Work zone traffic control plans were obtained for the construction of DLT intersections in Louisiana and Utah and are described below.

Sequence of Construction for DLT intersection in Baton Rouge, LA

The sequence of construction for the intersection of Airline Highway and Siegen Lane in Baton Rouge, LA, was obtained from the Louisiana Department of Transportation and Development (LA DOTD). An aerial photo of this intersection is shown in Exhibit D-1.



Exhibit D-1. Four-legged DLT intersection with major street displaced lefts and channelized right turns (Baton Rouge, LA).⁽¹⁾

For the purposes of this phasing sequence example, the north-south roadway will be referred to as the major road where left-turn crossovers were installed. The east-west roadway is the minor road, and the approaches were constructed in a manner similar to a conventional intersection. There were three phases of construction, which are discussed below.

Phase I

- Installation of temporary signal heads, poles, and new controllers at the main intersection, the minor intersection with frontage road, and the left-turn crossovers. (During phase II, installation of fiber optic interconnect cable for new signal system was also initiated.)

- Construction of frontage roads for DLT intersection lanes, new driveways along frontage roads, and turnouts.
- Construction of right-turn lanes along major roads, left-turn lanes along major roads, right-turn lane for frontage roads in southeast quadrant, and crossovers.
- Placement of permanent striping on southwest frontage roads. Temporary traffic signals operated on a new controller.

Phase II

- Installation of new signal poles at the main intersection, the minor intersection with a frontage road, and the left-turn crossovers. New signal heads on mast arms remain covered until placed in operation.
- Installation of permanent signing, high mast pole lighting, temporary striping for right-turn lanes along major roads (northbound), and temporary striping for turnouts.
- Construction of island on the service road and its temporary striping and signal heads.
- Construction of left-turn lanes along the median edge of major roads (northbound), right-turn lanes on the minor roads (eastbound), and left-turn DLT intersection lanes on the major roads (northbound).

Phase III

- Placement of permanent signals and removal of temporary signal systems at the main intersections.
- Installation of temporary striping on DLT intersection lanes.
- Removal of left-turn lanes and the construction of islands in the median of major roads between the two left-turn crossovers.
- Completion of islands at main intersections and remaining wearing course and permanent striping.

Sequence of Construction for DLT intersection in Salt Lake City, UT

Work on the DLT intersection in Salt Lake City, UT, began in March 2007, and the intersection opened to the public on September 16, 2007. A portion of the construction sequence was obtained from the Utah Department of Transportation (UDOT) Web site and is shown as follows:

Winter 2007

- Work began on the northeast and southwest corners of the intersection.

- The first noticeable traffic impact was the closure of right lanes in each direction near the intersection.
- Crews placed construction fencing, cleared two development on adjacent sites, and removed a section of the sound barrier wall.
- Some excavation and utilities work took place.

Spring 2007

- Excavation and utility work continued.
- Crews began concrete work and paving.

Summer 2007

- Crews completed concrete work and paving.
- New signals were installed.

Construction work was completed at this intersection by closing it off completely and utilizing the existing network to detour traffic. Detour signs were placed according to typical designs and were located 350 ft ahead of the upstream intersection. Exhibits D-2 and D-3 illustrate the detour routes as well as detour signing used during the work.

Displaced Left Turn Informational Guide

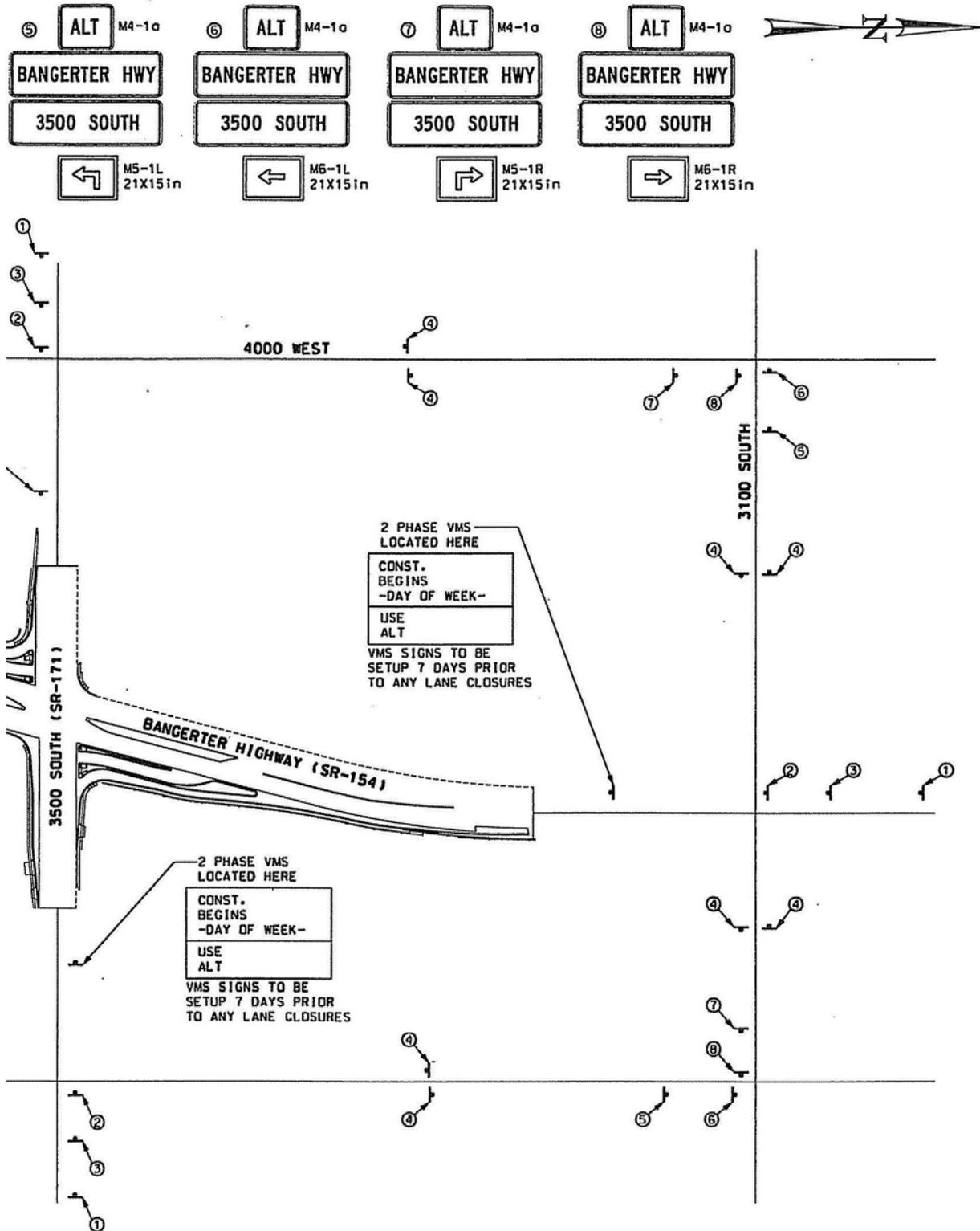


Exhibit D-2. Illustration. Detour routes for construction of a DLT intersection in Salt Lake City, UT—north end.

Displaced Left Turn Informational Guide

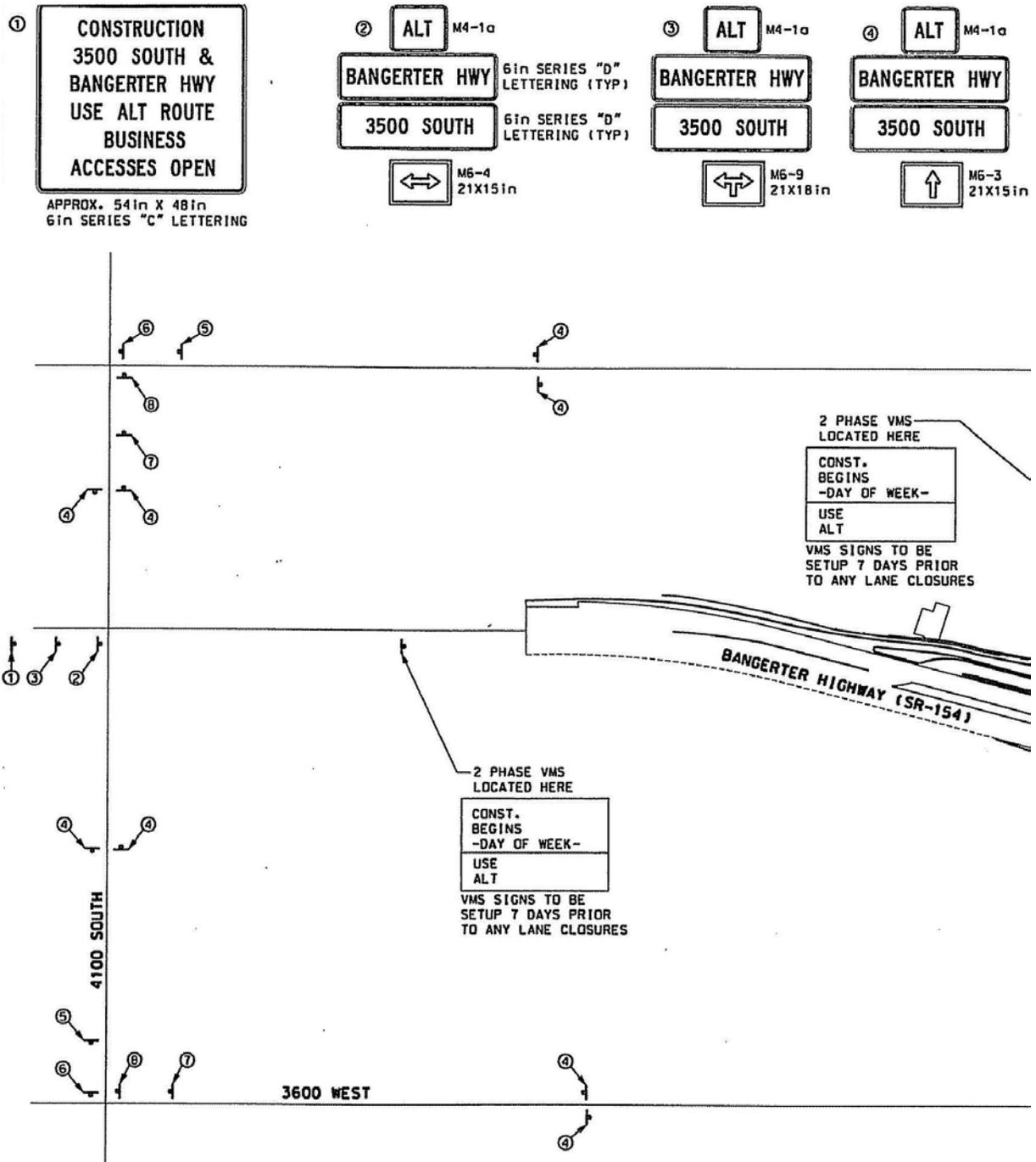


Exhibit D-3. Illustration. Detour routes for construction of DLT intersection in Salt Lake City, UT—south end.

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