

# Memorandum

*Making Conservation  
a California Way of Life.*

To: DISTRICT DIRECTORS  
DEPUTY DIRECTORS  
DIVISION CHIEFS

Date: December 14, 2017



From: JANICE BENTON  
Chief  
Division of Design

Subject: **DESIGN INFORMATION BULLETIN (DIB) 90**

DIB 90, "Diverging Diamond Interchange" is now available on the Division of Design website: <[www.dot.ca.gov/design/stp/dib/dib90.pdf](http://www.dot.ca.gov/design/stp/dib/dib90.pdf)>. For projects where the project development process has started, follow the procedures in the Highway Design Manual (HDM) Index 82.5 "Effective Date for Implementing Revisions to Design Standards."

## KEY CONCEPTS:

This Diverging Diamond Interchange (DDI) guidance issued is consistent with the Federal Highway Administration's technical publication, Diverging Diamond Interchange Informational Guide. The following is a summary of key concepts:

- The DDI configuration supplement the configurations provided in the Highway Design Manual and other Department guidance.
- The DDI is a viable alternative to conventional interchange forms.
- The primary difference between a DDI and a conventional diamond interchange is the design of the ramp terminal intersections.
- Directional crossover intersections on either side of the DDI divide and transpose the directions of local road traffic between the signalized crossover intersections.
- DDIs remove left-turning movements to and from the freeway facility at the signalized intersections.

Project specific applicability and questions should be referred to the Division of Design, Project Delivery Coordinators.

c: Antonette Clark, Chief, Office of Standards and Procedures  
Brian Frazer, Office of Project Support  
Project Delivery Coordinators

# DESIGN INFORMATION BULLETIN NUMBER 90

Department of Transportation  
Division of Design  
Office of Standards and Procedures

## DIVERGING DIAMOND INTERCHANGE

APPROVED BY:



---

JANICE BENTON  
DIVISION CHIEF  
DIVISION OF DESIGN

December 14, 2017

# Table of Contents

<b>1.0 INTRODUCTION.....</b>	<b>1</b>
1.1 DEFINITIONS & TERMS .....	3
1.2 KEY DESIGN CONCEPTS OF A DDI.....	3
1.3 HISTORY.....	3
1.4 KEY BENEFITS OF A DDI.....	3
1.5 CONCERNS WITH DDI.....	5
<b>2.0 DDI DESIGN CRITERIA.....</b>	<b>6</b>
2.1 APPROVALS .....	6
2.2 DEFINITION OF BOUNDARY OF DDI.....	7
2.3 DESIGN SPEED.....	7
2.4 SIGHT DISTANCE .....	8
2.5 DRIVER EXPECTATION AND DECISION SIGHT DISTANCE .....	8
2.6 HORIZONTAL ALIGNMENT AND SUPERELEVATION .....	9
2.7 LANE WIDTH.....	9
2.8 SHOULDER WIDTH.....	9
2.9 INTERSECTION GRADE.....	9
2.10 ANGLE OF INTERSECTION .....	10
2.11 TANGENT THROUGH CROSSOVER.....	13
2.12 THROUGH PATH .....	14
2.13 INTERSECTION SPACING.....	17
2.14 ON-RAMP MERGE .....	17
2.15 PEDESTRIANS FACILITIES .....	17
2.16 ACCOMMODATING BICYCLES.....	19
2.17 ACCESS MANAGEMENT .....	19
<b>3.0 OPERATIONAL CONSIDERATIONS .....</b>	<b>20</b>
3.1 SIGNAL TIMING .....	20

## List of Figures

<b>Figure 1.0A</b>	<b>Key Characteristics of a DDI .....</b>	<b>1</b>
<b>Figure 1.0B</b>	<b>One Signal Phase .....</b>	<b>2</b>
<b>Figure 1.0C</b>	<b>Other Signal Phase .....</b>	<b>2</b>
<b>Figure 2.2</b>	<b>Boundary of the DDI.....</b>	<b>7</b>
<b>Figure 2.10A</b>	<b>Line of Sight – Right-Turn .....</b>	<b>11</b>
<b>Figure 2.10B</b>	<b>Line of Sight – Left-turn .....</b>	<b>11</b>
<b>Figure 2.10C</b>	<b>Off-Ramp Intersection Angle - Right Turn .....</b>	<b>12</b>
<b>Figure 2.10D</b>	<b>Off-Ramp Intersection Angle – Left Turn .....</b>	<b>12</b>
<b>Figure 2.11</b>	<b>Path Overlap .....</b>	<b>13</b>
<b>Figure 2.12A</b>	<b>Through Path – Preferred .....</b>	<b>15</b>
<b>Figure 2.12B</b>	<b>Through Path – Undesirable .....</b>	<b>16</b>
<b>Figure 2.15A</b>	<b>Center Walkway .....</b>	<b>18</b>
<b>Figure 2.15B</b>	<b>Outside Walkway .....</b>	<b>18</b>

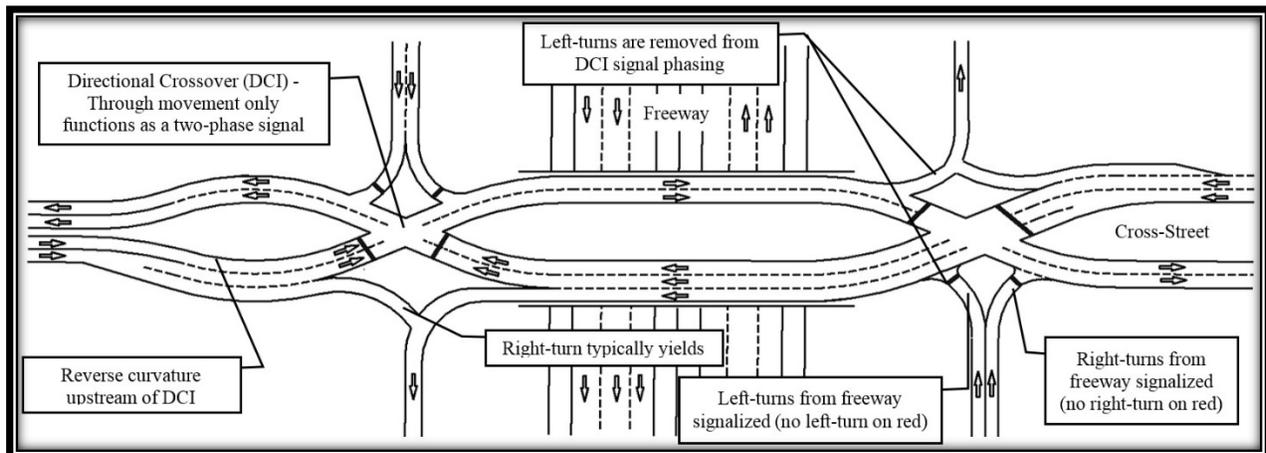
## List of Photos

<b>Photo 1</b>	<b>Example of Path Overlap.....</b>	<b>14</b>
<b>Photo 2</b>	<b>Adequate Overlap of Eyebrow .....</b>	<b>15</b>
<b>Photo 3</b>	<b>Inadequate Overlap of Eyebrow .....</b>	<b>16</b>
<b>Photo 4</b>	<b>Wide Central Walkway w/ Column.....</b>	<b>18</b>
<b>Photo 5</b>	<b>Central Walkway w/ High Barrier .....</b>	<b>19</b>

## 1.0 INTRODUCTION

California Department of Transportation (Caltrans) values innovation and seeks creative solutions. The diverging diamond interchange (DDI), is proving to be an efficient interchange configuration. The DDI is a viable alternative to conventional service interchange forms, such as a partial cloverleaf interchange. The primary difference between a DDI and a conventional diamond interchange is the design of the ramp terminal intersections. Directional crossover intersections (DCI) on either side of the interchange divide and transpose the directions of local road traffic between the signalized crossover intersections. Vehicles on the local road making a left-turn to or from the ramps do not conflict with vehicles approaching from other directions. Figure 1.0A shows the key characteristics of the DDI. The DDI design improves the operation of the ramp terminal intersection by removing left-turning movements to and from the freeway facility at the signalized intersections. See Figures 1.0B and 1.0C for typical phasing configurations of the DDI's two-phase traffic signal.

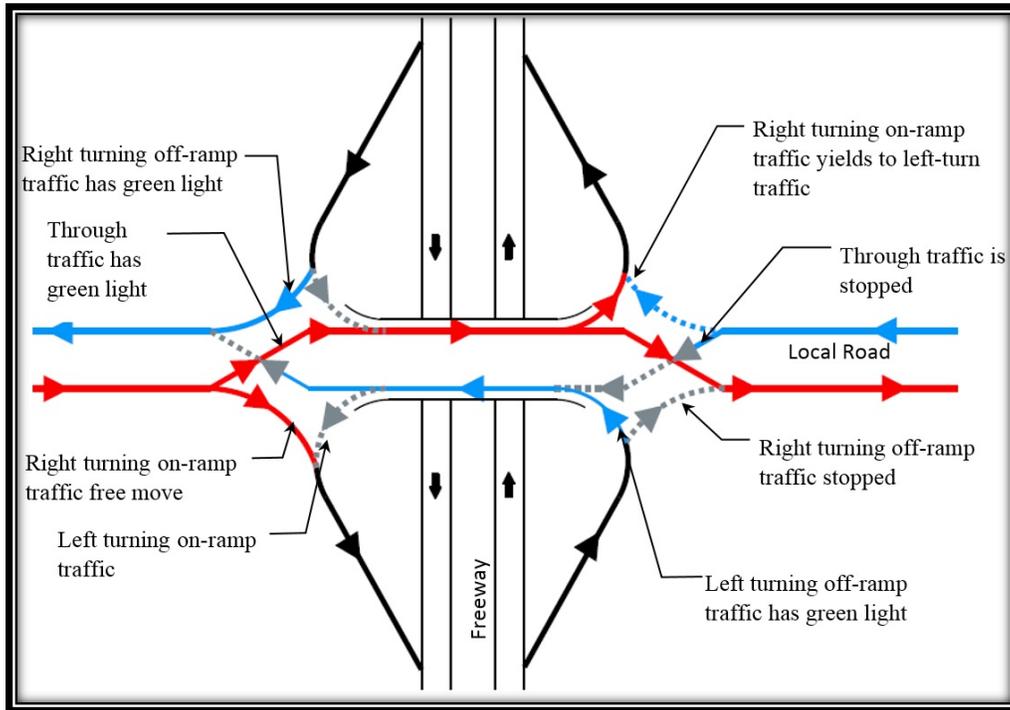
**Figure 1.0A**  
**Key Characteristics of a DDI**



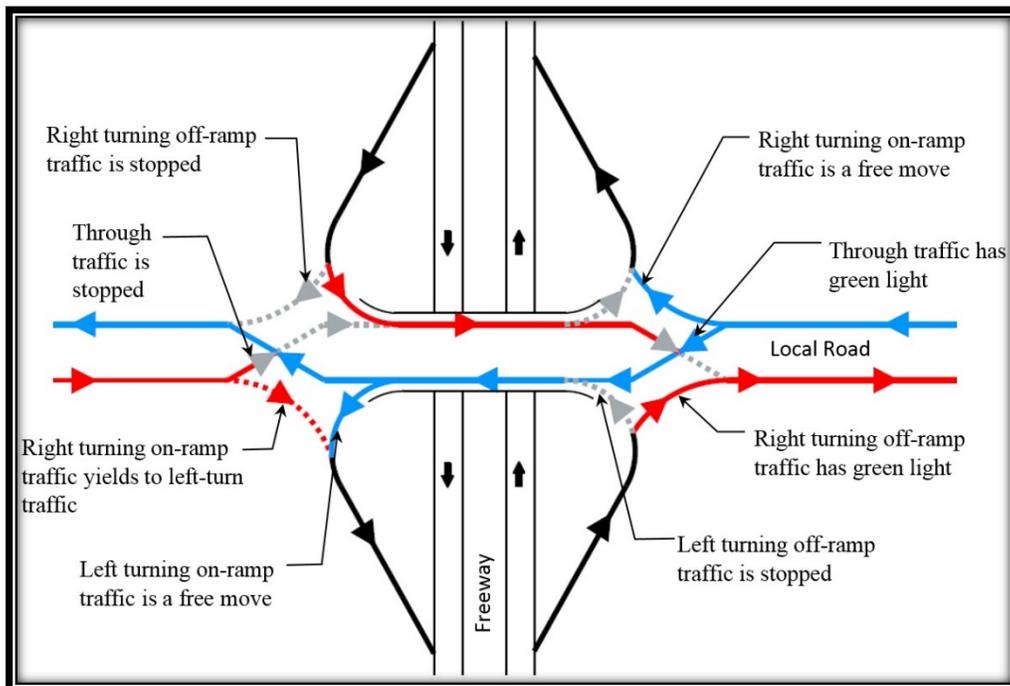
DDIs also improve safety by reducing the number of vehicle-to-vehicle, vehicle-to-pedestrian, and vehicle-to-bicycle conflict points at the ramp terminal intersections, as compared to a conventional diamond interchange. A recent study by the Transportation Research Board, *Safety Evaluation of Seven of the Earliest Diverging Diamond Interchanges Installed in the US*, shows that converting a traditional diamond interchange to a DDI reduced collisions by 33 percent and injury collisions by 41 percent.

The DDI configuration supplements the configurations provided in the Highway Design Manual (HDM) and other Department guidance, which supports our mission of providing a safe, sustainable, integrated and efficient transportation system.

**Figure 1.0B**  
**One Signal Phase**



**Figure 1.0C**  
**Other Signal Phase**



## 1.1 Definitions & Terms

Directional Crossover Intersections (DCI): a signalized intersection divides and transposes local road traffic to the opposite side within the interchange.

Eyebrow: The portion of the island separating the two roadways approaching the DCI and the left-turn and right-turn on-ramp that separates the two approaching through traffic lanes. See Figure 2.12A.

## 1.2 Key Design Concepts of a DDI

Design speeds may be lower ( $\leq 35$  miles per hour) for DDIs than a conventional interchange, with the intent to reduce vehicle speed at conflict points; thereby, reducing collision severity.

The crossover design divides and transposes local road traffic to the opposite side of the street between the signalized crossover intersections; as a result, vehicles making a left-turn to and from ramps do not conflict with vehicles approaching from the other directions.

The DCIs and the configuration of ramp connections to the local road place traffic in locations that are different from other interchanges and may create situations where on-coming vehicles are not where drivers or pedestrians may expect them to be. Sight distance and sight lines are important considerations. Designers should provide geometrics that support drivers to look at the appropriate locations for conflicts, while impeding locations where drivers may be incorrectly expecting traffic.

With the efficiency of the DDI operation, the proximity of the DCI to adjacent signalized intersections is critical to the operation of the DDI.

## 1.3 History

Three DDIs have existed in France for decades, with the first built in Versailles in the 1970's. The original inventors are unknown at this time, but in July 2003, a paper entitled *New Interchange and Intersection Designs: The Synchronized Split-Phasing Intersection and the Diverging Diamond Interchange*, was presented to the 2nd Urban Street Symposium in Anaheim, California. FHWA attended the presentation, which led to further study with sponsored research. After a few false starts, the first DDI outside of France was opened to traffic at the Interstate 44 and State Route 13 interchange in Springfield, Missouri on June 21, 2009. Missouri Department of Transportation then opened a second DDI approximately a year later at the Interstate 60 and National Avenue interchange, also in Springfield. Later in 2010, the Utah DOT opened a DDI at the Interstate 15 and Main Street interchange in American Fork.

As of July 2017, there are 89 DDIs in operation in 29 states throughout the country, 5 of which were opened in 2017. The current number and locations of existing DDIs in the country are described on the following website: <http://www.divergingdiamond.com/>.

## 1.4 Key Benefits of a DDI

*Intersection Operations (Reduced Delay):*

By separating the two directions of local road traffic and transposing them between the DCIs, separate left-turn movements are eliminated from the DCI signal phasing. Traffic signals at DDIs

operate with two-phase intervals compared to three or more phases at conventional diamond interchanges. This reduction in phase intervals allows for longer green time for each phase, improving overall throughput on the local road as well as turning movements. Therefore, the DDI operates efficiently, reducing delay and queueing.

#### *Intersection Safety:*

By transposing directions of local road traffic between the signalized DCI, vehicles making left-turns at on- or off-ramps do not conflict with vehicles approaching from other directions. Except for the crossing type conflicts at the DCIs, the remaining conflict points are merge/diverge type movements for turning traffic.

Local road traffic speeds are reduced through the interchange (desirably 35 miles per hour or less) with geometrics that encourage the speed reduction. DDIs reduce the number of crashes and crash severity by offering lower speed, fewer conflict points, and elimination of most crossing conflicts through the interchange.

#### *Bicycle/Pedestrian Safety:*

DDIs separate the conflict points between vehicles and non-motorized users so that only one direction of vehicular traffic is crossed at a time and the vehicular traffic focus should be on the road ahead. Vehicles at pedestrian crossings no longer need to look for a gap to make a turn nor need to look for other merging or diverging traffic. Bicycles will still have a vehicle conflict point at the right-turn pocket where the bicyclist continues from the shoulder and right-turning traffic crosses the bicycle path. Bicyclists and pedestrians do not have right-turning and left-turning vehicle conflicts at the DCIs. At the DCI, the two-phase traffic signal may provide a longer green time that provides more time per phase for bicyclists and pedestrians to cross the DCI. Pedestrian crossing distances are typically shortened at a DDI compared to other interchanges due to a reduction in turn lanes and because there is only one direction of traffic to cross at a time. While DCIs are signalized, the right- and left-turn movements to and from the freeway may not require signalization. Pedestrian crossings at unsignalized turn lanes may require alternative considerations such as enhanced sight lines between vehicles and pedestrians and using reduced curve radii or other geometric changes to reduce vehicle speeds.

#### *Reduced Construction Cost:*

In comparison to conventional diamond interchanges, where left-turning vehicles are stored between the two ramp terminals, DDIs require less storage because of the efficiency of left-turns onto the freeway. Therefore, the required structure width is reduced and can result in significant structure and right-of-way cost savings.

#### *Reduction of Freeway Wrong-Way Movements:*

DDIs channelize on- and off-ramps, which helps discourage wrong-way movements at exit ramps. If a wrong-way movement is made at a DCI, the vehicle would have to travel a distance before getting to a ramp and then make a maneuver to enter the freeway.

## 1.5 Concerns with DDI

### *Effect on Operation due to Adjacent Intersections:*

A concern of the DCI's two-phase traffic signals is that adjacent signalized intersections, which typically have more phases, may not be able to handle the increased throughput of traffic that is arriving from the DDI. Depending on the capacity of the local road intersection adjacent to the interchange and the distance between the intersections, there may be insufficient storage for vehicles, which could back up into the DCI and/or on- and off-ramps. Introducing intentional inefficiency in the DCI signal phasing could be a strategy to reduce the storage need for the adjacent intersection until the intersection could be improved, but this would require careful study.

### *Wrong-way Movements:*

To keep the DDI footprint small, the angle of intersection allowed at DCIs is much shallower than allowed at conventional intersections. This may introduce the added potential for wrong-way movements at the DCIs. Designers need to keep this in mind when balancing and optimizing trade-offs associated with performance, capacity, and costs along with right-of-way and environmental impacts.

### *Oversize Overweight (OSOW) Vehicles:*

DCIs do not readily accommodate a vehicle exiting and returning to the freeway to bypass vertical clearance issues associated with the crossing structure.

### *Larger Intersection:*

DDIs may require additional right-of-way or include increased environmental impacts as the footprint of the directional crossover intersections and ramp termini could be larger than that of a typical diamond interchange.

### *Line of Sight:*

Sight line considerations are unique at DCIs and ramp movements. DCIs create a situation where on-coming vehicles may not be where drivers would expect them to be. Designers should provide geometrics that encourage the driver to look at the appropriate location for conflicting vehicles and that discourages looking where they would typically be expecting traffic in a conventional interchange configuration. Section 2.10 provides more detailed guidance.

When DCIs are close to overcrossing structures, the structure barrier may obscure visibility to pedestrians crossing left-turning traffic. This may occur particularly when pedestrians are routed to the outside of the DDI rather than down the median. Wider right shoulders or unusual structure designs may be needed to provide sight lines between DCIs. See Chapter 3 of the Federal Highway Administration's (FHWA's) technical publication, *Diverging Diamond Interchange Informational Guide* (Guide) for more information.

The crest vertical curve of an overcrossing along with the median barrier of a center walkway may block sight lines to signal heads. The structure itself may block sight lines to signals on undercrossing interchanges if the structure vertical clearance is near the minimum and/or DCIs are close to the structure.

When the DCI is close to the overcrossing structure, intersection sight distance for right-turning off-ramps may be obstructed by the median barrier.

*Wider Cross Section:*

Although the DDI includes a median separation that may require a wider cross section and wider bridge structure, the efficiency of the two-phase DCI allows fewer lanes for vehicle storage at the intersection. See Chapter 7 of the Guide for design and cross section considerations.

*Prohibited U-Turn:*

Turning movements are prohibited at the DCI intersections since the turns to and from ramps have been separated from the intersection. This also prohibits U-turns. Users may have to travel through the DDI to the adjacent local road intersection to make a U-turn and proceed back through the DDI in order to complete a left turn.

## **2.0 DDI DESIGN CRITERIA**

Diverging diamond interchanges proposed on the State highway system must be developed and evaluated in accordance with the Federal Highway Administration's (FHWA's) technical publication, *Diverging Diamond Interchange Informational Guide* (Guide), the HDM, and this Design Information Bulletin (DIB). The Guide can be found at [http://safety.fhwa.dot.gov/intersection/alter\\_design/pdf/fhwasal4067\\_ddi\\_infoguide.pdf](http://safety.fhwa.dot.gov/intersection/alter_design/pdf/fhwasal4067_ddi_infoguide.pdf).

Many specific geometric features recommended by the Guide are inconsistent with the current standards in the HDM. To construct a DDI consistent with the Guide, several design exceptions would be required, per the HDM. This DIB provides additional guidance and relevant standards specific to DDI design, eliminating the need for HDM design exceptions within the boundary of the DDI to meet certain standards. The Guide and the HDM, along with this DIB, are to be used in the planning and design of DDIs on the State highway system. Where there are conflicting standards between the HDM and the Guide, this DIB will govern. For signing, pavement markings, and traffic signals for DDIs, see the California Manual of Uniform Traffic Control Devices (CA MUTCD) as well as Section 3.1

This DIB follows the nomenclature provided in HDM Index 82. Any deviation from geometric design standards in this DIB need to be approved in accordance with HDM Index 82.2, the Project Development Procedures Manual (PDPM) Chapter 21, Exceptions to Design Standards and the District Delegation Agreement. The standards in this DIB are not "new" standards, but are modifications to existing standards to adjust to design geometrics of DDIs.

DDI design involves balancing and optimizing performance objectives for all users, right-of-way impacts, environmental concerns, maintenance needs, construction staging, and costs, among other considerations. The goal is to increase person and goods throughput, highway mobility and safety in a manner that is compatible with, or which enhances adjacent community values and plans. Designers use this philosophy to provide a flexible design that is appropriate for the project.

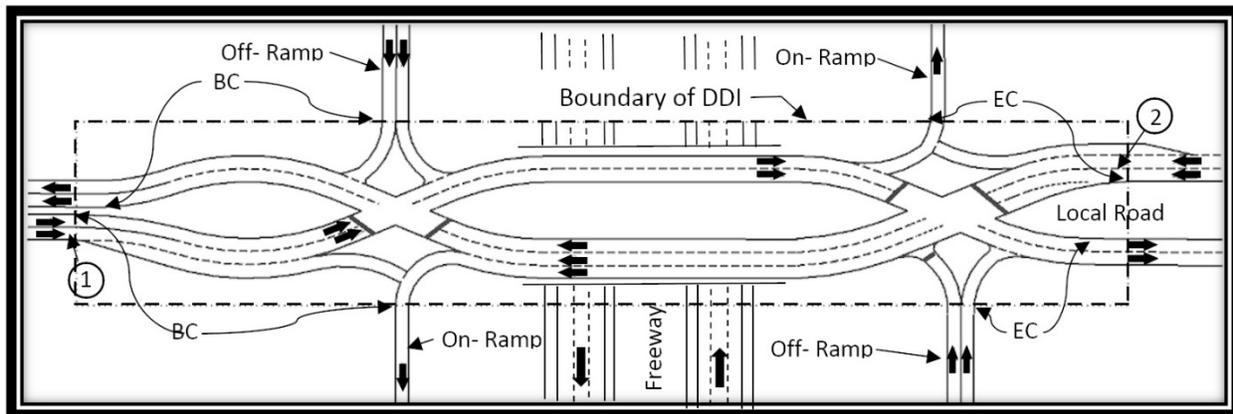
### **2.1 Approvals**

To be consistent with how a project development team selects an interchange type, DDIs require the same reviews and approvals as other interchange types as specified in HDM Index 503.2.

## 2.2 Definition of Boundary of DDI

The HDM design standards and guidance apply to DDI design within the boundary of the DDI except as indicated in this DIB. Figure 2.2 illustrates graphically the boundary of the DDI. From the left side of Figure 2.2, the boundary of the DDI is between the points where the two directions of traffic on the local road are no longer parallel to each other (Point 1) to the point where two opposing traveled ways are once again parallel on the opposite side of the interchange (Point 2). The boundary of the DDI, along the ramps, extends away from the local road to the farthest BC or EC of the curves connecting the ramps to the local road.

**Figure 2.2**  
**Boundary of the DDI**



## 2.3 Design Speed

The HDM and the Guide differ in design speed guidance for the local road within the boundary of the DDI. Chapter 7 of the Guide recommends a range of design speed from 25 to 35 miles per hour, to promote reduced and consistent speed through the interchange. Speed reduction through the interchange is achieved through horizontal geometric design, curvature and curbs. The Guide uses the same speed-radius chart that is used for roundabout design, but unlike roundabouts, it is not a “fastest path” performance check. The speed-radius chart applies to the lane striping for a target operating speed approach. See the Guide, Chapter 7, Design Guidance for more details.

The selected design speed will directly influence the reverse curve radii at the DCI approaches and the DDI channelization for turning movements. The curvature in advance of the DCI provides transition from the parallel movement of the two directions of travel along the local road to the formation of the crossover intersection with sufficient angle (see Section 2.10) to facilitate efficient passage through the crossover. In addition to providing the necessary approach angle through the crossover, the curvature also acts to control speeds and enhances safety performance. Existing right-of-way and environmental constraints, skew angle, alignment curvatures or offset alignment may make achieving curvature in advance of the DCI challenging. When making geometric design trade-offs it is preferable to provide the traffic approaching the DDI with curvature prior to the DCI, rather than the traffic departing the DDI. Lack of curvature in advance of the DCI should not be seen as a fatal flaw; mitigation such as signing and lighting can be used as a visual queue in advance of high speed approaches.

**Design speed shall range from 25 to 35 miles per hour within the boundary of the DDI. The horizontal alignment through the reversing curves on the local road shall correspond to a maximum design speed of 35 miles per hour.** The design speed of the horizontal curves from the ramps may be less than 25 miles per hour and may accommodate lower speeds in the realm of 15-20 mph, especially at pedestrian crossings. See Section 2.5 of this DIB for driver expectation and decision sight distance information.

## 2.4 Sight Distance

In addition to the stopping sight distance requirements in HDM Index 201, for horizontal and vertical alignments, lines of sight at the DCI and pedestrian crossings are key design considerations for a DDI.

Off-ramps with narrow left shoulder widths at the DCI approaches and curve radii less than 300 feet may result in the structure barriers or abutments impeding on the stopping sight distance length. A wider left shoulder may be needed from the left-turn off-ramp at the local road between the DCIs. Additionally, the left-turn from the local road to the on-ramp may need a wider shoulder to provide sufficient stopping sight distance for the pedestrian waiting to cross at an outside sidewalk. Check stopping sight distance for approach traffic to the pedestrian crossings as well as vehicle storage or waiting areas at uncontrolled on- and off-ramps.

The Guide's intersection sight distance (ISD) is different than the corner sight distance guidance of the HDM. The Guide has ISD values for a passenger car, single unit truck, and combination truck and are based on a vehicle entering the local road in a time gap of 8, 10, and 12 seconds, respectively. HDM Index 405.1 corner sight distance does not apply to DDIs. **ISD values in Exhibit 7-30 of the Guide shall apply to DDIs.** However, use HDM Index 405.1, for passenger car eye height and object height. For truck eye height use American Association of State Highways and Transportation Officials' (AASHTO's) *A Policy on Geometric Design of Highways and Streets, 2011* guidance of 7.6 feet. Use HDM Index 405.1 for driver set back at the intersection.

Designers should also confirm that the signal head is visible to approaching vehicles. The crest vertical curve of an overcrossing along with the median barrier of a center walkway can obstruct sight lines to the signal head. The structure itself can obstruct sight lines to signals on undercrossing interchanges, if the structure vertical clearance is near minimum and/or the DCIs are close to the structure.

Strategically placed, appropriate landscape/plantings can be used to block driver's views to where a driver would typically look for conflicting traffic (no longer necessary due to the DDI configuration) and directing their vision to where traffic will be coming from.

## 2.5 Driver Expectation and Decision Sight Distance

For the driver of a vehicle approaching the DCI from an overcrossing at a DDI, the DCI is offset to the driver's right, which is not consistent with driver expectation. The DDI also has the two directions of traffic approaching the crossover directly towards each other; therefore, the sight distance to the curb of the "eyebrow" is critical. HDM Index 201.7 applies to the eyebrow of the DDI.

## 2.6 Horizontal Alignment and Superelevation

As with roundabouts, speed control on the local road through the DDI crossover is an important component to the safety benefit of the DDI. Curvature, reversing curves, compound curves, tangent, and superelevation guidance in HDM Topic 202 and Topic 203, do not apply within the DDI boundary. The Guide's horizontal and speed-radius relationship controls horizontal alignment and cross slope design. See the Guide's Exhibit 7-14 for further horizontal alignment and superelevation guidance.

## 2.7 Lane Width

The geometric design of DDIs to control speed through the crossover intersections will typically result in curve radii of 300 feet or less, requiring wider lanes to accommodate truck off-tracking in all lanes not just the right-most lane. See HDM Index 301.1 and Table 504.3 for further information.

## 2.8 Shoulder Width

Considerations for shoulder width on the local road within the boundary of the DDI is also different. Since shoulders are typically less effective than raised curbs for channelizing vehicles through the crossover, wide shoulders are not recommended within the vicinity of the crossover to appropriately direct vehicles in the direction of travel, discouraging wrong-way movements.

### *Left shoulders:*

The left shoulder should be eliminated (width = 0 feet) at the approach to the DCI to discourage wrong-way movements and to appropriately direct vehicles. **Between crossover intersections, the left shoulder shall be 2 feet minimum, or wider if needed for sight distance, 4 feet preferred.**

### *Right shoulders:*

At the vehicle approaches to the DCI, the right shoulder should be only as wide as needed to accommodate bicycles. Wider shoulder width will require larger angles and/or longer tangents through the DCI to discourage wrong-way movement. See Sections 2.11 and 2.12 of this DIB for related information. **At vehicle approaches to and between DCIs, the right shoulder shall be a minimum of 4 feet wide when vertical elements, such as curb or guardrail are present, or 3 feet measured from the stripe to the joint between the shoulder pavement and the gutter.** Between DCIs, 6-foot shoulders are preferred next to traffic barriers.

Shoulder widths at the vehicle departure side of the DCI, ramps, and left- and right-turn lanes to or from the ramps are to follow HDM Index 302.1.

## 2.9 Intersection Grade

HDM Index 504.3 (3) does not apply to the directional crossover intersections.

HDM Index 204.3 applies within the boundary of the DDI. Grades within the DCI and within 50 feet of the approaches and departures of the DCI should not be more than 5 percent; this provides a facility that does not require vehicles to stop or accelerate on steep grades and is consistent with ADA requirements for crosswalks. Verify that grade and cross slopes at pedestrian

crossings comply with the current DIB 82, Pedestrian Accessibility Guidelines for Highway Projects.

## 2.10 Angle of Intersection

*Directional Crossover Intersection:*

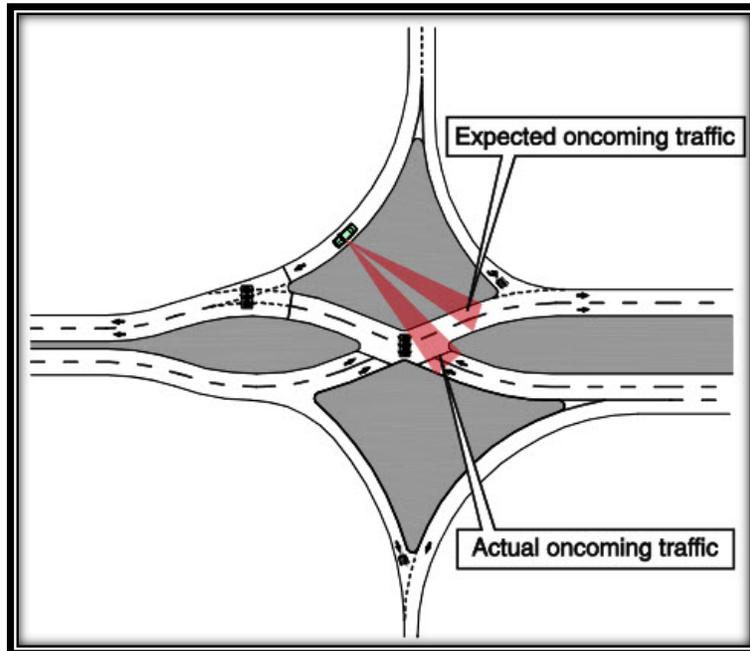
HDM Index 403.3 does not apply to DDI intersections. A 40-degree angle should be the minimum angle of intersection for a DCI.

The DCI's angle of intersection is an important feature unique to DDI design. Traditional intersections discourage intersection angles less than 75 degrees to discourage wrong-way movements, accommodate older drivers, and minimizing the crossing distance. Achieving larger angles at the DCI is not typically feasible due to cost and right-of-way constraints. Research in other states that have used angles as small as 25 degrees due to space constraints indicate a correlation between lower DCI angles and the likelihood of wrong-way movements. A 40-50 degree DCI angle of intersection is desirable. The Guide recommends a DCI angle of not less than 45 degrees between approaches and opposing departures. As the number of lanes increase at the DCI, the higher the angle of intersection needed to allow for a median large enough to separate traffic and accommodate pedestrians, and to create an eyebrow that will discourage wrong-way movement, see Section 2.12, Through Path, of this DIB.

*Off-ramp:*

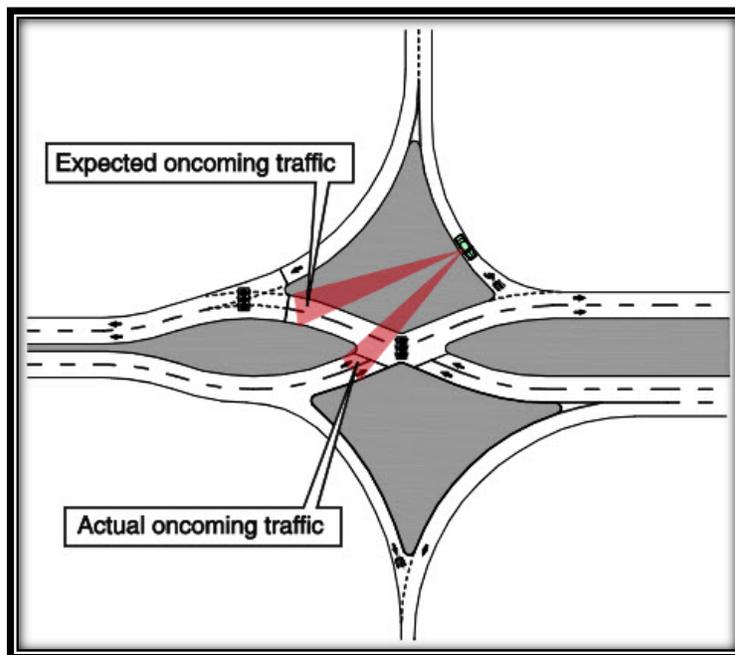
The Guide also discusses the angle of approach for off-ramp intersections. The DDI crossovers create a situation where the location of approaching traffic is not where drivers would typically expect, see Figures 2.10A and B. The angle of the off-ramp intersection should be designed such that, from the driver's perspective when stopped at the yield or stop line, the location of approaching traffic is in the same view location as a typical intersection. It is recommended to use angles from 60 to 100 degrees to the approaching traffic, 90 degrees being preferred. To accommodate older drivers keep the angle to 110 degrees maximum, see Figure 2.10C. Although, the off-ramp turn movements are typically signalized, these angles are important for right- or left-turn-on-red or when signals go to flashing red.

**Figure 2.10A**  
**Line of Sight – Right-Turn**



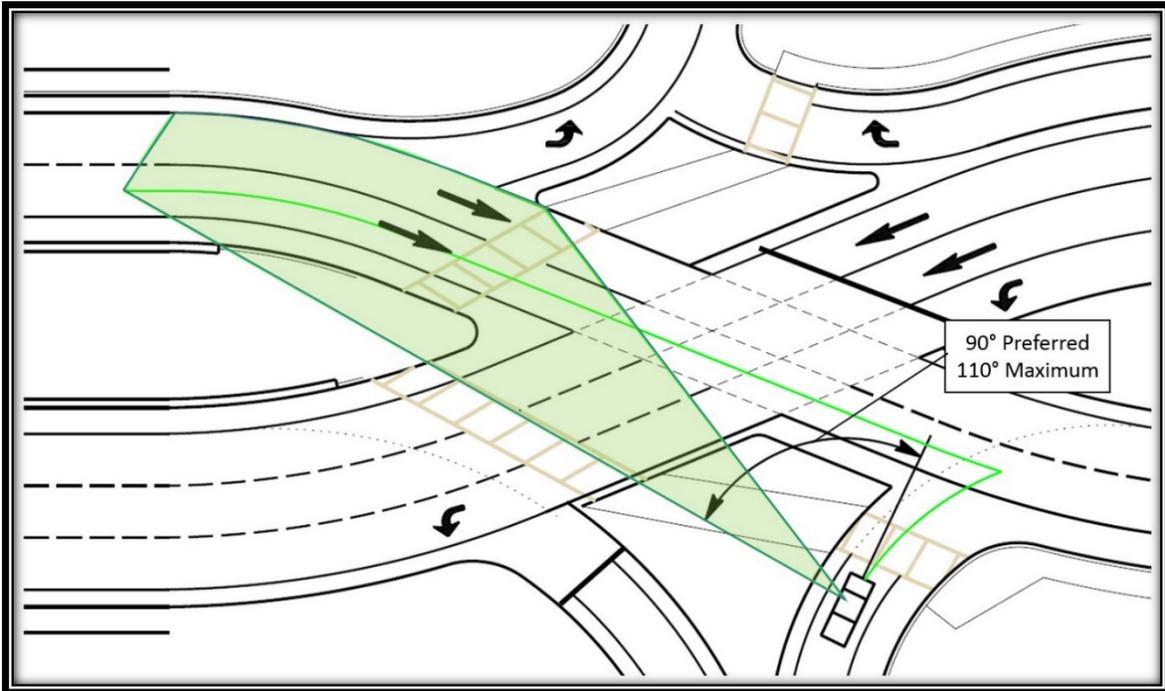
Source: FHWA-SA-14-067\_DDI\_Informational Guide

**Figure 2.10B**  
**Line of Sight – Left-turn**

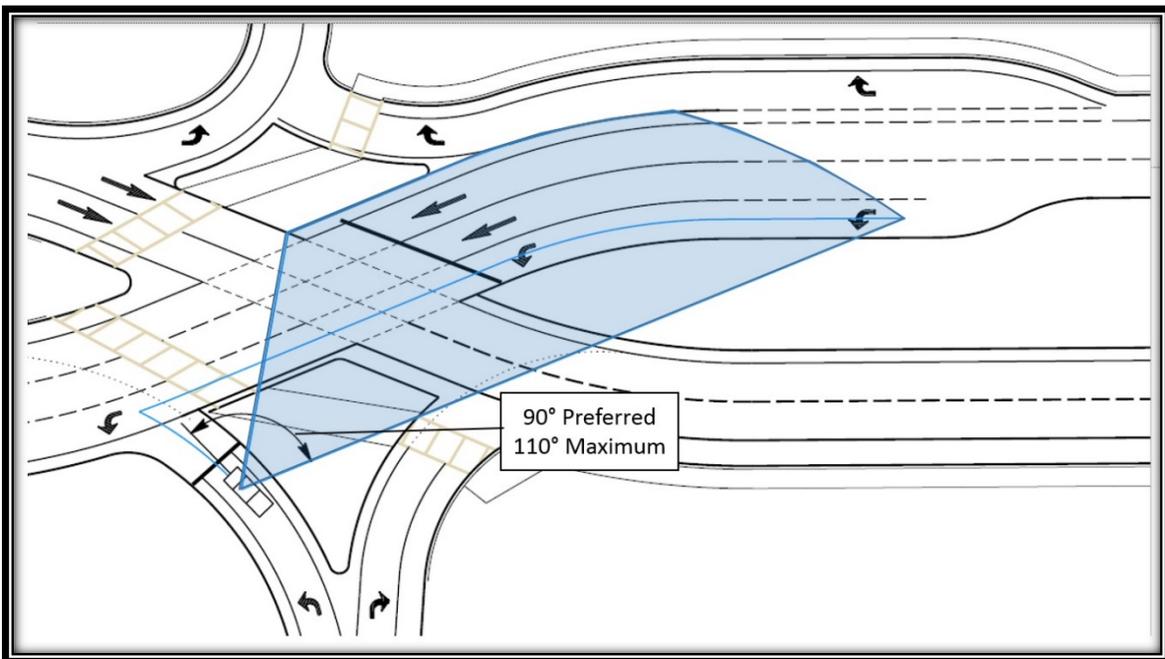


Source: FHWA-SA-14-067\_DDI\_Informational Guide

**Figure 2.10C**  
**Off-Ramp Intersection Angle - Right Turn**



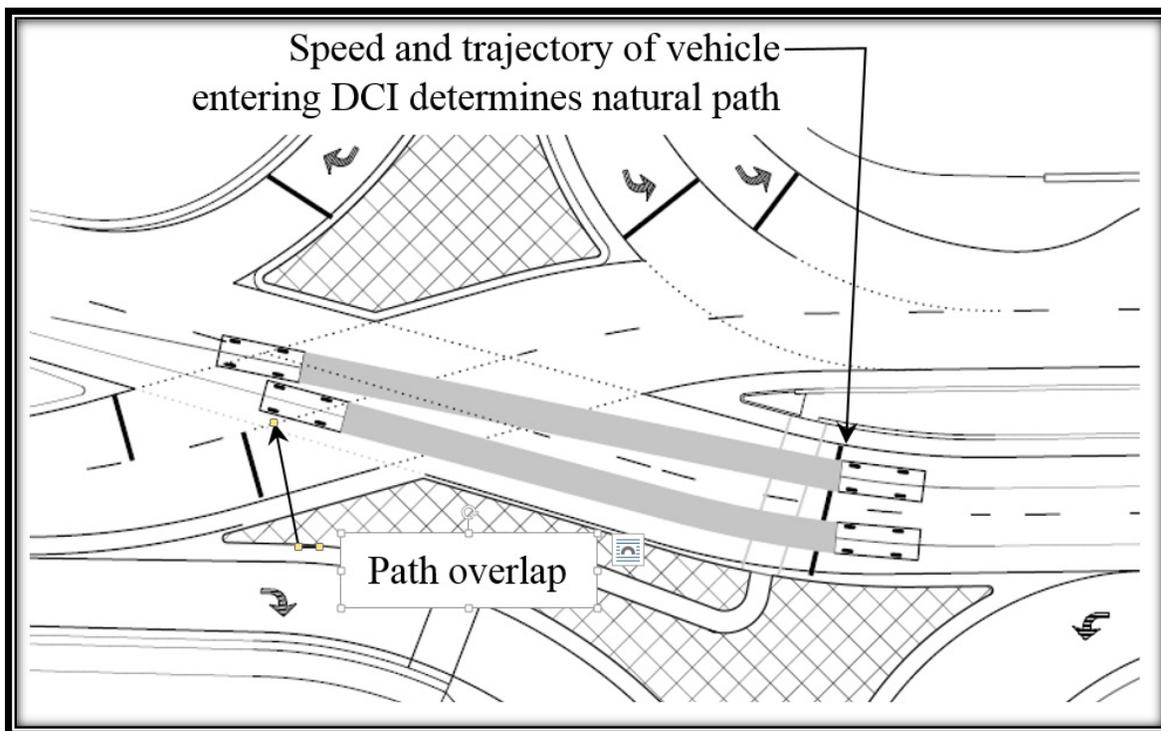
**Figure 2.10D**  
**Off-Ramp Intersection Angle - Left Turn**



## 2.11 Tangent Through Crossover

The Guide discusses a minimum 15 to 25 feet of tangent after the vehicle gets to the stop bar, see the Guide, Exhibit 7-6. The tangent requirement provides sufficient distance to ensure vehicles are directed to their lane and not into the path of the adjacent lane. Vehicle path overlap is a vehicular conflict that occurs when the natural path of the adjacent lanes cross one another. Figure 2.11 illustrates path overlap. The Guide does not require performance checks as with roundabout design, yet there is value in the concept of checking if a design has met this performance objective. Natural path or path overlap is one of the critical performance checks introduced in roundabout design. DDI's rely on tight curvature to reduce speeds entering the DCI; therefore, designers must check approaches to DCIs for path overlap. See Figure 2.11 and Photo 1 for an example of path overlap.

**Figure 2.11**  
**Path Overlap**





**Photo 1 Example of Path Overlap**

Source: Kentucky Transportation Cabinet, US 68 DDI

## 2.12 Through Path

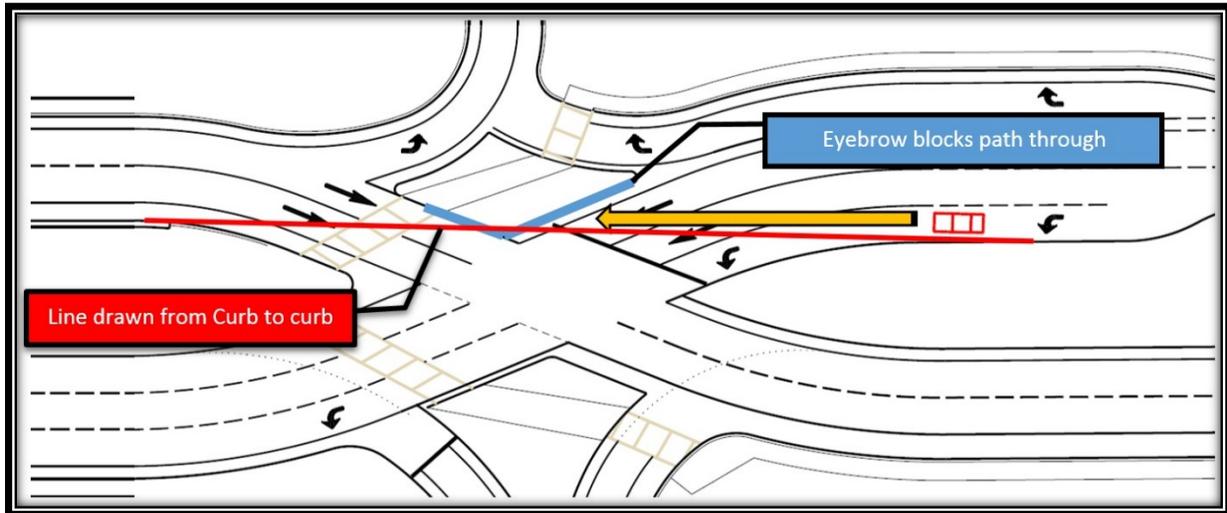
Through path at the eyebrow (see Section 1.1 for definition) is a concept emerging among some practitioners. The eyebrow should break the line of sight (path) between the two approach legs of the DCI, discouraging wrong-way movements. To check the through path draw a line from the median curb of one direction's approach to the median curb of the other direction's approach. Ideally the through path distance, the distance between the eyebrow curb and the line, should include zero "overlap", see Figure 2.12A. Even a small distance from zero "overlap" makes it obvious to the driver that there is no way to pass through. Figure 2.12A and Photo 2 are preferred examples where the eyebrow blocks the through path. Figure 2.12B and Photo 3 are undesirable examples where a vehicle could continue straight through the intersection and end up on the wrong side of the road.

The through path is influenced by several geometric features; angle of intersection, length of tangent, median width, the number of lanes, lane and shoulder widths. Achieving the desired overlap of the line and curb requires a balance between providing a smooth transition through the DCI and meeting driver's expectation as with a conventional square intersection. Additionally, with smaller angles of intersection at the DCI, designs that block the through path become more difficult to achieve.

The use of sharp curb corners in the design of the island (as opposed to the normally rounded corners), may help emphasize to drivers that a turn should not be made. Painting the vertical face of the concrete curb white (to match the edge line color) along the eyebrow may also help improve

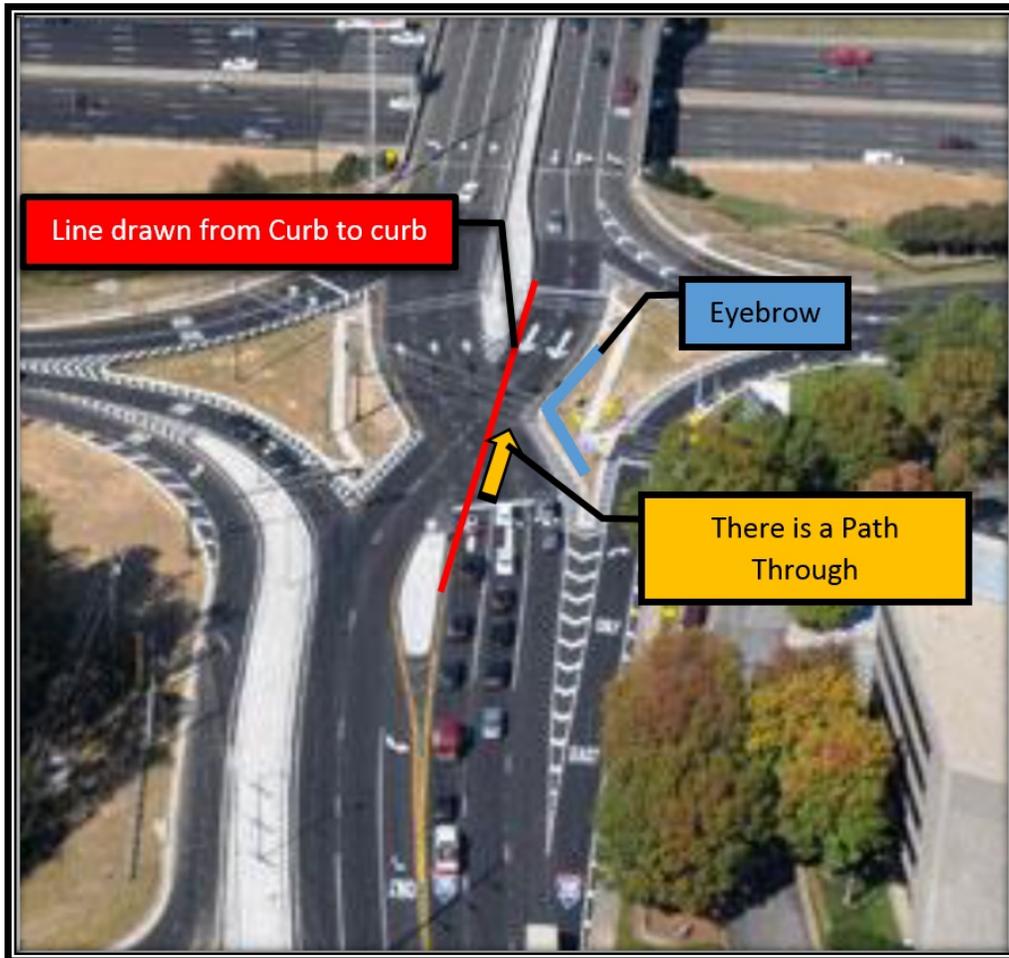
conspicuity of the channelization and guide drivers into the proper path. Once traffic is between the two DCIs, a traffic barrier may be used to separate traffic directions, and block the view of oncoming headlights and traffic.

**Figure 2.12A**  
**Through Path – Preferred**



**Photo 2 Adequate Overlap of Eyebrow**

**Figure 2.12B**  
**Through Path – Undesirable**



**Photo 3 Inadequate Overlap of Eyebrow**

### 2.13 Intersection spacing

Local road intersections in close proximity to DCIs and ramp intersections are problematic for many interchange configurations. The two-phase signals at the DCI provide higher throughput than the adjacent signals with more phases. This combined with limited storage can create the potential for queuing into the DCI and/or off-ramps. This queuing may prevent right-turning off-ramp traffic from weaving to the left-turn lane of the local road intersection, resulting in vehicles remaining at the ramp terminus until the maneuver can be accomplished. Closely spaced local road intersections may need to be closed, altered, or relocated further from the DDI. Consider modifying the local intersection upstream to a roundabout to maintain flows and reduce queue length. Traffic operational analysis will determine if the adjacent intersection is too close.

Concerns also arise for vehicles turning right from an off-ramp and weaving across traffic to make a left at the adjacent intersection. Because throughput is high, the Guide recommends prohibiting right-turn-on-red at the off-ramp.

HDM Index 504.3(3), “**The minimum distance (curb return to curb return) between ramp intersections and local road intersections shall be 400 feet. The preferred minimum distance should be 500 feet.**” Even if this standard is met, a traffic analysis is still needed to determine if the distance from the directional crossover intersection and adjacent intersection is adequate to provide queue storage that will not interfere with exit ramp traffic.

### 2.14 On-Ramp Merge

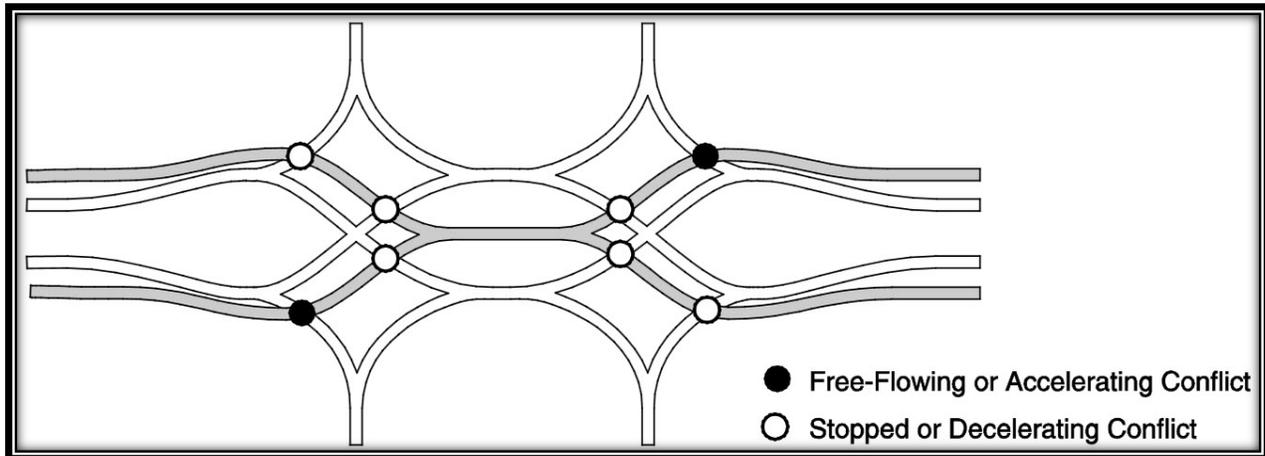
On-ramps should be designed as provided in the Guide, where the right-turning vehicles yield to the left-turning vehicles. When the right-turn volume is high or when queuing of the right-turn traffic is excessive, consider providing right-turning traffic a receiving lane to improve merging with left-turn traffic. If this is done consider the geometrics of both right-turn and left-turn traffic, and potential speed differentials at the merge point. If there is more than 10 mph speed differential between traffic movements, provide a small gore area before the lanes join, to allow a reduction in speed differential.

### 2.15 Pedestrians Facilities

At least one pedestrian path through the interchange must to be provided. Chapter 3, Multimodal Considerations, of the Guide provides extensive guidance on designing for pedestrians. DIB 82, Pedestrian Accessibility Guidelines for Highway Projects as well as the HDM pedestrian guidance apply to DDIs.

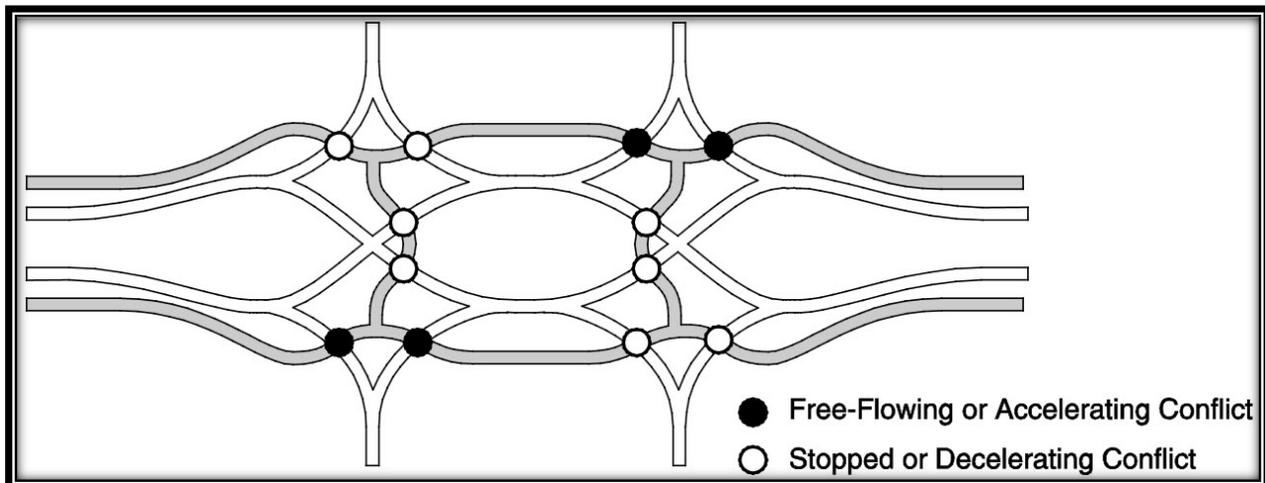
Pedestrian passage through a DDI can be provided in one of two ways, as a walkway outside the traveled way or as a “center walkway” in the median, between the directions of travel. The outside walkway is similar to a typical diamond interchange and can be designed as a typical sidewalk. The center walkway is a unique feature accommodated by the DCI, see Figure 2.15A for an example of a center walkway and conflict points. See Figure 2.15B for an example of an outside walkway and conflict points. See the Guide, Exhibits 3-7 and 3-8 for advantages and challenges of both options.

**Figure 2.15A**  
**Center Walkway**



Source: FHWA-SA-14-067\_DDI\_Informational Guide

**Figure 2.15B**  
**Outside Walkway**



Source: FHWA-SA-14-067\_DDI\_Informational Guide

The center walkway may accommodate both pedestrians and bicyclists. To accommodate both pedestrians and bicyclists the width of the center walkway should be 10 feet minimum, 14 feet preferred. Wider center walkways improve comfort and reduce conflicts between non-motorized users. Wider paths, or fully separated bicycle paths may be needed in cases where high pedestrian and bicycle volumes are expected, such as when a path or trail system goes through the interchange. A low barrier may be used to separate the center walkway from traffic, as well as serve to channelize traffic through the DCI. Typically, concrete barrier such as Type 60 Concrete Barrier is used, but a traffic barrier is not needed, see Photo 4. Typically, barriers between traffic and the sidewalk are not needed due to lower speeds. Additionally, barriers cost more and may

not be aesthetically pleasing. Examples of low barrier could be, but are not limited to, fencing, landscaping, and planter boxes to help channelize traffic and pedestrians. The barrier should be a low barrier so as not to give pedestrians the feeling of being “tunneled”, see Photo 5, and to prevent bicyclist (between traffic and the barrier) from feeling trapped next to a wall.



**Photo 4 Wide Central Walkway w/ Column**



**Photo 5 Central Walkway w/ High Barrier**

DDIs at undercrossings typically provide a pedestrian path on the outside of the crossing, similar to typical diamond interchanges. Where pedestrians cross uncontrolled vehicle turning movements at on- or off-ramps, HDM Index 405.3(2)(b), applies to both right- and left-turns. Speed reduction is provided by the roadway curvature at conflict points, where vehicle speeds are typically 20 miles per hour or less at pedestrian crossings of free turning movements. Pedestrian crossings should be placed far enough into the curve where vehicles have slowed appropriately, but not so far that pedestrians are not visible to approaching drivers.

## 2.16 Accommodating Bicycles

California law affords bicyclists the same rights and responsibilities as vehicle drivers to operate on the roadway unless prohibited. See Section 2.8 for shoulder width guidance and the Guide Chapter 3, Multimodal Considerations, for further bicycle accommodation guidance through the DDI. A bicyclist riding with traffic on the outside shoulder at the approach to the first DCI would proceed across the intersection with through traffic. This results in the bicyclist operating on the inside shoulder between the DCIs, which eliminates the conflict points with the left-turn movements to or from the ramps. At the downstream DCI, the bicyclist again crosses with through traffic and back to the outside shoulder, which is compatible with Class 2 bike lanes and shoulder width guidance. Bicyclists may use the central walkway. Bicycle signals could supplement pedestrian signals and reinforce the intended route of travel for bicycles. Note U-turns are not permitted at DCIs. A bicycle use area between the right-turn-only and through lanes at both on- and off-ramp movements should be considered, see HDM Index 403.6. HDM Index 1003.1(8) does not apply to DDIs.

## 2.17 Access Management

Access control adjacent to ramp termini is required for DDIs per HDM Index 504.8. Close proximity of driveways to ramp termini can create problems for interchange function. With the

higher throughput of DDIs, close driveways can further create challenges. Ideally, access should be eliminated between the ramp termini to the adjacent local road intersection.

### **3.0 Operational Considerations**

The Guide provides guidance on operational considerations. Additional analysis may be required to ensure that the extended corridor along the local road operates efficiently in an integrated manner. Experience in California designing DDIs in dense urban areas has shown the need to analyze not only the adjacent intersection, but also surrounding intersections. Modification to the local road corridor, such as adjacent intersection improvements, may be required to achieve the operational benefits of the DDI.

#### **3.1 Signal Timing**

Signal timing should consider the needs of all users. Consideration should be given to prevent excessive wait times for pedestrians who are exposed to wind and weather. Consider bicycle signal activation (active or passive) to prevent excessive waiting when no vehicles are present to trigger signals. Consider all flashing red during low volumes to reduce wait time for all users.

For additional guidance beyond the Guide, see 2016 TRB Annual Meeting Online paper, *DDI Signal Timing Fundamentals, Concepts and Recommended Applications*, at <http://docs.trb.org/prp/16-6273.pdf> and Caltrans Traffic Signal Operations Manual