

DDI Guideline

A UDOT Guide to Diverging Diamond Interchanges

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EXECUTIVE SUMMARY

Reflecting on human tendencies, Abraham Maslow once said, “I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail.” This maxim, known as Maslow’s Hammer, has been frequently observed in science and engineering fields. As new innovations are introduced and applied, they sometimes struggle for initial acceptance but then gain in popularity until they are often over-applied.

In August of 2010 the Utah Department of Transportation (UDOT) added a new tool to its transportation tool belt – the Diverging Diamond Interchange, or DDI. As of 2013, DDIs have been constructed in five Utah locations and have been evaluated for design or construction in several more. Overall, the DDI has proven effective in the right circumstances. It has economically reduced congestion at key interchanges by improving safety and mobility to and from Utah highways and interstates.

Despite this initial success, the DDI is not a one size fits all solution, and it is certainly not the Department’s only tool for improving interchanges. Thus, it is important to reiterate that while the DDI has performed very well at some locations, it has failed to impress at others. While it has been a valuable congestion mitigation solution under favorable traffic conditions, it has not fully met expectations in less favorable conditions. Consequently, the DDI may not be appropriate when compared to other interchange types in these less unfavorable circumstances.

While the performance of Utah DDIs has not disappointed, the Department does have some concern with a developing tendency towards over-application. While UDOT is comfortable with the DDI concept, it is important to recognize that we are still learning the limits of this transportation tool. To help better define what we actually know about these limits and the appropriate application of DDIs, UDOT has gathered and documented the lessons learned from previous DDI projects. These lessons learned will provide transportation leaders, planners,

project managers, engineers, and designers with better guidance about when the DDI is likely an appropriate solution and when its limitations make its use questionable.

The purposes of this *DDI Guideline* are to accelerate understanding of the DDI’s strengths and limitations to aid decision making, to encourage a comprehensive alternative selection process that evaluates DDIs in context with other favorable alternatives, to formalize critical design elements, and to help foster acceptance of critical decision factors and design elements. The *DDI Guideline* promotes these goals by providing a detailed accounting of the following items, as experienced during DDI implementations throughout the State:

- Key concept principles
- Design variations
- Decision making factors
- Evaluation standards
- Design standards
- Construction practices
- Public involvement tools
- Lessons learned

The consolidation of this information into a single guideline is intended to answer questions about the DDI, to remove or mitigate some elements of risk from decision making, to provide design guidance that confidently encourages appropriate implementation, and to advance the state of the practice in general.

The lessons learned, collective design experiences, successes, and challenges of implementing Utah’s DDI concepts represent a wealth of information to be captured,

summarized, and made accessible to others. With easy access to this information, UDOT hopes that project managers and design teams will consider the *DDI Guideline* as an informative guide and as a reliable reference to use when considering interchange improvements throughout the State. The money and time expended to gather this information into one place is an effort to encourage UDOT professionals, in all regions, to consider the appropriate application of the DDI concept along with all of its opportunities, benefits, and challenges.

The *DDI Guideline* is written specifically for project managers and design teams. Sections 1-3 of the *DDI Guideline* are intended to guide project managers through the

“Man must shape his tools lest they shape him.”

— Arthur Miller

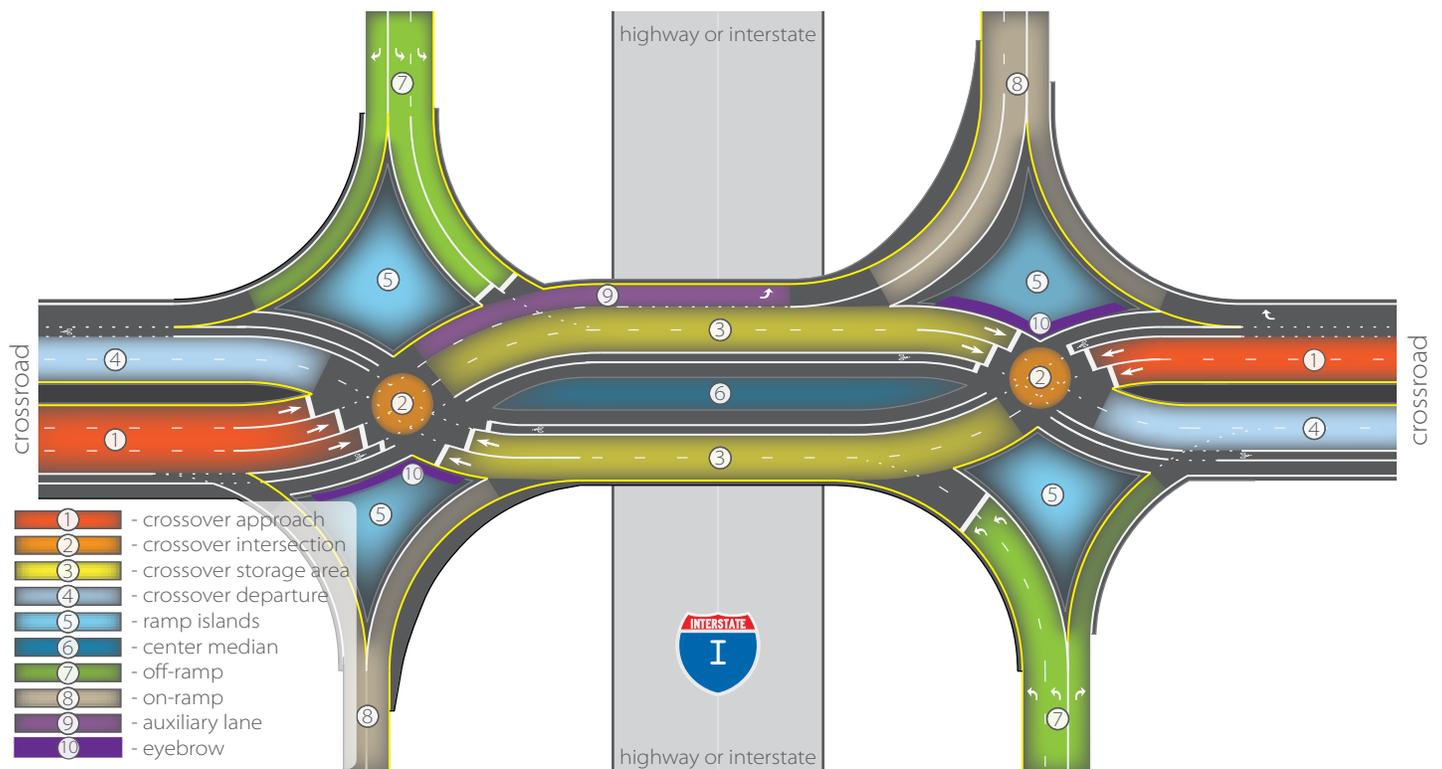
process of deciding when and where to consider a DDI. Sections 2, 4 and 5 are written primarily to inform and support design teams. They contain the nitty-gritty details of DDI design, including rules of thumb, lessons learned, technical details, and section references to accepted design standards. Understanding that the *DDI Guideline's* greatest potential benefit is in areas where DDIs are still considered a novel concept, Section 6 contains a messaging guide for project managers to foster greater public acceptance of the DDI.

Expansion (I-15 CORE) project team, and UDOT Region 2 Traffic. These groups delivered UDOT's first full-build DDI (Pioneer Crossing), first retrofit DDI (Timpanogos Highway), and the DDIs at 500 East & I-15, and at SR-201 & Bangor Highway.

We hope that project managers and design teams will appreciate the *DDI Guideline* for what it is. It is intended not as a straitjacket, but rather as a guideline of best practices and a starting point for continuing innovation on future projects. With a concept as unique as the DDI, UDOT recognizes the need for "educated design compromises" that conform to common safety and operations principles without jeopardizing reasonable project goals or the intended operation of the DDI concept. As in the design of all transportation improvements, sound engineering judgement should guide the application of any such "educated design compromises."

These guidelines were developed with guidance from the Access Utah County (AUC) team, the I-15 Corridor

exhibit ex-1: anatomy of a ddi

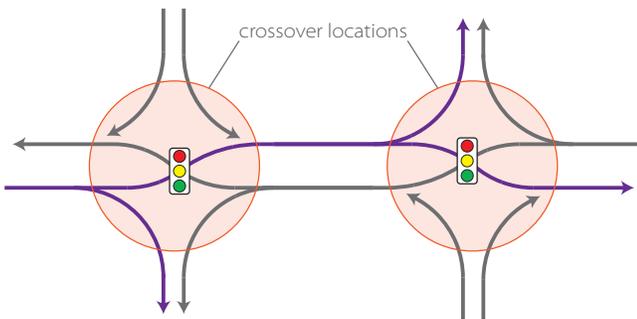


SECTION 1 DDI OVERVIEW & BASIC CONSIDERATIONS

DDI Concept Basics

The fundamental DDI concept simplifies the interaction of turn movements at interchange ramp terminals by crossing side street through movements over each other at each of the two ramp terminal locations. Crossing these through movements over to the opposite side of the road replaces left turn crossing conflicts with merge/diverge movements and removes signal phases from ramp terminals. This

exhibit 1-1: ddi crossover interaction



strategy reduces congestion through more efficient signal operation, and improves safety by reducing the number of crossing conflicts.

How does a DDI work? Each direction of signalized side street through traffic (through traffic that would normally pass over or under the grade separated facility by passing through the ramp terminals) crosses over to the left side (or the opposite side) of opposing through traffic at the first ramp terminal and then crosses back to the right side of opposing traffic at the subsequent ramp terminal as shown in Exhibits 1-1 and 1-2. By crossing through traffic over at the terminals, traffic entering on-ramps can make left and right turn movements as typical free diverging movements instead of as yield, stop, or signal controlled crossing movements. Similarly, off-ramp traffic is free to make left and right turns as merging movements that can be free, yield, stop, or signal controlled movements. For both on-ramp and off-ramp traffic, eliminating crossing conflicts in favor of merge/diverge conflicts reduces signal phases and allows free or reduced conflict yield, stop, or signal controlled turn movements.

It is important to recognize that the simplification of turn movement interactions at the DDI ramp terminals is accomplished at the expense of the crossover side street through movements at the ramp terminals. Consequently,

exhibit 1-2: anatomy of a ddi

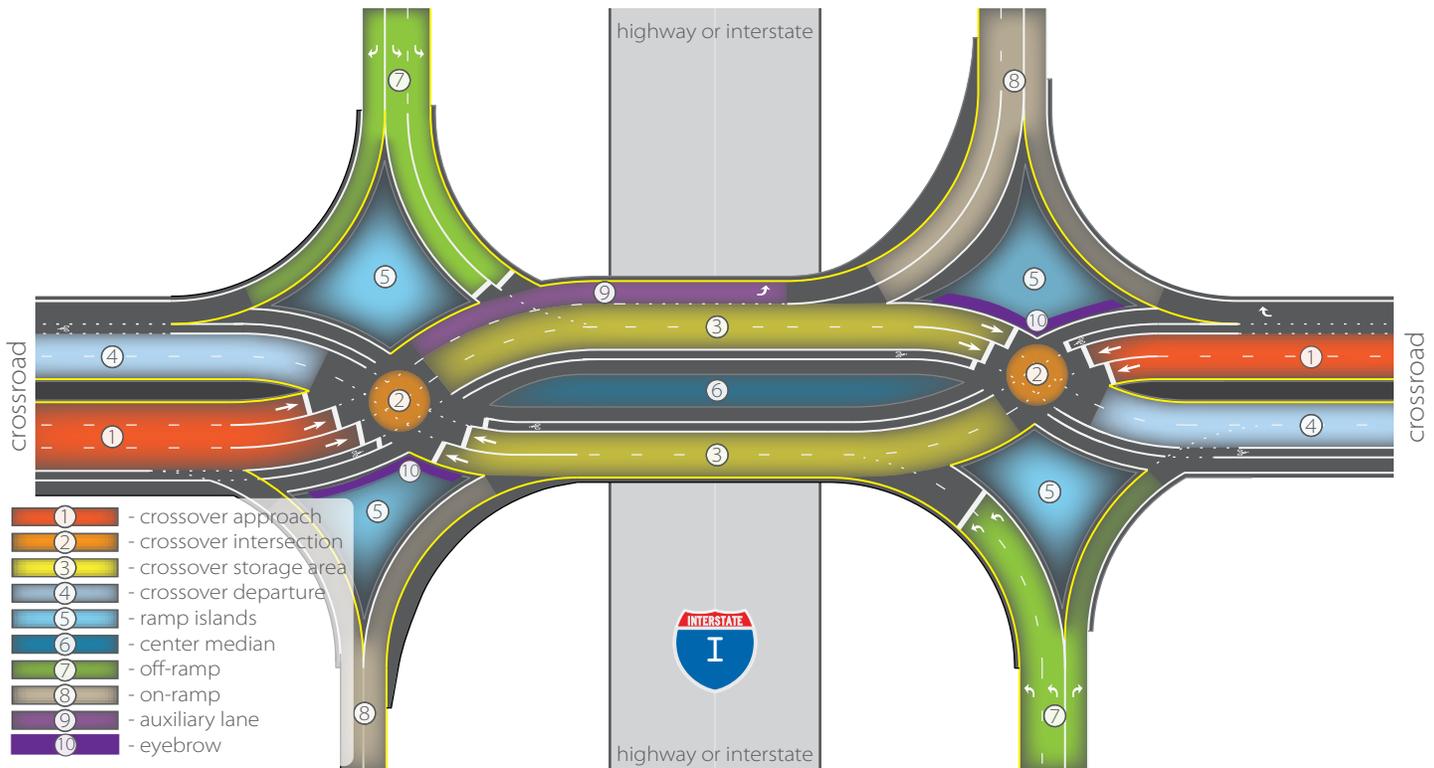
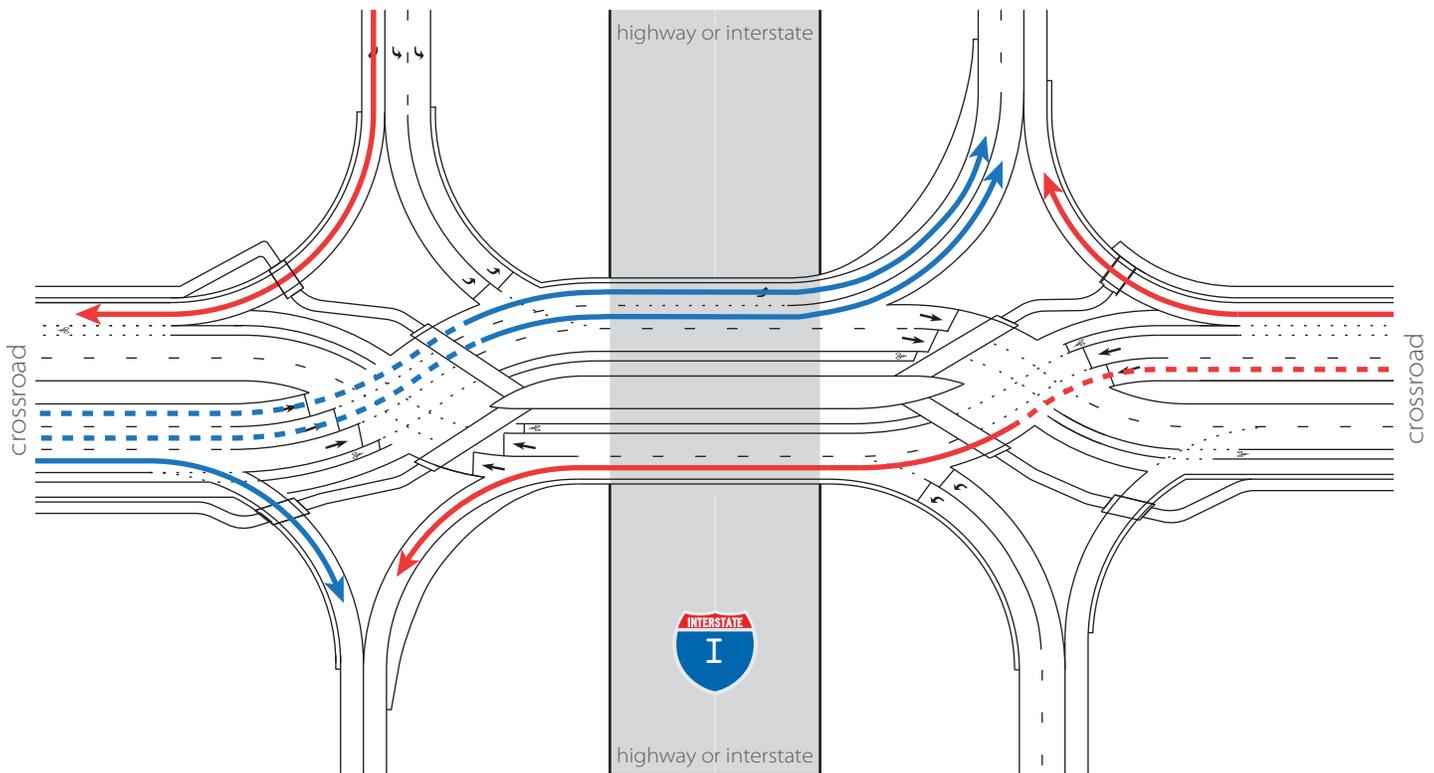


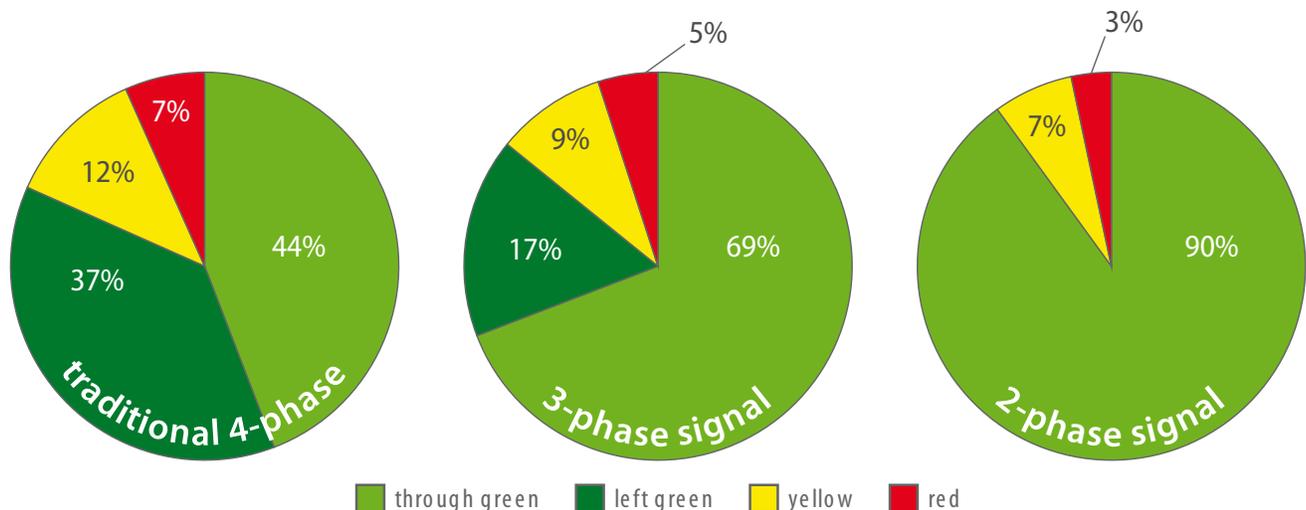
exhibit 1-3: ddi free ramp movements



when through movement volumes are light (relative to ramp traffic volumes), prioritizing ramp traffic interactions above through movement interactions is relatively simple and intuitive. When through movement volumes are high in combination with high ramp traffic volumes, this trade-off requires additional consideration to ensure that a DDI will adequately and efficiently serve all interchange movements.

DDI crossovers may be signalized or stop controlled depending on the volume of traffic served at the interchange. As of 2013, all DDI crossovers constructed in Utah have been signalized due to the high volumes served. When DDIs are signalized, crossover signals at each intersection are required and operate as two-phase signals, plus a small additional clearance interval phase. However, the nature of a DDI results in split phase signal operations for

exhibit 1-4: ddi green time savings



*Comparison based on sample 4-phase intersection with 120 second cycle length and typical UDOT timing standards

cross-street through-traffic, limiting the ability of simultaneous continuous through movement for both directions.

The green time saved by eliminating a phase (or partial phase) at each ramp terminal adds to the green time that jointly serves the left turning on/off-ramp traffic and side street through movements at the crossovers. Adding more green time to all movements at the interchange reduces delay and improves capacity. Since green time added to any signal phase is effectively added at the end of that green phase (when vehicles are already traveling at speed), even small additions of green time can be much more effective. In fact, these small additions of green time are so effective that the DDI can potentially improve the capacity of interchange ramp terminals between 30% and 50%, as identified in operational and observational studies performed by UDOT. Exhibit 1-4 illustrates how eliminating left turn phases at a DDI translates to more green time.

Even in cases where no additional green time is given to specific movements, DDIs may be more efficient in some circumstances due to shorter cycle lengths. In implementing short cycle lengths, care should be taken to ensure compatible cycle lengths and offsets (spacing) relative to adjacent multi-phase signals for effective progression.

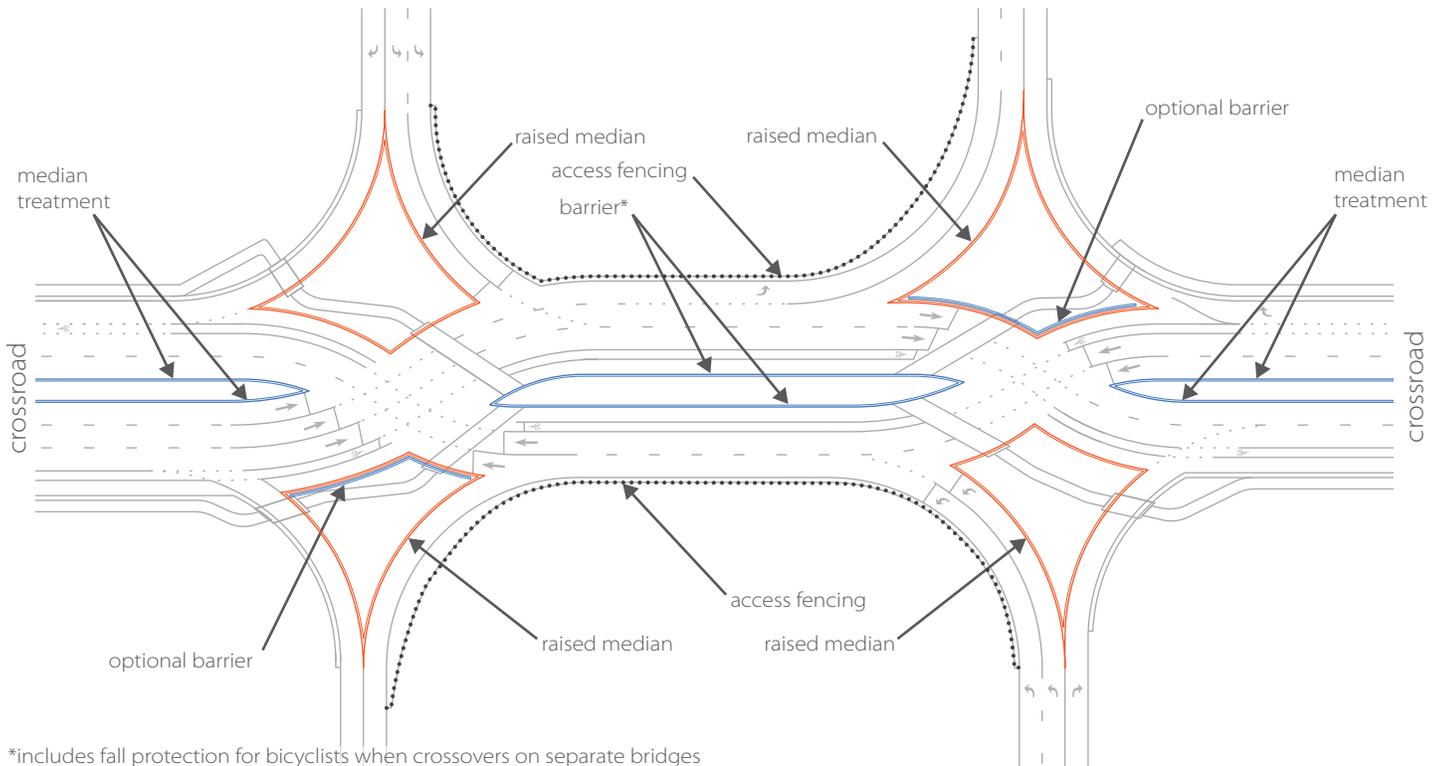
Channelizing Medians

To avoid potential conflicts at crossovers and at merge/diverge conflict areas, nearly all of the movements within a DDI are channelized using medians. DDI medians direct traffic into the appropriate lanes at crossover locations, channelize turn movements to avoid receiving lane conflicts, provide refuge for pedestrians, allow the flexible location of signal poles and signs within the intersection, and provide snow storage for winter maintenance. Consequently, the design of median locations and shapes within the DDI is an important function of DDI design.

Median separation for the purpose of access control is typically provided in the crossover storage areas of DDIs as well as in the crossovers themselves. This is not surprising considering the access restrictions common at grade separated interchanges. As at other interchanges, these access restrictions are necessary for safety and operations. They can also be considered an opportunity for access consolidation in retrofit applications, depending on the surrounding context. Generally access within the immediate vicinity of the DDI is either restricted to right in, right out, or is prohibited altogether.

Typical DDI medians are illustrated in Exhibit 1-5. Median design is described in greater detail in the Section 2—Conceptual Design and Section 4—DDI Design Parameters.

exhibit 1-5: ddi median and barrier



Bicycles and Pedestrians

Bicycle movements through a DDI are not much different than those at a conventional interchange, except that they must perform the same crossover movements as other vehicles and are generally prohibited from making turn movements to enter or exit the limited access facilities served by the interchange ramps. The lack of established convention and the general lack of experience with DDIs, however, encourages positive guidance to help bicyclists navigate a DDI. DDI bicycle crossings should be addressed on a case by case basis and should consider signal timing, signing, striping, and detection needs. Exhibit 1-6 illustrates the typical bicycle navigation of a DDI.

Bicycle accommodations at a DDI should also acknowledge the different types of bicyclists likely to pass through the interchange. Some bicyclists are comfortable operating amongst vehicular traffic (road cyclists), and some bicyclists are less confident in these conditions (recreational cyclists). Different types of bicyclists require varying needs, which should be addressed during design. A more detailed discussion of potential provisions for bicyclists can be found in Section 4—DDI Design Parameters.

UDOT prefers that pedestrians cross DDIs using an island located in the middle of the interchange. While the first

of Utah’s DDIs crossed pedestrians on the outside of the interchange, this placed them in the position of crossing free movements at locations with limited visibility. Recent designs have shifted pedestrians to the median. This improves lines of sight for both pedestrians and vehicles to and from the crossings and allows pedestrians to cross through traffic at a signalized location to clarify pedestrian/vehicle rights of way. Left turns to the entrance ramps can also run freely without conflict with pedestrian crossings. Regardless of the crossing strategy used, multi-stage pedestrian crossings using median islands for refuge are common for most DDIs. Additional discussion of pedestrian considerations is found in Sections 2 and 4.

History and Evolution of the DDI

In 2009, the first DDI in the United States (a retrofit) was constructed in Springfield, Missouri. UDOT’s first DDI (the first new build and second DDI in the US) was constructed approximately one year later at American Fork Main Street & I-15 (Pioneer Crossing). In 2011, UDOT constructed three additional DDIs (two retrofits and one new build), at locations in Utah and Salt Lake Counties.

The DDI has continued to evolve with the unique circumstances of each new implementation both inside and outside of Utah. In Utah, designers have experimented

exhibit 1-6: ddi bicycle navigation

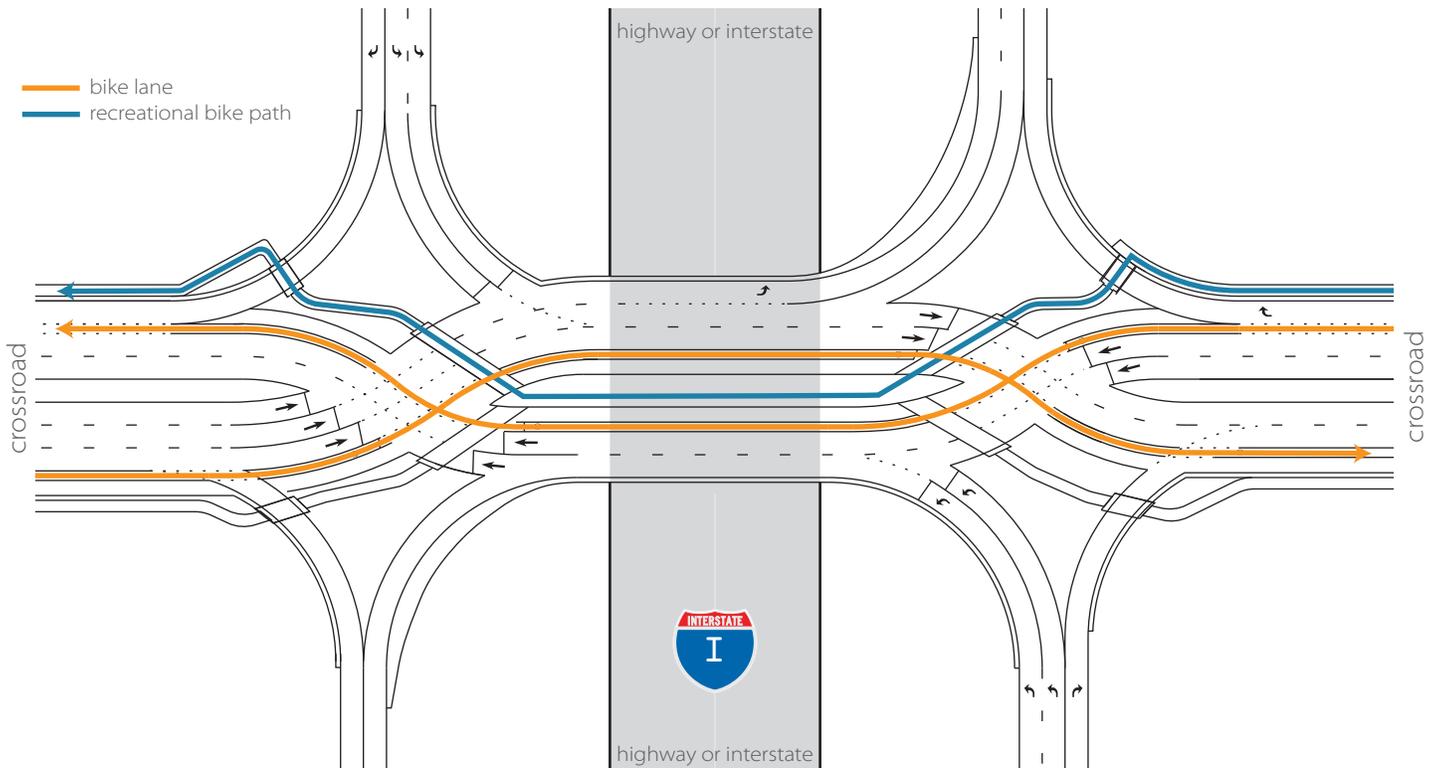


exhibit 1-7: ddi costs

Cost	Location
<i>New Construction</i>	
\$22 M	American Fork, UT (I-15/Pioneer Crossing)
\$20 M	American Fork, UT (I-15/500 East)
\$17.5M	St. Cloud, MN (Hwy 15/CR 120)
\$14 M	St. Peters, MO (I-70/Mid Rivers)
<i>Retrofit</i>	
\$2.8 M	Salt Lake City, UT (SR 201/Bangerter Hwy)
\$3.2 M	Springfield, MO (I-44/MO 13)
\$8.2 M	Springfield, MO (National Ave/MO 60)
\$7.1 M	Lehi, UT (I-15/Timpanogos Hwy)
\$4.5 M	Rochester, NY (I-590/Winton Rd)
\$2.9 M	Alcoa, TN (US 129/Bessemer St)
\$5.5 M	Lexington, KY (Harrodsburg Rd)

with lower crossover angles, auxiliary lane configurations, ramp signalization options, various signal timing strategies, navigational signs, and numerous other features in order to reduce project costs and improve the capacity and flexibility of the DDI concept.

With several more DDIs planned for construction in Utah over the next few years, the DDI will certainly continue to evolve as it is applied in new circumstances with unique needs. These unique needs underscore the fact that while there are some general principles that apply to all DDIs, there is no one-size-fits-all DDI solution that is capable of addressing the unique needs of every interchange.

Cost and Innovation

In Utah, cost has been a driving motive for implementing innovative concepts such as the DDI. In fact, the DDI entered Utah’s innovative toolbox as part of a design-build project that focused on both cost savings and operational benefits provided by a DDI concept that allowed for shorter structural spans, a reduced interchange footprint, and an improved ability to serve interchange ramp traffic as compared to more traditional alternatives like the dia-

exhibit 1-8: retrofit ddi (sr-201/bangerter)

SR-201 & Bangerter (2009)



SR-201 & Bangerter (2012) - DDI retrofit



exhibit 1-9: pioneer crossing ddi (first in utah)

Pioneer Crossing & I-15 (2009)



Pioneer Crossing (2012) - DDI



mond interchange and the single point urban interchange (SPUI).

Regardless of whether current environmental procedures allow consideration of cost or not, the factor of cost is nevertheless crucial in selecting which alternatives will actually become funded construction projects. Cost is part of the reason why four DDIs have been built in Utah between 2010 and 2013, and why DDIs have continued to be recommended as improvements throughout Utah.

Unfortunately, cost can also be expected to be a factor in the potential misapplication of DDIs. Because of the narrow structure widths required for a very basic DDI concept, a common use for the DDI is as a retrofit of existing diamond interchanges. Retrofit DDI costs frequently come in less than \$5 million, and often come in under \$3 million. To keep costs low enough for

retrofit consideration, however, critical capacity features such as auxiliary lanes are often omitted, which can limit the life of the improvement. In some cases, this has resulted in an improvement which has minor overall delay savings and that merely shifts delay from ramp terminals to crossroad through movements.

“Technology is nothing. What’s important is that you have a faith in people, that they’re basically good and smart, and if you give them tools, they’ll do wonderful things with them.”

— Steve Jobs

With retrofit DDI applications, a consensus has developed within UDOT that in some cases these improvements tend to be shorter term improvements that may not meet expectations for longer term congestion mitigation. Consequently, UDOT recommends a comprehensive review of alternatives to explore and identify alternatives

that may provide equal or greater capacity benefits at the same cost or with marginal additional expense. Given the vast number of innovative interchange and intersection concepts now available, it is highly likely that other alternatives exist to rival the DDI in terms of both cost and

operational performance at many locations. Exploring these options more fully using a full-fledged alternatives analysis (and VISSIM microsimulation analysis as the operational evaluation component) to ensure that the DDI really is the best use of precious transportation resources is just good decision making practice. Therefore, UDOT requires that DDIs not be recommended for construction without a complete alternatives evaluation.

Lessons Learned

The evolution of the DDI has provided numerous lessons learned. Utah's first DDI at Pioneer Crossing is considered "The Cadillac" of DDIs in Utah. Several features included in this interchange were not included in other DDI interchanges, including a distance greater than 1000' between crossover locations, the development of left turn pockets prior to the crossovers, four lanes in each direction over the structure including auxiliary lanes, and overhead sign structures.

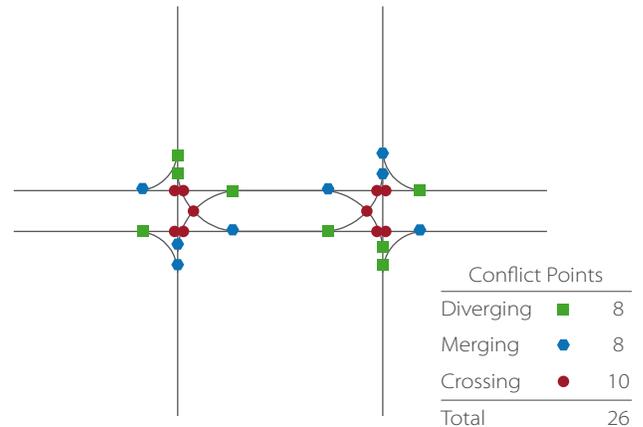
The next two DDIs constructed in Utah were retrofits that were planned to serve traffic for shorter time frames than at Pioneer Crossing DDI. These DDIs had much shorter distances between crossover locations (700 to 850 feet), fewer lanes over or under the structure in order to preserve the original structure, and shortened or eliminated auxiliary lanes. At SR-201 and Bangerter, the overhead signs were eliminated in place of cantilevered and road-side signs.

The elimination or reduction of these features in the retrofit scenarios significantly reduced the capacity of the DDI concept, while the elimination of overhead signs contributed to additional driver confusion. The primary lessons learned from these retrofit locations then were about the value of additional length between the crossovers, the value of more lanes across the structures, the value of even short auxiliary lanes (adding a short auxiliary lane pocket at SR-201 and Bangerter made a surprisingly meaningful difference in traffic operations), and the value of clear overhead signage for navigation. It is clear that compromising one or more of these features in future applications can significantly impact the performance of the alternative.

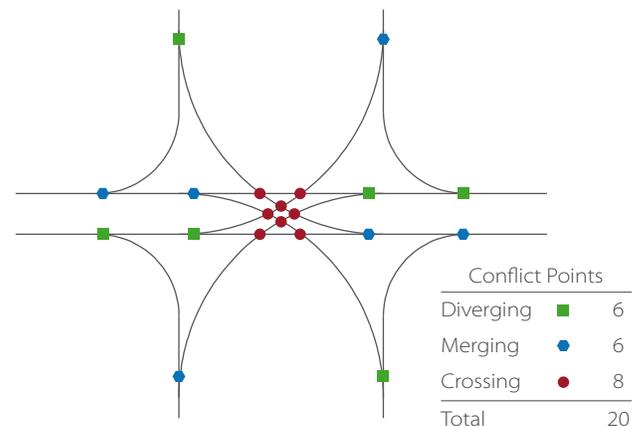
Another lesson learned at Utah's DDIs was the difficulty of crossing pedestrians across multiple free lanes of traffic. Pedestrian crossings of free lanes on the outside of the interchange were subject to limited pedestrian visibility by motorists, and some of these locations are now being retrofitted with pedestrian signals in order to improve

exhibit 1-10: ddi conflict point comparison

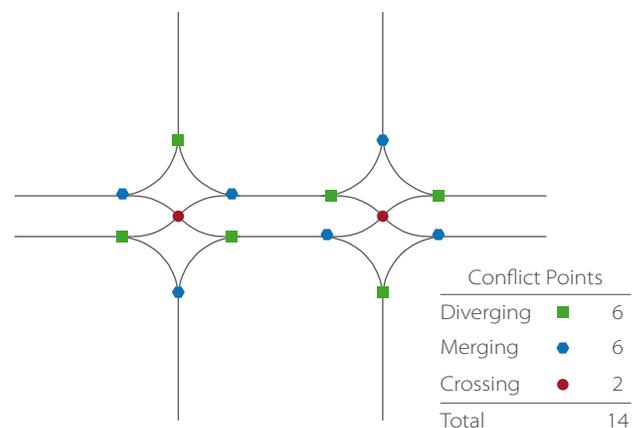
Diamond interchange



SPUI interchange



DDI interchange



pedestrian safety. Consequently, DDIs under current consideration should be proposed with pedestrians using the center median in order to reduce the number of free crossings.

Signs and signal variations have also evolved as a result of the many different viewpoints of design professionals that have worked on each of the DDIs. While some design and timing strategies are clear betterments, some are merely individual preferences that have minimal impact on the operation of DDI interchanges. Taken as a whole, however, these small differences, individual preferences, and minor inconsistencies tend to confuse drivers and reflect poorly on design consistency. Another lesson learned then, is that some consistency of design is necessary in order to better manage a multitude of individual design preferences and driver expectations.

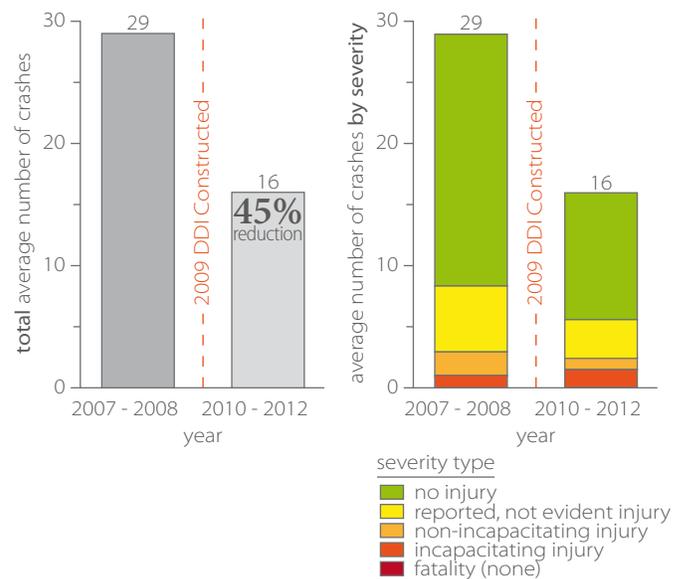
Lessons learned include the fact that radar detection should be installed for flexibility in optimizing traffic operations. When traffic volumes are lighter, detection enables flexible and optimized traffic operations through the DDI. Where the DDI is more capacity constrained, detection has allowed efficient coordination that protects the high speed facility at the expense of the crossroad. Radar detection at DDIs is also critical to ensure proper clearance of the intersection before starting opposing phases of movement.

Safety

One of the ways the DDI improves traffic safety in comparison to the conventional interchange is by reducing and/or spreading out the total number of conflict points at the interchange. Exhibit 1-10 graphically compares the number of conflict points at conventional interchanges to the ones at the Pioneer Crossing DDI. The DDI also reduces the number of the most dangerous crossing conflicts at the interchange (e.g. left turn to through movement conflicts). A safety summary is provided in Exhibit 1-11.

To further improve safety at DDIs, design elements and geometry should create an environment that is intuitive for drivers, bicyclists, and pedestrians. Since the DDI may be a new concept to many users, this means that positive guidance is necessary, including medians, striping, channelization, and appropriate navigational signage. In implementing this positive guidance, care should be taken to avoid complex messages or message densities that are too high for drivers to absorb, thereby limiting driver confusion.

exhibit 1-11: pioneer crossing ddi safety



Not many DDIs in Utah have been operational long enough to provide statistically valid crash statistic comparisons. Preliminary reports from the few DDIs that have been operational the longest are encouraging. Crash statistics from the Pioneer Crossing DDI show a 45% reduction in crashes. These results are not surprising given the DDI's ability to reduce congestion, and (in most cases) the total number of conflict points at the interchange.

DDI Strengths and Weaknesses

The DDI generally has a higher capacity for left-turn movements compared to comparable conventional diamond interchanges. The structural footprint of a DDI is generally smaller than a traditional diamond interchange since exclusive left-turn lanes are not always necessary for the DDI left turn movements. This smaller footprint, however, is not always possible since widening may be necessary at the crossovers to ensure a large enough crossing angle for clarity of direction in vehicular movements. As discussed previously, DDIs are theoretically safer than other conventional interchanges since they have fewer and less severe conflict points.

There are enough misconceptions about DDIs that some direct discussion of strengths and weakness is warranted. It should also be noted that different contexts can turn strengths into weakness, and vice-versa. Consequently, care should be taken in interpreting any catalog of strengths and weaknesses too literally. Context and traffic characteristics are powerful constraints that can break common rules and sometimes require a more nuanced

interpretation of strengths and weaknesses. Exhibit 1-12 lists strengths and weaknesses of the DDI as perceived by UDOT.

exhibit 1-12: ddi strengths and weaknesses

		Strength	Weakness	
Safety	1	●		Fewer collisions than traditional interchanges
	2	●		Reduced collision severity versus traditional interchanges
	3	●		Reduced number of conflict points, especially crossing conflicts
	4	●		Medians and curves provide traffic calming
	5	●		Highly functional during power outage
	6	●		Limits wrong way movement potential for highway ramps
	7		●	Wrong way potential exists for crossover movement
	8		●	Potential headlight glare from opposing traffic
Traffic Operations	9	●		Increase in turn movement capacities, decreases congestion
	10	●		Serves high volume facilities, favors high volume turn movements
	11	●		2-phase signal operation can favor peak period movements
	12	●		Possibility of shortened cycle lengths
	13	●		Increased green time
	14	●		Accommodates u-turns from highway
	15		●	Higher failure potential, especially with short crossover distance & high crossroad through traffic
	16		●	Not suitable for high ramp traffic with high crossroad traffic
	17		●	Locking crossover progression potential
	18		●	Difficult crossroad progression
	19		●	Through movements required to use crossover lanes
	20		●	Spacing to adjacent intersection with more complex signal phasing
Cost & Impact	21	●		High delay savings per dollar expended, exceeds cost in few years
	22	●		Context sensitive (retrofit interchanges)
	23	●		Reduced cost versus bridge widening, low cost compared to SPUI
	24	●		Shorter bridge spans (pillars in middle), narrower structures
	25	●		Reduced construction time
	26	●		Free or simplified left turn movements (not out-of-direction)
	27		●	Retrofits often require auxiliary lanes
Public Perception	28	●		Drivers adapt quickly to the concept, acceptance is high
	29		●	Public confusion with new concept
	30		●	Driving on opposite side of roadway
	31		●	Free right and left movements complicate ped crossing
	32		●	Flexibility of design variations, inconsistent signing potential
Design	33	●		Short at grade pedestrian crossing
	34	●		Bikes & Pedestrians can be accommodated at grade
	35	●	●	Peds may require 2-stage crossings, refuges, structures
	36		●	Medians and vertical separators required
Bike & Ped	37	●		Relatively simple pedestrian crossing when crossing in the middle
	38		●	Complicated pedestrian crossing when crossing on the outside
Maintenance	39		●	Little space for snow storage, snow removal routes complicated

SECTION 2 CONCEPTUAL DESIGN

When should you consider a DDI?

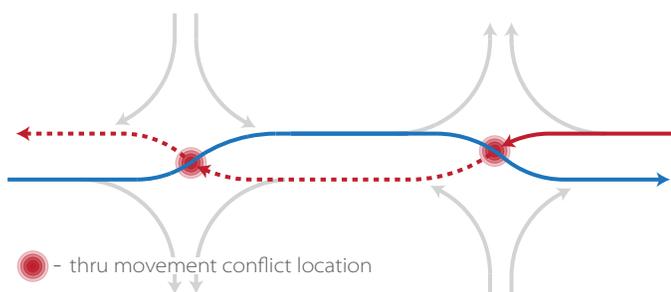
The DDI is a flexible and robust interchange treatment that is appropriate to consider in a number of circumstances, but it is not appropriate in every circumstance. Considerations for the appropriateness of a DDI should begin with capacity and geometric constraints. The DDI is a strong candidate for improving an interchange if an existing diamond interchange is approaching, at, or over capacity; where most crossroad traffic is headed to and from the highway instead of straight through the interchange, or where straight through interchange traffic is heavy and traffic to/from the highway is light; and where conventional improvements are prohibitive on account of expensive ROW or intrusion to surrounding economic activity.

Capacity Considerations

With regard to capacity, the DDI best serves heavy traffic volumes to and from interchange ramps. Heavy crossroad volumes moving from one side of the interchange to the other are not usually as well served by the DDI unless ramp traffic is light. This difficulty in serving high volume crossroad through movements is due in part to the phasing required by crossing opposing through lane traffic movements over each other at two separate locations. This dual crossover movement tends to “lock” the movement of one through direction in order for the opposing through movement to progress, effectively preventing both opposing through movements from moving simultaneously.

The DDI also requires enough green time at the crossover to serve left turning off-ramp traffic and same direction through traffic. Consequently, if left turning off-ramp

exhibit 2-1: the “locking” ddi



volumes, left turning on-ramp volumes, and crossroad through volumes are all high, the DDI may not be able to coordinate all movements effectively, leading to a need for increased crossover storage to adequately store vehicles between crossover intersections. This is especially true in DDI configurations with relatively short distances (less than 700') between the crossover locations. Lengthening the distance between crossover locations generally improves signal coordination and queue storage under heavy traffic conditions and allows greater flexibility with regard to cycle lengths and signal timing coordination.

Due to the wide variety of geometric and timing configurations available at a DDI, and the range of possible performance available under different traffic conditions and the configurations, a VISSIM model should be developed to evaluate the adequacy of each potential DDI application. Thresholds of adequate operation for a DDI include queue lengths that do not reach upstream intersections or the main line of the freeway, or that do not spill back from the DDI's free right or left turn movements onto the freeway ramps; LOS at or above C at the crossover

Capacity Constraints

Consider a DDI if:

- Heavy ramp traffic and light through traffic are present
- Heavy through traffic and light ramp traffic are present

Do not consider a DDI if:

- Heavy ramp traffic and heavy through traffic are present
- Future volume growth indicates heavy ramp traffic and heavy through traffic

intersections; and LOS D at the signals adjacent to the interchange on the cross street.

Context Considerations

The primary context considerations for a DDI are whether the interchange is a new build or a retrofit, the proximity of adjacent signalized intersections, the length available between crossover locations, roadway skew, right-of-way, and utilities.

At existing diamond interchanges where additional capacity is needed, it is often advantageous to convert a conventional diamond interchange into a DDI. Retrofit DDIs are often far less costly than options that might include widening the major and minor roadways at the interchange (including widening the bridge) and adding additional lanes to the ramps. Although retrofit DDIs are typically less expensive than other alternatives, under some circumstances bridge widening may still be required in order to provide adequate operations at the interchange.

The proximity of adjacent signals can provide an easy pass-fail criterion. When signals are too close, installing a new crossover signal may not even be possible due to the long queue lengths typical of through movements at a DDI. Even if it is possible to combine the crossover at an ideally spaced existing signal, the existing signal would be complicated by the crossover movement, which would limit that signal to split phase operation. The addition of new signal phases and geometric constraints to crossover

movements can also result in operational failure at the crossover itself.

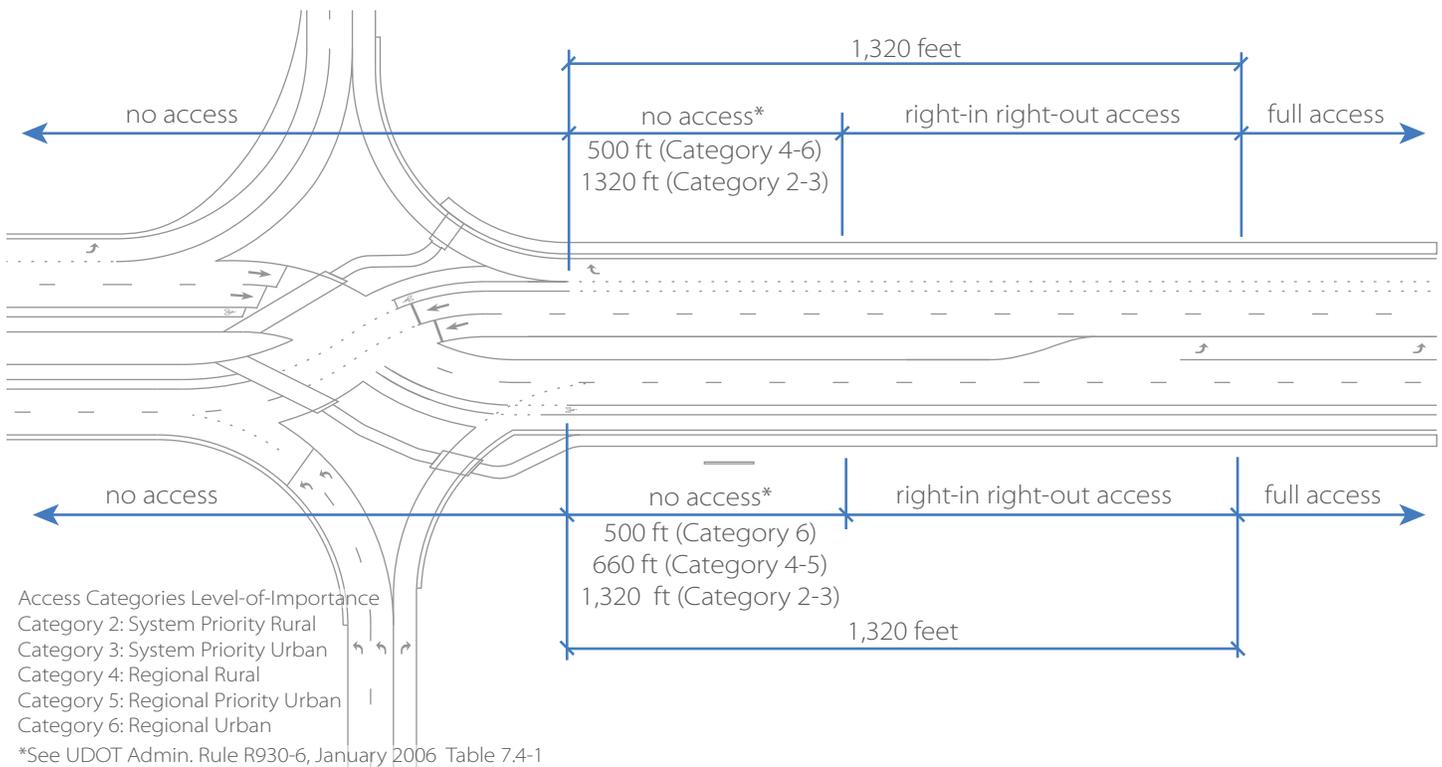
To handle high volume turn movements or through movements, DDIs can sometimes require the use of additional through lanes or auxiliary lanes. Frequently this requires additional right-of-way or expanded structure widths. This

can create impacts on adjacent property and on utilities, especially in situations where the roadway is skewed. While neither property impacts nor utility impacts are fatal flaws, the need to mitigate these impacts raises the cost of DDI implementation. While the higher cost of implementation

“A determined soul will do more with a rusty monkey wrench than a loafer will accomplish with all the tools in a machine shop.”

— Robert Hughes

exhibit 2-2: ddi access restrictions



may still be justified based on the anticipated operational benefits, consideration should be given to other alternatives that may provide similar benefits at a lower cost.

The final context consideration is the distance available between crossover locations. Previous evaluations have shown that it is desirable to have at least 850 feet between crossover locations whenever possible in order to provide maximum capacity and flexibility with regard to operations. Interestingly, skewed roadways often provide the best opportunity for longer distances between crossover locations, while orthogonal roadway crossings at tight diamond interchanges provide exceptionally short distances between the crossovers. In retrofit applications where high traffic volumes and dense property uses are part of the interchange context, this consideration could also be a pass/fail criterion.

Access Restrictions

The DDI is a grade separated interchange that usually connects high-speed, restricted or limited-access facilities such as interstates, highways, or parkways with lower speed arterial crossroads that allow business access. "No Access" lines at DDIs should protect the restricted or limited-access facilities in their entirety, and should also entirely restrict access on the arterial roadway between the

crossover locations (which is usually not a problem since this area is usually on or under a structure). Required access restrictions are detailed in Exhibit 2-2.

DDIs on access restricted corridors are ideal, since close proximity to adjacent multi-phase traffic signals can have significant negative impact on operations, potentially rendering the DDI an unacceptable alternative in some cases. Still, DDIs can be built in heavily commercialized areas with access consolidation considerations that can allow implementation of more robust interchange improvements that adequately serve traffic demands while also creating access consolidation opportunities.

DDI Variations

Conceptual design flows naturally from the volumes and context considerations discussed in the previous section. To accommodate the constraints of capacity and surrounding context, DDIs can be custom configured as listed below and as illustrated in Exhibit 2-3:

- Crossover angle
- Crossover distance
- Auxiliary lanes & turn pockets
- Signal phasing options
- Pedestrian routing/central median
- On and off-ramps

exhibit 2-3: ddi configuration areas

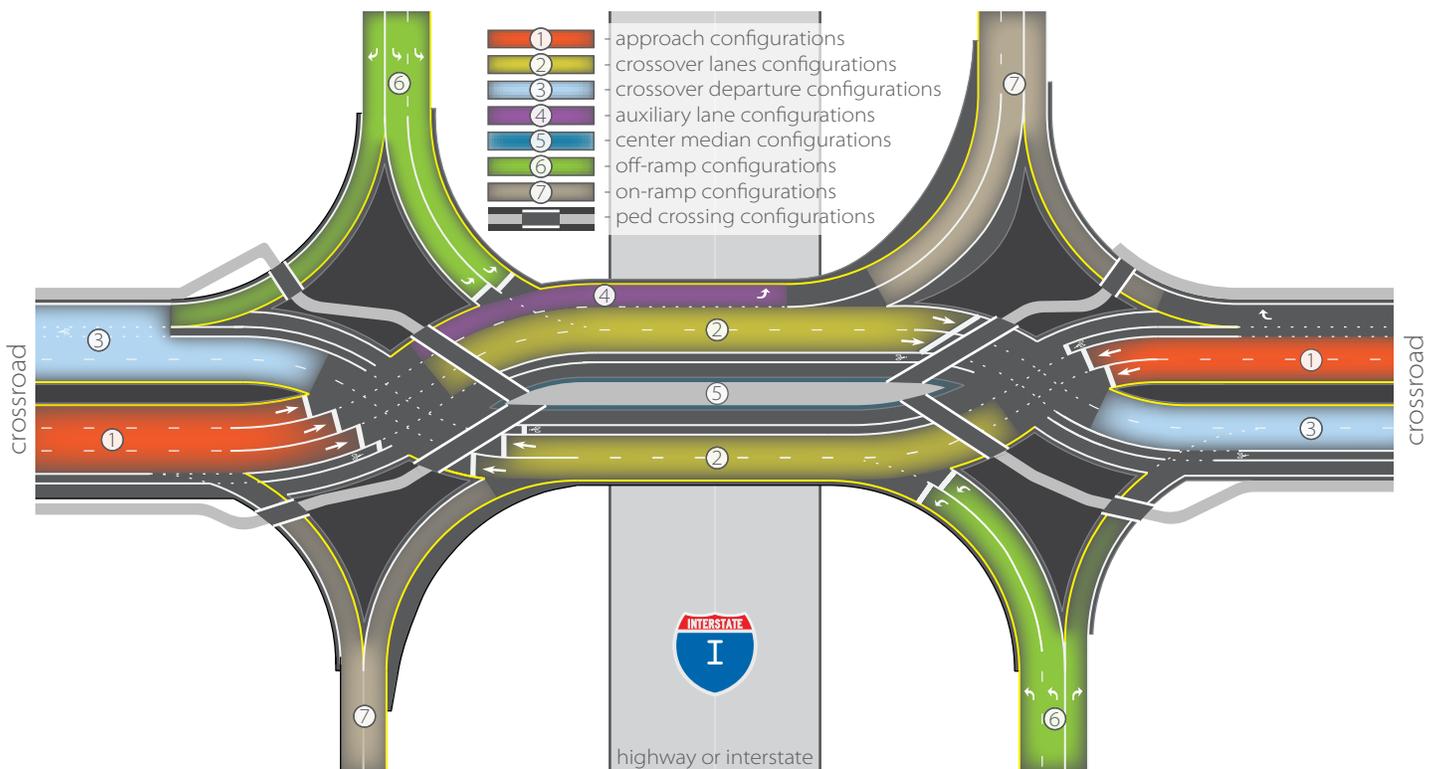
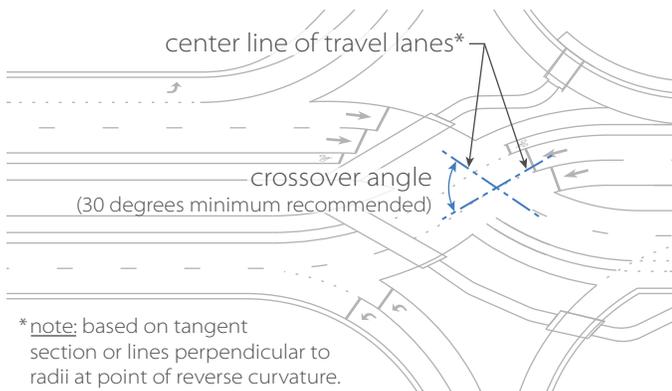


exhibit 2-4: ddi crossover angle

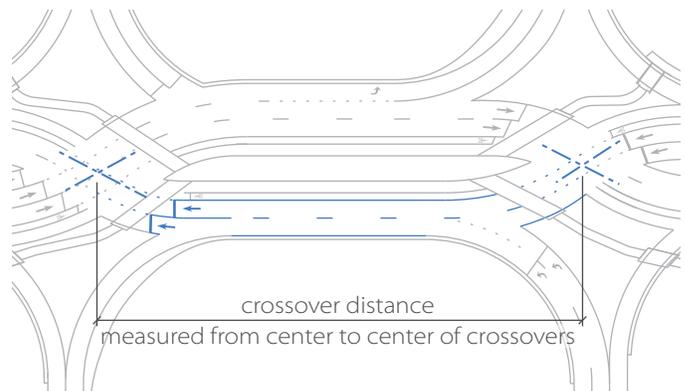


Crossover Angle

DDI crossover types fall into two types: narrow angle crossovers (30 to 40 degrees) and wide angle crossovers (greater than 40 degrees). Crossover angle is illustrated in Exhibit 2-4.

Narrow angle crossovers are the variety most implemented to date in Utah. They tend to minimize the size of the center median, can be implemented with two structures instead of a single structure, and usually move pedestrians through the perimeter of the interchange.

exhibit 2-5: ddi crossover distance

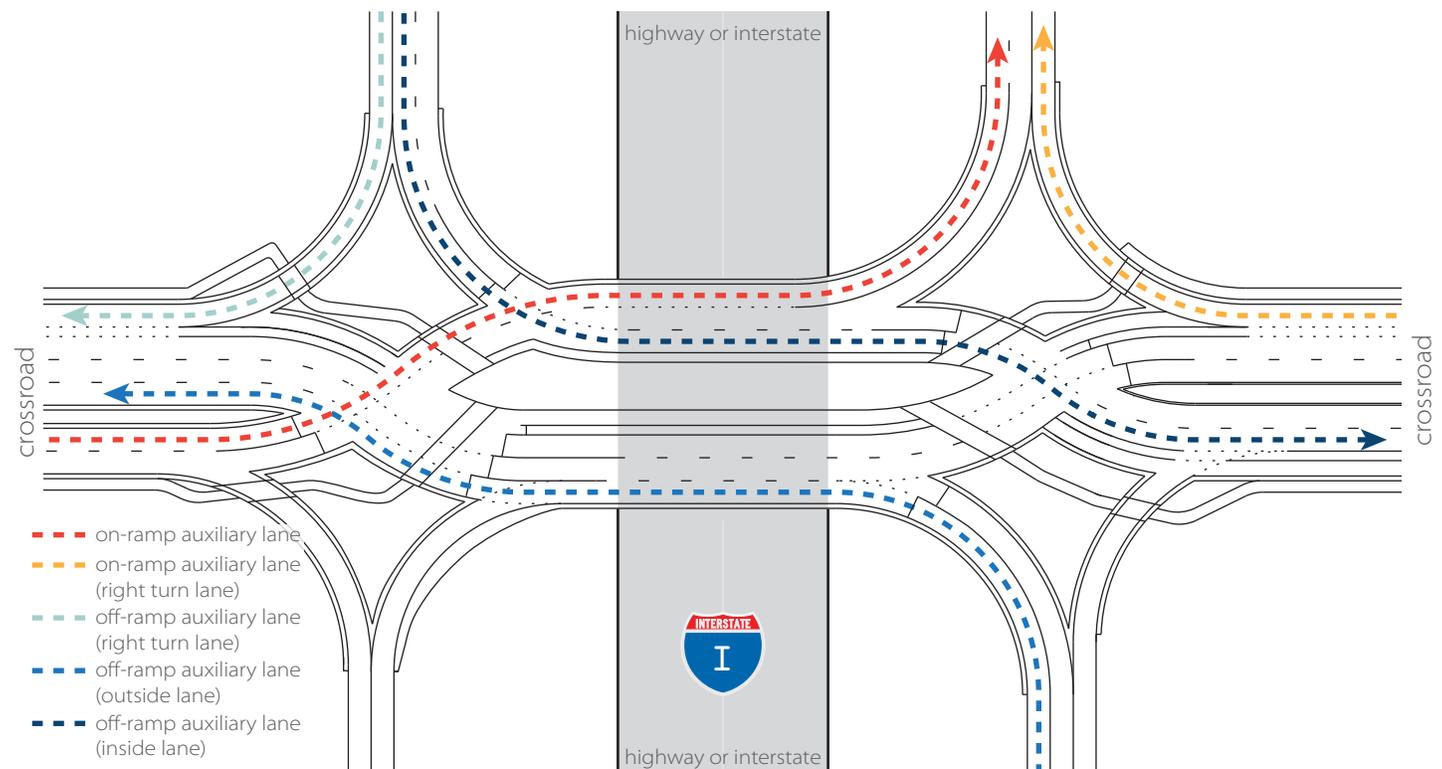


Wide angle crossovers are characterized by a wide median in the middle of the interchange that is often used as a pedestrian refuge for crossings. Utah is currently considering several of these designs due to the benefits afforded to pedestrians in crossing fewer “free” turn movements and the ability to cross busy arterials under the protection of signalized pedestrian movements.

Crossover Distance

The distance between crossovers, or crossover distance as shown in Exhibit 2-5, typically falls between 300 and 1500 feet. Shorter distances (less than 700 feet) tend not

exhibit 2-6: auxiliary lanes



to perform as well operationally, are more susceptible to failure (especially with moderate to high through volumes), do not provide as much signal flexibility, and are usually found in retrofit scenarios. Longer distances (700 to 1500 feet) provide the best operations and signal flexibility, but are usually associated with new structures and or skewed interchanges. Where possible, crossover distances of 850 feet or greater are recommended.

An important consideration in determining crossover distance is an understanding of the relationship between cycle length and the distance between crossover intersections given by the formula:

$$c = 2d/s,$$

where

c=optimal cycle length,

d=distance between intersections, and

s=speed

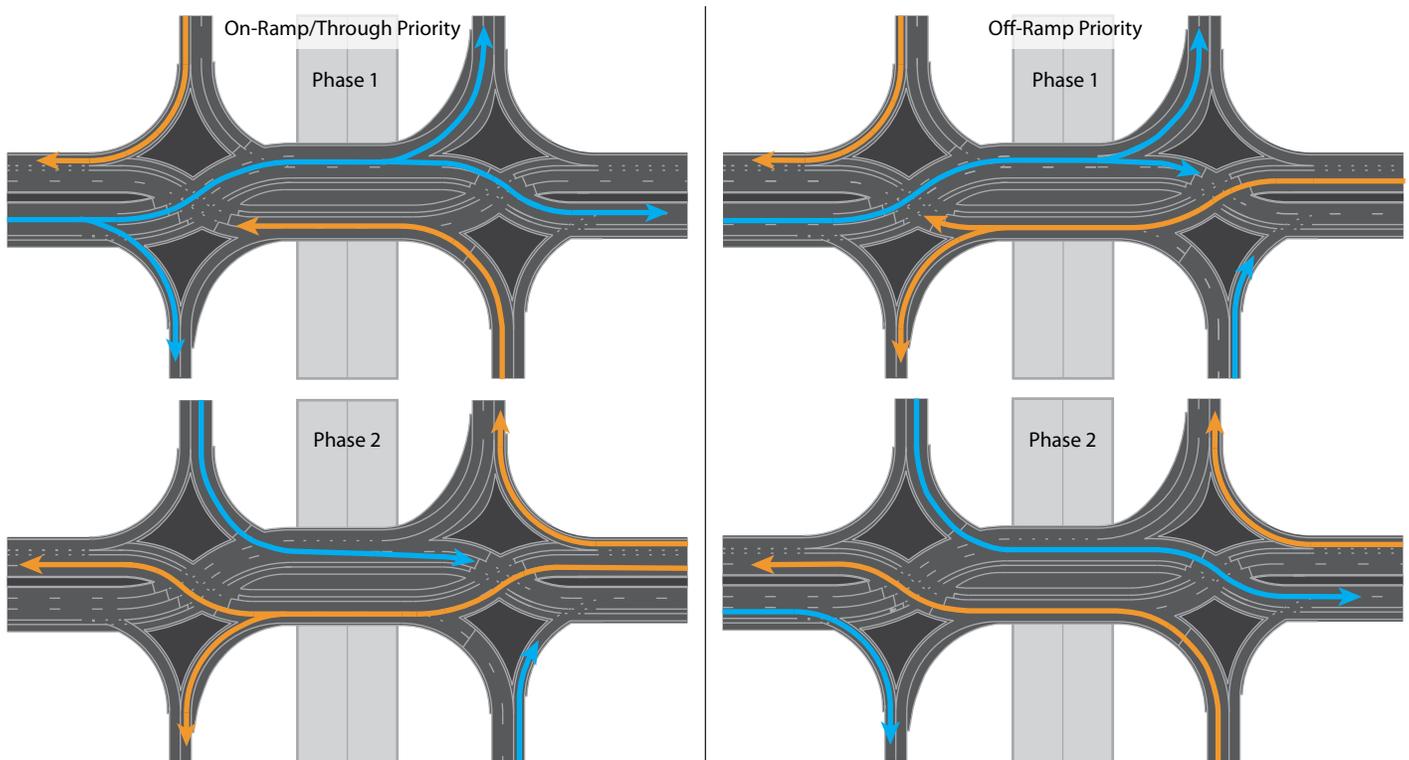
At design speeds near 35 mph and crossover distances less than a quarter mile, this formula indicates typical optimal cycle lengths between 35 and 75 seconds. Since

the higher cycle lengths are associated with lower speeds and longer distances, and the lower cycle lengths are associated with higher speeds and shorter distances, lower speeds and longer crossover distances tend to harmonize best with “longer” DDI cycle lengths. Since these “longer” DDI cycle lengths also tend to correspond with typical half cycle lengths for typical arterial corridors this also tends to provide a little better flexibility in signal timing. In practice, UDOT typically runs cycle lengths between 45 and 90 seconds for DDIs, and so the longer crossover distances and lower design speeds are generally preferred from a signal operations perspective for greater flexibility within this range.

Auxiliary Lanes and Turn Pockets

As needed to support the efficient flow of various turn movements, DDIs can be configured with a variety of auxiliary lanes as shown in Exhibit 2-6. These include approach lanes, departure lanes, and turn lanes on both the outside and the inside (near the median) of the DDI. Auxiliary lanes reduce weaving and improve both through movement and turn movement capacities. They are used strategically in both new build DDIs and in retrofit DDIs to increase capacities for critical movements while minimizing the structural impacts from general roadway widening.

exhibit 2-7: ddi phasing strategies



Signal Phasing Options

Two basic signal phasing strategies have been deployed in Utah as shown in Exhibit 2-7. One favors crossroad movements and on-ramp movements (crossroad/on-ramp phasing) while the other favors off-ramp movements (off-ramp phasing). As would be expected, crossroad/on-ramp phasing tends to better serve higher through and left turn on-ramp volumes, while off-ramp phasing tends to better serve higher left turn off-ramp volumes. Other phasing strategies have been deployed outside of Utah, such as one that keeps the crossover storage area clear of vehicles and functions more like a split interchange for all movements.

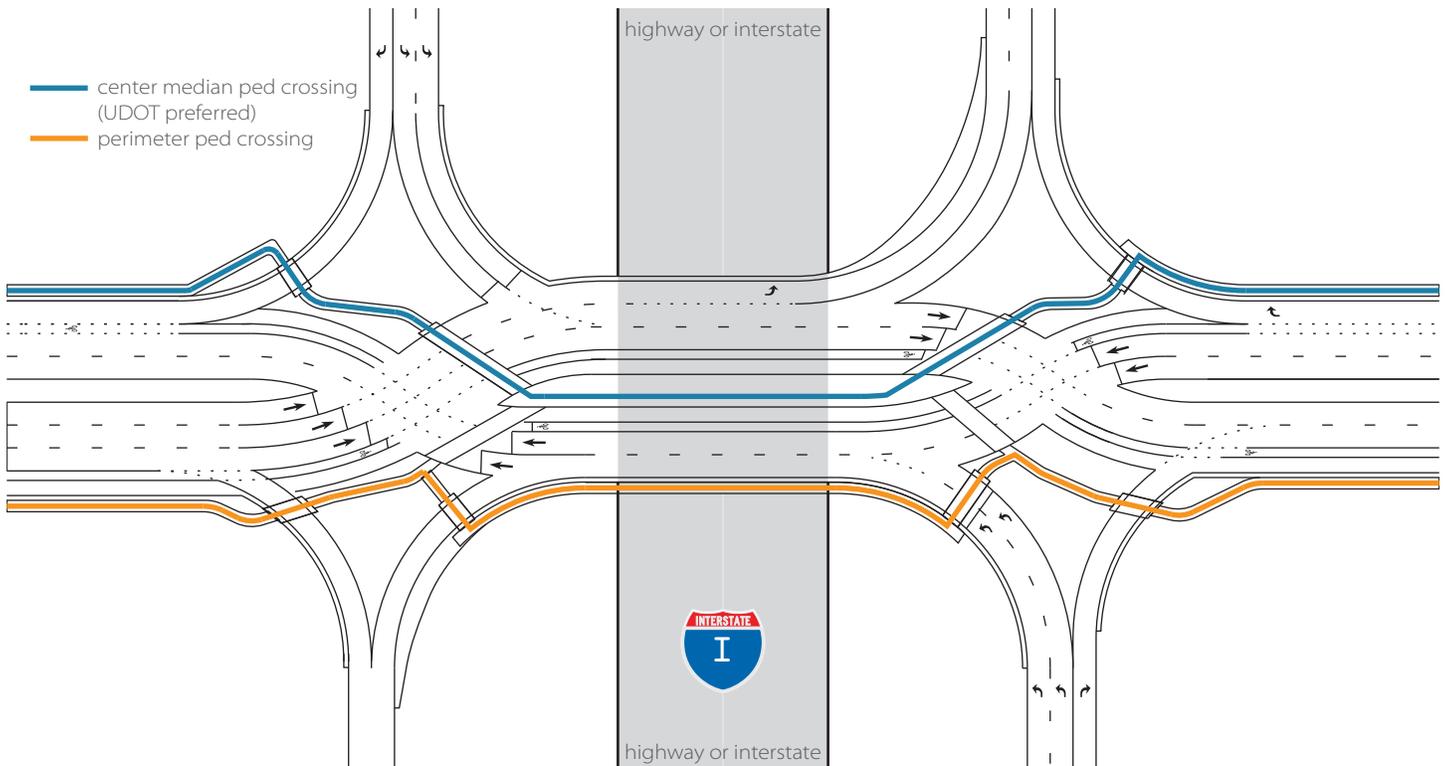
Regardless of what phasing strategy is used, the goal is usually to minimize the queuing between the crossover intersections, thus ensuring that left-turning vehicles onto the on-ramps are not blocked from entering the ramp. Both strategies may be used at different times of day for the same interchange depending on traffic demands throughout the day. Regardless of the signal phasing strategy that is used at a DDI, in essence the interchange functions as a split phase signal for the cross street, which may create operational issues at locations with heavy through traffic volumes in each direction on the cross-street.

Depending on the traffic volumes to be served, left and right turn movements to and from the interchange ramps may also be customized as protected only signalized movements, protected-permissive signalized movements, stop controlled movements, or free movements. New legislation in Utah specifically allows for left turn on red movements at DDI off-ramps, which can further improve the operations of off-ramp movements. In these cases, left turn on red may be possible for one or two-lane movements, but is not recommended for three-lane movements.

On and Off-Ramps

On and off-ramps are configured similar to other interchanges, with the configuration of ramps often being directly tied to the development or termination of auxiliary lanes and turn pockets. One significant point of note is that signal control plays a significant part in the configuration of ramps which can be significantly impacted by free ramp movements, yield movements, turning on red for both left and right turns, and ramp metering. Ramp meters are of particular concern since ramp queues that back into the crossover areas from the ramp meter can cause the DDI to lock up.

exhibit 2-8: ddi pedestrian crossing



Pedestrian Configurations

Pedestrians typically cross DDIs at-grade by using an island located in the center median of the interchange or by using the perimeter of the interchange. Both options are depicted in Exhibit 2-8.

As previously discussed, the first of Utah's DDIs crosses pedestrians on the perimeter of the interchange, which often places them in the position of crossing free movements at locations with limited visibility. Recent designs have shifted pedestrians to the center median. This improves lines of sight for both pedestrians and vehicles to and from the crossings, allowing left turns to the entrance ramps to run freely without conflicting with pedestrian crossings. Also, by employing the median crossing strategy, pedestrians cross at the signalized crossover intersections, consistent with expectations of both drivers and pedestrians. Thus, UDOT recommends that all future DDI designs utilize the center median crossing option for pedestrians.

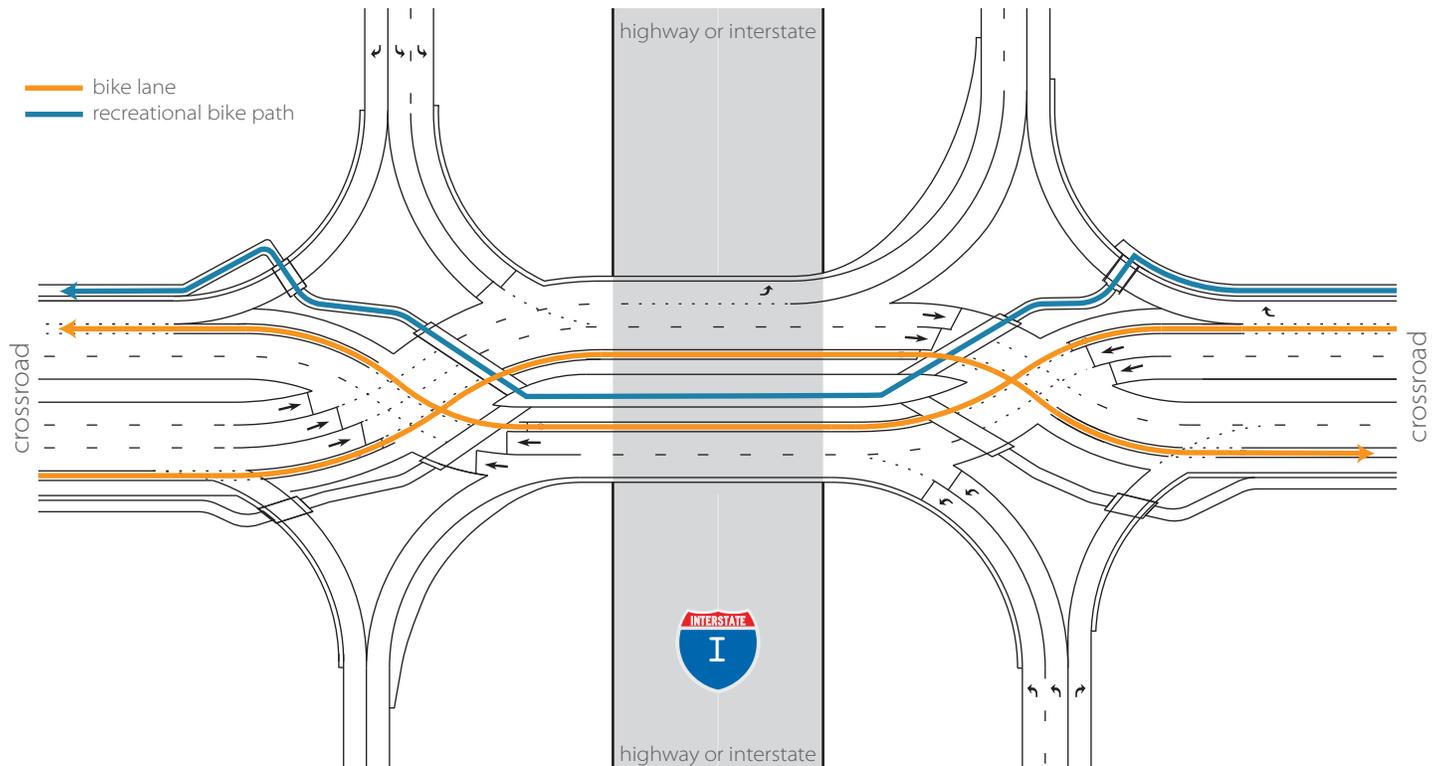
While all of Utah's DDIs have currently been designed with at-grade pedestrian crossings, grade separated pedestrian crossings that remove pedestrian movements from the interchange altogether could also be considered. Even though grade separated pedestrian crossings are costly, they are nevertheless advantageous from a

traffic operations standpoint. Removing pedestrians from the intersection via grade-separation improves pedestrian safety, simplifies signals, and allows greater flexibility with signal timing. On the other hand, grade-separated pedestrian crossings increase the traveled distance and the effort required for pedestrians to cross the intersection, which sometimes leaves those structures underutilized while pedestrians continue to risk at-grade crossings for the purpose of convenience. Thus, grade separation should be limited to locations where there are high pedestrian volumes conflicting with high turning volumes. Though not a DDI interchange, University Parkway and I-15 provides a good example of grade separation for such a situation.

To more closely match the expectations and tendencies of pedestrians, at-grade crossings should be given due consideration. In addition to matching pedestrian expectations, at-grade crossings have the added benefit of avoiding many property impacts, utility impacts, and costs.

Pedestrian crossings of free right or left turn lanes usually require turning vehicles to yield when pedestrians are in the crosswalk. Depending on the design speed of the roadway and crosswalk visibility, flashers or other advanced warning signs/devices may be advisable.

exhibit 2-9: ddi bicycle navigation



Pedestrian crossings of these movements may also be signalized with pedestrian call buttons and timed pedestrian phases. Pedestrian phasing should be tied to the overall signal phasing structure to ensure pedestrian crossings are not occurring at the same time as vehicles are arriving at the crossing location. Signalized pedestrian crossings should be shortened whenever possible in order to allow maximum signal timing flexibility.

As is the case with other types of interchanges, pedestrian hybrid beacons should not be used for pedestrian crossings at DDIs.

Bicycle Accommodations

Bicycle movements at a DDI should be accommodated in the same way as other vehicles. They can be provided with a bike lane (or widened shoulder area) to the right of vehicular traffic that allows bicycle crossover movements at the same time as vehicular crossover movement, or bikes can share travel lanes with vehicles. Shared use of vehicular lanes is usually not a huge concern at DDIs due to the slower speeds typically associated with the crossover areas.

A more detailed discussion of potential provisions for bicyclists can be found in Section 4–DDI Design Parameters.

Basic Design Geometry

Basic design geometry including lane widths, receiving lanes, and turn radii should follow UDOT design guidelines, including allowances for design exceptions where appropriate. Generally speaking, crossover angles should be between 30 and 60 degrees, with minimum back to back curve radii, as appropriate given the design speed and cross slope, with short tangent sections at the actual crossover. Turn radii should be evaluated using appropriate turning templates.

Medians, barriers, and glare screening should be used to provide positive guidance and appropriate separation between opposing traffic movements or between pedestrians and vehicles. Medians in DDIs are used to channelize and direct vehicular movements, to provide pedestrian refuge, and to provide placement locations for overhead sign structures, signals, and other roadway signs.

Specific geometric design guidance is provided in greater detail in Section 4–DDI Design Parameters.

SECTION 3 TRAFFIC EVALUATION

VISSIM Modeling

To confidently evaluate DDI traffic characteristics with variable alternatives, appropriate tools are required. No one size fits all DDI exists, particularly in retrofit applications where each of the previously discussed conceptual design variations has the potential to vary the traffic operations and performance of the interchange, or to significantly enlarge the design footprint.

Traffic microsimulation software provides reliability and flexibility to evaluate the various unique elements of a DDI. For the analysis of DDIs, UDOT requires the use of VISSIM, which is a robust path and behavior-based microsimulation software that simulates each transportation mode (train, bus, car, bike, or person) individually.

Other less sophisticated analysis tools such as HCS, Cap-X, and Synchro are empirical tools which provide results based on specific variables and equations. This means that generally, for any given set of variables, the calculations will always produce the same results, regardless of the traffic behavior that is influenced by intersection spacing, queue spill back, weaving, or other complex traffic characteristics. While other microsimulation tools such as SimTraffic (or older tools like CORSIM) are stochastically based, they sometimes lack the ability to accurately evaluate the more complicated operation of a DDI for a design-level analysis. While these may be very adequate tools for other intersection configurations, or even a high planning-level analysis of a DDI, experience has shown that these less robust tools are generally not flexible enough to accurately and confidently model the complex travel behavior which occurs at a DDI or other innovative intersection.

VISSIM's robust features have made it UDOT's tool of choice for modeling complex traffic operations at innovative intersections like the DDI. This does not mean that other tools do not have value in other traffic analysis and optimization tasks, or that VISSIM is infallible due to its robustness and flexibility. On the contrary, VISSIM's robust flexibility can also be particularly dangerous if driver

parameters, decision points, and network paths are not kept true to observed driver behaviors and traffic characteristics.

It is important to remember that other solutions being considered and compared to a DDI (which may be satisfactorily evaluated using another software) should also be evaluated using the same software (e.g. VISSIM) and be developed from the same base model from which the DDI concept is being evaluated to preserve and ensure appropriate comparisons can be made. Furthermore, the coding of the VISSIM model should follow generally accepted industry practices. Additional guidance can be found in the Federal Highway Administration (FHWA) publication *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software*.

Unrecognized and unchecked deviations from observed behaviors and poor modeling practices lead to analysis that potentially misrepresents traffic operations by over-

stating the benefits of marginal improvements and understating the benefits of more robust improvements. Inaccurate measures of effectiveness (MOEs) alter traffic-based design recommendations, producing sub-optimal designs. And ultimately, the MOEs provided by microsimulation analysis affect decision making—determining what alter-

natives will be built, what design features they will have, and how those features should be designed or sized. It is therefore critical that traffic models emulate real behaviors to provide confident results for making decisions.

Calibration and Validation of Models

An existing conditions microsimulation model does not become a credible basis for developing alternative models until it demonstrates the ability to reliably mimic existing conditions. The calibration and validation of traffic models is necessary to ensuring that microsimulation models do, in fact, emulate real traffic behaviors and characteristics. Every intersection is different. Lane geometries, driver behaviors, turn movements, turn storage areas, transition areas, origin destination routes, and signal timings are a little bit different for every location. Each of these traffic characteristics should be confidently replicated in the microsimulation model based on field observations and

“You can’t expect to meet the challenges of today with yesterday’s tools and expect to be in business tomorrow.”

— Nelson Jackson

Operations Thresholds

- *No queuing into mainline*
- *No queuing from free turn movements onto ramps*
- *LOS C or above at crossovers*
- *LOS D or above at adjacent crossroad signals*

data collection. In calibrating microsimulation models, especially a high-capacity intersection like a DDI, special consideration should be given to observed traffic characteristics such as (to name a few):

- Unserved peak hour traffic volumes
- Observed queue lengths
- Travel times
- Lane utilization
- Saturation flow rates
- Friction areas
- Origin destination and other critical paths

Once critical traffic characteristics have been identified, they can be replicated in the microsimulation model at several different points. Some of the more common areas requiring calibration are:

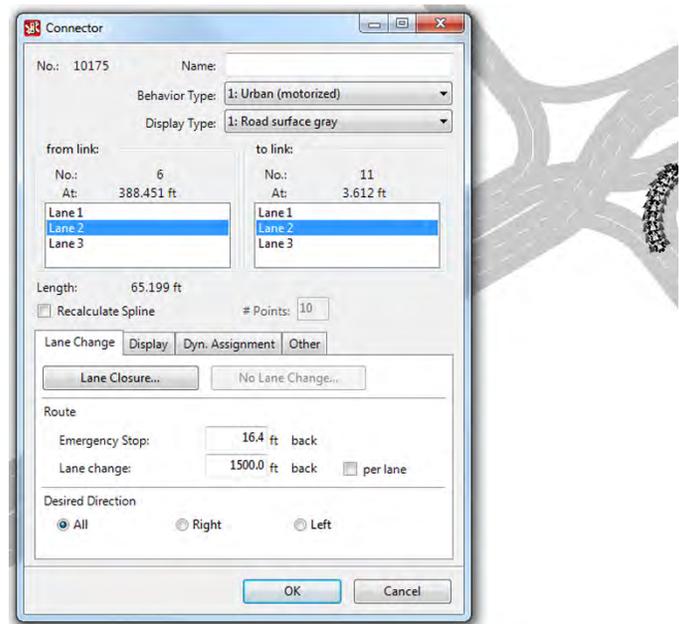
1. Individual route characteristics and lane change distances
2. Global link and lane change behaviors (saturation flow rate parameters)
3. Accurate signal timing & logic (RBC may not be enough in some instances, sometimes it may require software in the loop (SIL) to be more accurate)
4. Priority rules and conflict areas
5. Speed profiles, desired speed decisions, and reduced speed areas

The following details are intended to provide a general overview of these specific parameters as they might relate to special DDI considerations and are not intended to address all the options or strategies for calibrating a

microsimulation model. Furthermore, additional information should be sought and reviewed in the appropriate software manuals to more fully understand these parameters and their functions in the software.

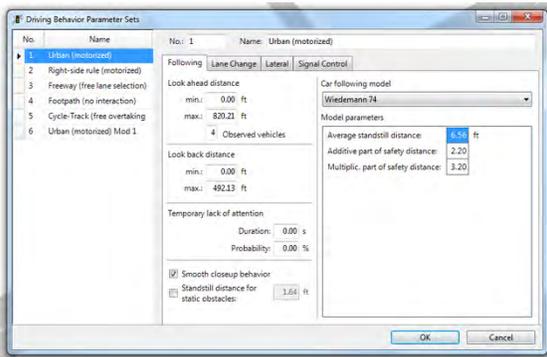
1. *Individual route characteristics and lane change distances.* Links and connectors provide the path-based connectivity through the network of a VISSIM model and the parameters governing lane change behavior. The emergency stop and lane change parameters (Exhibit 3-1) are used to help control the lane change behavior for vehicles. Emergency stop defines the last possible position for a vehicle to change lanes. Lane change defines the distance at which vehicles will begin to attempt to change lanes (e.g. a sign distance from a turn). If the per lane option is active, the given lane change value will be multiplied by the number of lanes the vehicle has to change to reach the connector. Additional care should be given to these settings with respect to proper lane utilization and lane change planning through the DDI.
2. *Global link and lane change behaviors.* Both the car following and lane change models in VISSIM use an extensive range of parameters (Exhibit 3-2). Some of these may be adapted by the experienced user to change basic driving behavior. As these parameters directly affect the vehicle interaction and can cause substantial differences in simulation results, only experienced users should modify, if necessary, any of these

exhibit 3-1: lane change parameters



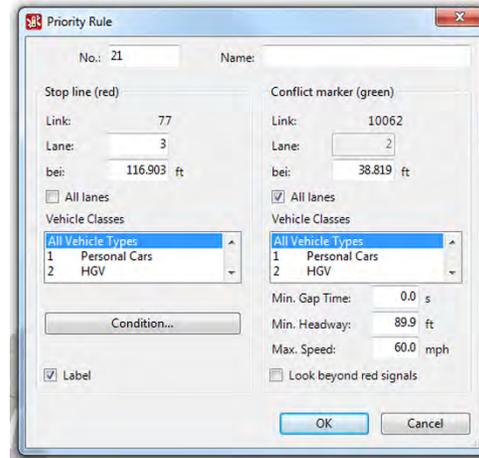
parameters. Particular attention should be given to these settings to appropriately calibrate link capacities for DDIs given their unique operation and potentially higher capacity capabilities. Refer to the software user manual for additional detail and specifics for these settings.

exhibit 3-2: global link parameters



replicate decisions drivers make before crossing conflicting travel lanes (e.g. decision points).

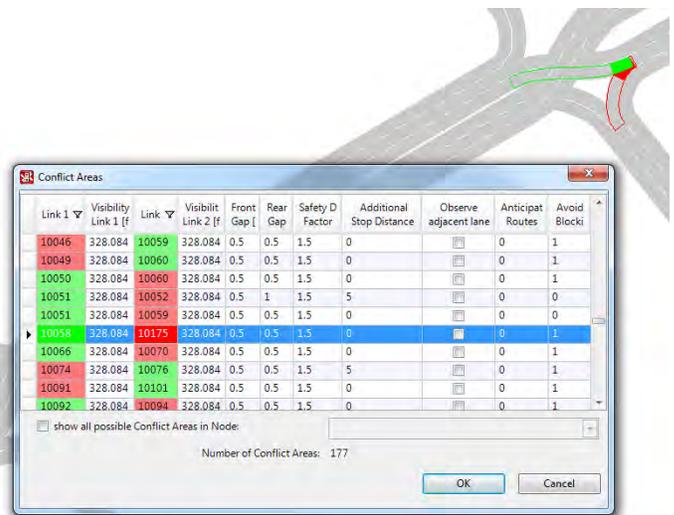
exhibit 3-3: priority rules



3. *Accurate signal timing.* An elementary part of calibrating any traffic model includes inputting accurate signal timing. Because DDIs operate uniquely and rely on more sophisticated signal timing strategies such as overlaps to operate efficiently, special attention should be given to assuring signal timing operation is accurate for the DDI configuration. Due to the additional capacity potential of a DDI, properly placed signal detectors can have a significant impact on the operation of the interchange and should, therefore, be coded appropriately. Some other special areas of focus should include the ring and barrier structure, phase sequence, left turn phasing type, offsets, pedestrian and vehicle splits, overlaps, minimum green times, clearance intervals; passage/minimum gap times, and reasonably expected signal optimization for alternative scenarios. Ultimately, consult with UDOT signal staff (or specific agency staff in other locations) to assure accurate operation.

Conflict areas (Exhibit 3-4), like priority rules, are another parameter in VISSIM that helps simulate yielding behaviors (e.g. decision points). A conflict area can be defined wherever two links/connectors in the VISSIM network overlap.

exhibit 3-4: conflict areas



Utah recently (in 2013) changed the local law to allow a vehicle to make a left turn on red from a one-way street into a one-way street if traffic is clear and signs are provided which allow the movement. This traffic behavior should be modeled appropriately based on intended implementation and operation.

Both parameters are used to help control permissive movements and warrant additional attention when developing a DDI model, especially at unique DDI

4. *Priority rules and conflict areas.* Priority rules are used to model driver behavior (Exhibit 3-3) to more closely

features. Refer to the software manual for details and direction on the application of these parameters.

5. *Speed profiles, desired speed decisions, and reduced speed areas.* It is important to define speed profiles accurately (for any evaluation performed in VISSIM), based on data collected from the field. This parameter can have a significant effect on travel time calibration and should be adequately considered during model development.

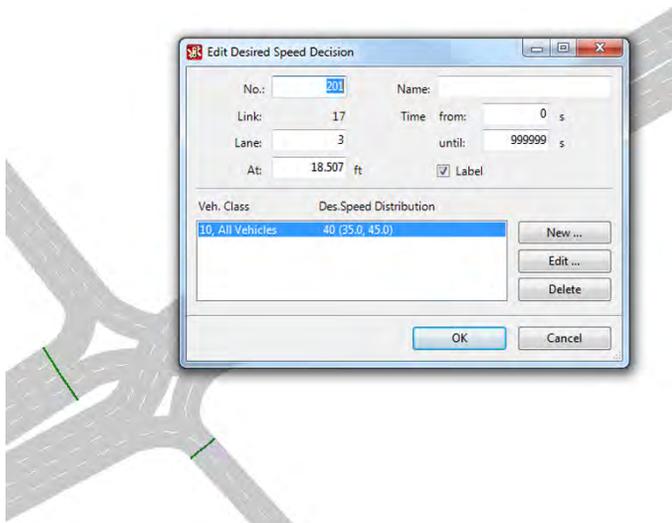
Locations particular to a DDI exist where speeds must be adjusted to account for unique geometric layout features. A desired speed decision (Exhibit 3-5) should

be placed at a location where a permanent speed change should occur. Consider the appropriateness for use at, and through, the crossover locations.

Reduced speed areas (Exhibit 3-6) change the vehicle speed profile over the portion of a link where it is placed - typically used where vehicles turn and only temporarily slow. Specific attention should be given at turning locations for a DDI where radii may be different than a typical intersection. Again, refer to the software manual for details and application of these parameters.

Careful consideration and application of these parameters with validation will help improve the reliability and accuracy of DDI models, evaluations, and results.

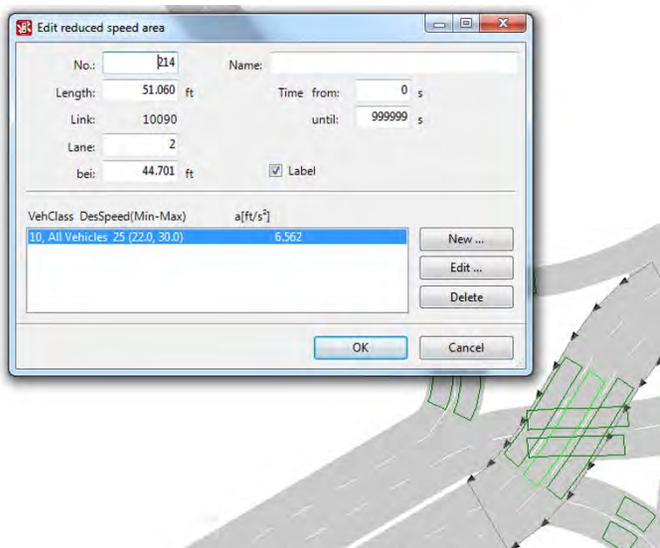
exhibit 3-5: speed decisions



Avoiding “Forced Calibration” of Models

The calibration and validation of models can be a difficult and time consuming process, but it is also an extremely critical process to developing confidence in evaluation models. Consequently, it should be recognized that when budgets are tight and/or experience is lacking, frustrated attempts may be made to “force calibration” by changing parameters that are not true to actual driver behaviors, roadway geometries, or traffic characteristics. For example, a driver traveling in the inside most lane on multi-lane arterial will not typically, and consistently,

exhibit 3-6: reduced speed areas



Questions for evaluating calibration techniques:

1. Is it reasonable to expect drivers to behave in this way?
2. Does this technique represent actual driver behavior at the location during the time of day being evaluated?
3. Are there other driver behaviors, roadway geometries, or traffic characteristics that may also contribute to the observed behavior?
4. How will the proposed calibration method affect the evaluation of alternatives?

make a decision to change lanes and turn right a mere 300' from the intersection. Consequently, a microsimulation model developed with a 300' lane change distance for right turns originating in the far left lane with the sole intent to induce congestion, lengthen travel times, or meet validation criteria would be considered inappropriately calibrated. Some additional examples of "forced calibration" could, but are not limited to, include: (a) changing the Desired Speed Decision parameters along a corridor from the observed free flow speeds to conform to corridor throughput or travel times, (b) changing the speed of the Reduced Speed Area parameter contrary to observed speed to either simulate queuing or show traffic demand being served, or (c) allowing conflicting vehicle movements to occur simultaneously in order to increase signal throughput.

Project managers and UDOT technical staff should be savvy to the process of calibration and validation along with common "forced calibration" shortcuts in order to ensure models are developed based on a realistic representation of actual traffic conditions. Simply, it is important to be able to assess the reliability of the model to accurately evaluate improvement scenarios.

Furthermore, it is important to remember that calibration precedes validation. After initial efforts are made to calibrate a model, thorough validation helps confirm the accuracy of the model (its ability to replicate field traffic conditions) and builds confidence in the tool's ability to accurately evaluate other traffic scenarios. Often, the process of calibration and validation is iterative in an effort to align the traffic operations in the model to those observed in the field.

Data Collection

The type and reliability of data collected is critical to the model calibration and validation process. In order to ensure proper model calibration and validation, consider collecting the following data:

1. *Average Daily Traffic (ADT)*. Every traffic count is a snapshot in time. ADT data is helpful to validate the other data to be collected based on historical patterns and for comparisons to other traffic forecasting tools like regional travel demand models.
2. *Turn movement counts*. Ideally, all turn movement counts for a study area should be collected on the same day (or for multiple days). Attention should be given to the accuracy of the data collection depending

on the needs of the evaluation (e.g. 15 minute bins). The process to review, balance, and input the traffic volumes into the model is one of the first steps in creating a reliable microsimulation model.

3. *Queue lengths*. Observing queue lengths provides a visual check to gauge congestion that can be useful in calibrating the microsimulation models to the existing conditions. Observing queue lengths every 15 minutes during the count can also help identify extending queues that could indicate unmet traffic demand. This unserved traffic would then be added to turn movement counts in the microsimulation model in order to more accurately replicate existing congestion.
4. *Saturation flow rate*. This information can be helpful to understand driver behaviors that affect congestion and translate them into the microsimulation model as headways, following distances, and other driver parameters.
5. *Roadway geometry*. Sub-standard lane widths and other geometric features such as merges and lane drops are common areas of friction for replication in the microsimulation model.
6. *Driveways*. In heavily commercialized areas, driveways can have a significant impact on roadway friction. Collecting driveways can also be helpful for understanding access opportunities and for messaging potential improvements to adjacent property owners.
7. *Signal timing*. Correctly modeling traffic signal timing plans is critical to replicating existing conditions.
8. *Travel times*. Travel times can be very useful, when collected at the same time as the other data, to validate the traffic model. Regardless of whether travel times are collected using drivers, GPS, or Bluetooth technology, it is important to ensure that enough data is collected to provide a reliable and confident data set from which to base travel time run estimates. The Student's T distribution can be used to determine the required sample size based on the standard deviation of the results.
9. *Video collection*. Video recorders can be used to collect turn movement counts and driveways. Having a video record is also very useful in identifying critical weave movements, origin destination routes, traffic splits, lane utilization, and other important travel characteristics. Video recorders can also be set

to record not just turn movement counts, but other critical movements as well. In path based models like VISSIM, knowing and mimicking these routes can be important to emulating actual traffic behavior.

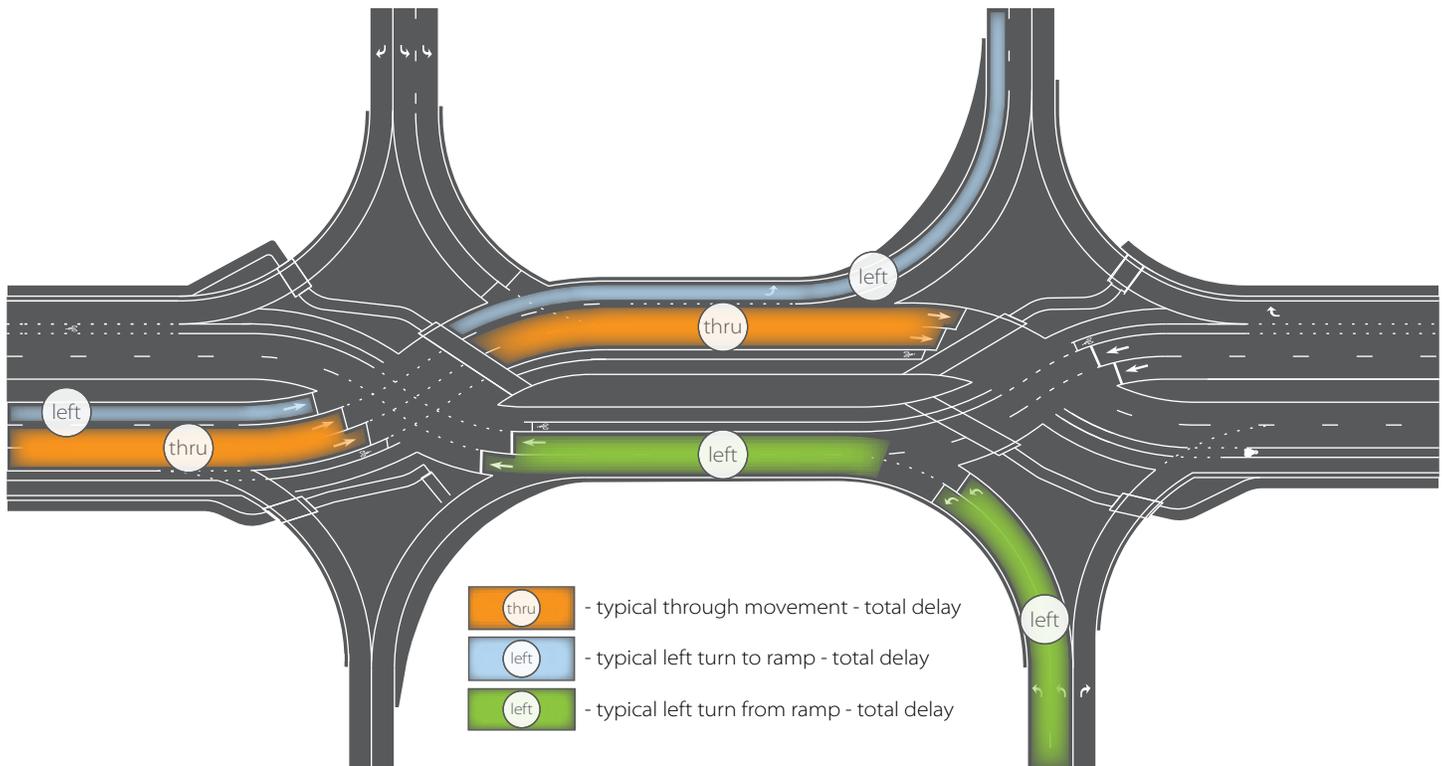
Evaluation standards can vary depending on the owner’s standards or requirements, the funding source, the environmental processes required, and/or the federal/state agencies involved. It should go without saying that consideration should be given to any requirements necessary prior to proceeding with evaluation efforts. However, a discussion about those requirements and any potential risks or nuances associated with the evaluation of a DDI is a valuable discussion early in the process.

DDI Measures of Effectiveness

Even though multiple signals are usually required to operate a single DDI intersection, the delays for all of the movements at these signals are typically aggregated into a single delay measure for each movement. For example, the delay for a crossroad crossover through movement would be added to the same direction on-ramp left turn delay (which is usually close to zero) to provide a single aggregate delay for the entire on-ramp left turn movement. Similarly, left turn delay at an off-ramp left turn movement would be added to the delay of the same direction crossroad through movement at the crossover to provide a single aggregate delay for the entire off-ramp left turn movement and through delay at each crossover would be aggregated to produce a single through movement delay.

This method of aggregating delay allows a good “apples to apples” comparison between a traditional interchange and a DDI alternative, and also falls in line with ramp terminal analysis in the 2010 HCM. The suggested aggregation of delay at a DDI is illustrated in Exhibit 3-7.

exhibit 3-7: ddi delay aggregation



SECTION 4 DDI DESIGN PARAMETERS

As introduced in previous sections, the intent of the information in this section is to identify areas requiring unique attention and is not intended to be overly prescriptive in its guidance. As with any intersection design, care should be taken to identify and address items specific or unique to each design. The DDI design guidance provided in this chapter is meant to supplement the guidance provided by the latest editions of publications such as the American Association of State Highway and Transportation Officials’ (AASHTO) *A Policy on Geometric Design of Highways and Streets* (Green Book) and *Roadside Design Guide*, UDOT’s *Manual on Uniform Traffic Control Devices* (Utah MUTCD), and UDOT Standard Drawings. For reference, some characteristics of Utah DDIs are found in Exhibit 4-1.

“Do not wait; the time will never be ‘just right.’ Start where you stand, and work with whatever tools you may have at your command, and better tools will be found as you go along.”

— Napoleon Hill

Microsimulation Use in Design Iteration

The capacity of a DDI is a function of its geometric design and signal timing. Although rules of thumb can be applied in developing a DDI design, optimizing that design requires a keen understanding of how driver behaviors, such as speed and acceleration, influence ideal geometric parameters such as the crossover distance, auxiliary lane

use, and signal phasing options. While rules of thumb can provide guidance for first iteration geometrics, the most efficient way to develop an effective DDI footprint is to use microsimulation tools during traffic analysis to iteratively develop a preliminary DDI footprint. Microsimulation using a well-calibrated model allows evaluators to confidently develop optimal DDI capacity by simultaneously and iteratively adjusting key geometric and signal timing parameters. Once an optimal DDI footprint is established using microsimulation, the modeled footprint can be used as the basis of a CAD design. Flexibility should be provided throughout the design process to align and fine-tune geometric design constraints with the microsimulation models, while being conscientious of the potential effects of design changes on signal timing and operations.

Geometric Design

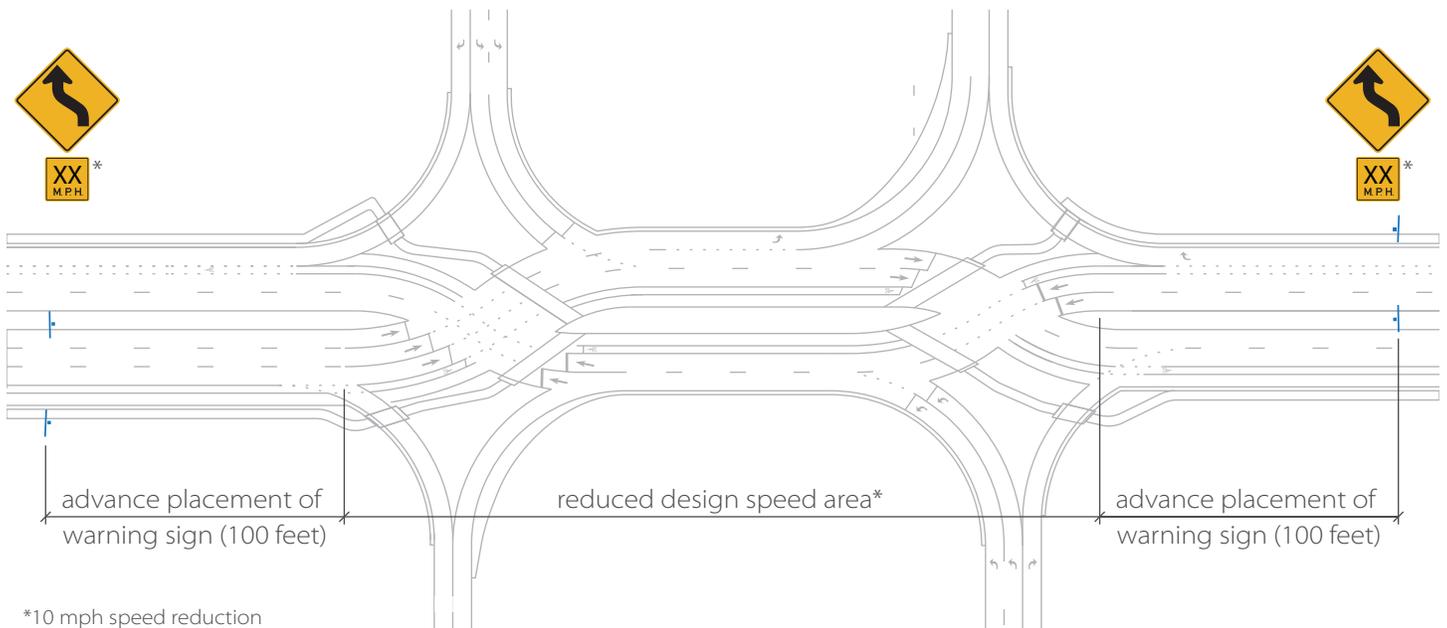
DDIs are very site-specific in their design characteristics. While the key elements of a DDI are interrelated and the

overall concept remains the same from one application to another, specific design measures, such as design speed, reverse curve radii, median widths, and other features may vary from one application to another. Educated design compromises may be necessary to balance project goals with good engineering judgment regarding operations, maintenance, and public safety.

exhibit 4-1: utah ddi characteristics

design elements	SR-201 & Bangarter Salt Lake City, UT	I-15 & Pioneer Crossing American Fork, UT	I-15 & Timpanogos Hwy Lehi, UT	I-15 & 500 East American Fork, UT	I-15 & St George Blvd St George, UT
opened to traffic	september 2011	august 2010	august 2011	november 2011	november 2013
design speed (roadway)	50 mph	45 mph	40 mph	40 mph	40 mph
design speed (DDI)	40 mph	35 mph	30 mph	30 mph	30 mph
distance between crossovers	830 feet	940 feet	720 feet	905 feet	780 feet
crossover angle	30 degrees w/ tangent	46 degrees w/ prc	42 degrees w/ small tangent	32 degrees w/ prc	30 degrees w/ tangent
overhead signs	no	yes	yes	yes	yes
glare screen barrier in median	yes - cwb	yes - cwb	yes - cwb	yes - cwb	yes - cwb
glare screen barrier at “eyebrow”	no - candle sticks	yes - cwb	yes - cwb	yes - cwb	yes - cwb
signal at right turn movements	yes	no	yes / no	no	yes
direction of cross slope through DDI	normal crown	split crown / low center crown	normal crown	low center crown	normal crown
pedestrians	n/a	yes - outside	n/a	yes - outside	yes - median
bike lanes	no	yes	no	yes	no
retrofit	yes	no	yes	no	yes
DDI over/under	over	over	under	over	over

exhibit 4-2: crossover speed area



*10 mph speed reduction

Design Speed

As of 2013, Utah has constructed DDIs on roadways with DDI crossroad speed limits ranging from 35 mph to 55 mph and high speed access restricted facility speed limits ranging from 55 mph to 70 mph. Since the crossover area of a DDI tends to operate best at lower speeds, designing DDIs on high speed crossroad facilities requires that speeds be lowered in advance of the DDI crossover area, with advance warning signs and geometric features provided to slow vehicles down as they approach the DDI, per Exhibit 4-2.

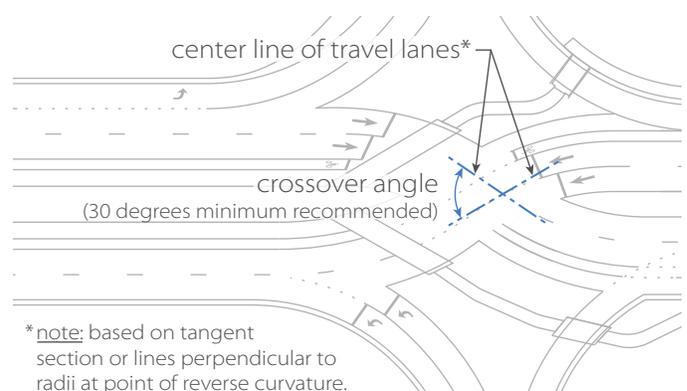
In UDOT current practice the design speed of the curves in the crossover areas has been less than the design speed of the approaching crossroad facility. This speed reduction has been at least 10 mph unless the reduction results in a design speed of less than 25 mph. UDOT has designed crossover areas for travel speeds of 25 to 40 mph. Actual design speed reductions for future DDIs should be determined by the design engineer.

The reduction of at least 10 mph in design speed within the DDI is current practice for several reasons. The first of these is driver familiarity. Interchanges that require drivers to crossover twice in less than a quarter mile are still a relatively new concept and some element of traffic calming is seen as beneficial in areas of lower driver familiarity. Additionally, signal operations tend to be more flexible with lower speeds and longer crossover distances, which make the DDI easier and more flexible for traffic

operations. Another added benefit of reduced speed is geometry. The small reverse curve radii associated with crossing over twice in less than a quarter mile simply require lower speeds. This curve geometry is complicated by crowns and adverse crowns at various parts of the roadway, which can lengthen radius requirements. Finally, additional reasons for reduced speed include reduced site distance requirements, the presence of pedestrian activity, reduced speed differentials with merging and diverging traffic, as well as progression benefits.

For roadways with higher design speeds, other traffic calming measures such as narrow shoulders, striping, and signing may be appropriate to reduce the approach speed. In the absence of right-of-way limitations or other geometric constraints that encourage smaller crossover

exhibit 4-3: crossover angle



* note: based on tangent section or lines perpendicular to radii at point of reverse curvature.

curve radii, a higher crossover design speed could be achieved if desired by increasing the radii of crossover curves. Horizontal and/or vertical curves in crossover approach areas should also be designed to provide adequate stopping sight distance in advance of the DDI crossover storage.

Crossover Angle

The closer the intersection angle is to 90 degrees the better. The minimum allowable intersection angle is 30 degrees, as measured in Exhibit 4-3. Crossing intersection angles in Utah have typically measured between 25 and 60 degrees.

Crossover Distance

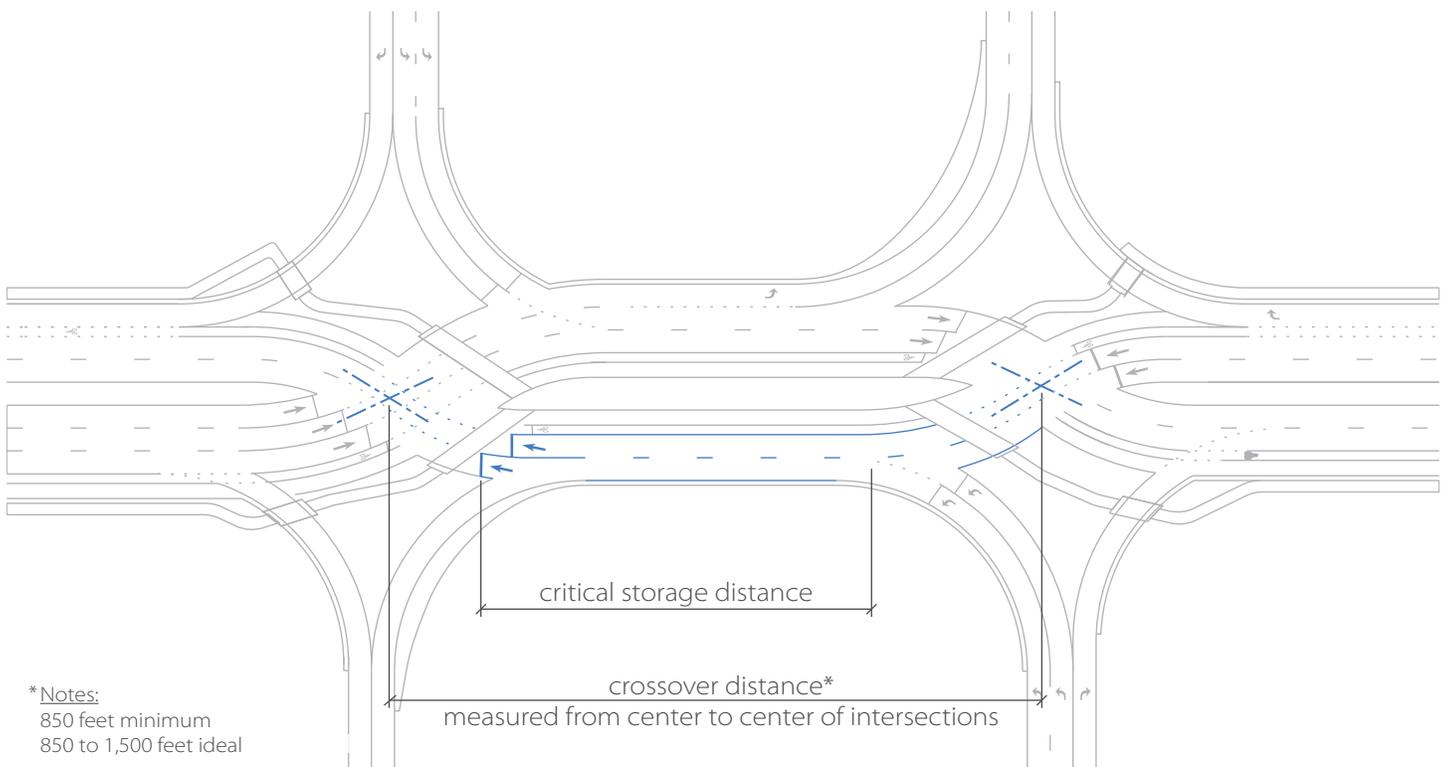
The minimum distance between ramp terminals, or crossover distance, as shown in Exhibit 4-4, will be governed by design constraints, traffic operations, and site conditions. Typically, the crossover distance falls between 300 and 1500 feet. Shorter distances (300 to 700 feet) tend not to perform as well operationally, are more susceptible to failure (especially with through volumes), do not provide as much signal flexibility, and are usually applied in scenarios that utilize existing structures. Longer distances (750 to 1500 feet) provide the best operations and signal

flexibility, but are usually associated with new structures and or skewed interchanges. Where possible, crossover distances of 850 feet or greater are recommended.

With insufficient crossover distance, queues from vehicles passing through the interchange on the crossroad facility may be trapped in the crossover area, blocking the left turn path onto the on-ramp and shortening the length available for lane changes. Consequently, the crossover distance on the arterial crossroad should be designed to provide storage for some through movement queue storage while simultaneously accommodating on-ramp left turn access and appropriate lane change distances.

Observational studies conducted by UDOT have found that a minimum of 850 feet of crossover distance (measured from center to center of crossover intersections) will normally provide adequate operational distance. In theoretical modeling of the concept and direct observation of DDIs with shorter crossover distances, reducing this minimum crossover distance has been shown to reduce capacity. Consequently, 850 feet should be used as a minimum rule of thumb for the initial design of crossover distance, with variations to this rule dictated by traffic microsimulation modeling in VISSIM and consultation with UDOT operations staff at the Traffic Management Division. In addition to VISSIM modeling, a weave/merge

exhibit 4-4: crossover distance



analysis should be completed for cases where off-ramps will not be signalized. Both the VISSIM model and the weave/merge analysis should be provided to UDOT as a design submittal requirement.

In cases where available crossover distance is limited by design constraints, an auxiliary lane may be needed between the ramp terminals to provide adequate storage and to avoid through movement blocking of the left turn movement.

Striping and Signing

Striping provides helpful navigation information to the traveling public using the DDI. Although the DDI is an unconventional intersection, striping consistent with the standards established by the Utah MUTCD ensures that a consistent message is always conveyed to drivers.

Non-standard striping items for DDIs include the placement of directional arrows at the stop bars to emphasize the correct direction of travel, and widened stop bars. See Exhibit 4-5 for typical striping at a DDI.

Dotted white lines or “turkey tracks” are typically used to delineate the path of crossover movements in order to guide left turning vehicles and to discourage them from

entering the conflicting through lanes in a wrong way movement. Designers should consider whether to provide these dotted lines on just one side of the crossover path, or on both sides. Pavement markings, especially dotted lines, tend to fade over time and require periodic maintenance. Strategically eliminating some dotted lines at crossover locations or at intersection left turn locations saves both time and money in long-term maintenance but should be looked at carefully to avoid over-minimization and its effects on DDI operation. Alternately, designers should consider specifying grooved thermoplastic markings that would resist friction from tire paths and snow plows.

Designers should consider wider-than-usual stop bars, up to 24 inches wide, to draw drivers’ attention to the stop bar at the crossovers and ramps and to discourage drivers creeping too far into the intersection (typical behavior when a stop bar is placed back farther from the intersection). Crosswalk designs at a DDI should meet the standards for either school or non-school crossings. Staggered and slanted stop bars are permitted as may be necessary to best meet the needs of the project.

Solid striping spaced at least 2’ from the edge of roadway should be used on either side of the medians to provide buffer to traveling vehicles per UDOT standard. Yellow

exhibit 4-5: ddi striping

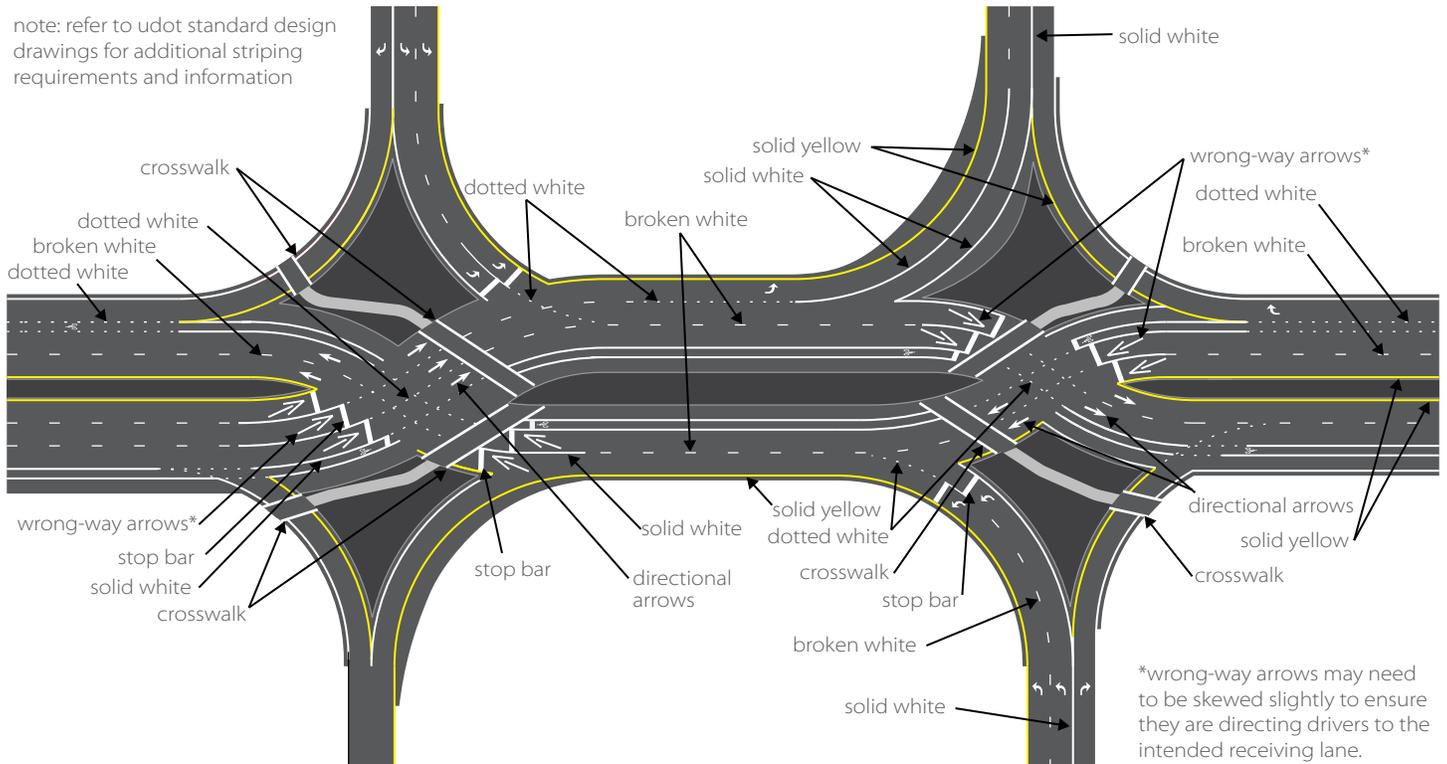
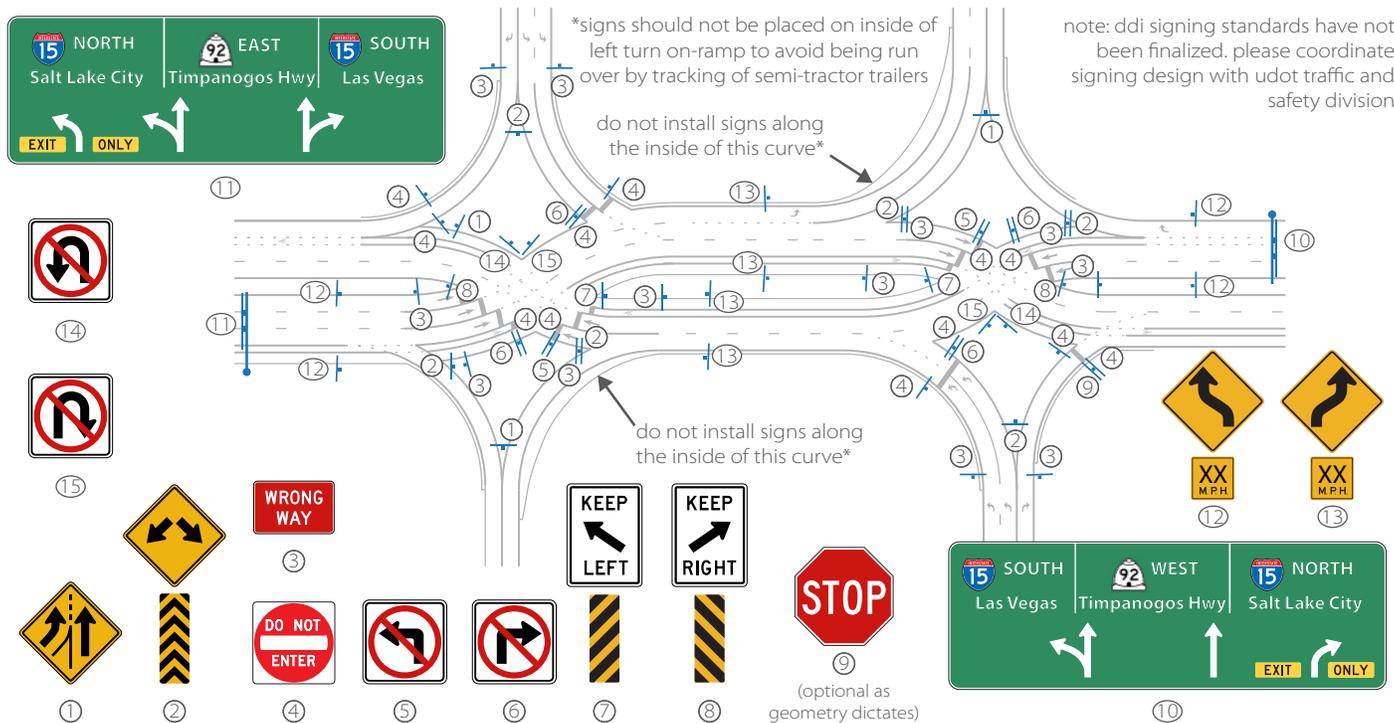


exhibit 4-6: ddi signing



striping should be used against medians on the driver's left side and white striping against medians on the driver's right side. In areas where single or multiple lanes are completely channelized while negotiating turns or curves (displaced left turn lanes for example), attempt should be made to provide more than a 2' buffer between travel lanes and the median, or to widen the lane widths.

At a minimum, the design of a DDI should include:

- Overhead and roadside signs which direct drivers to the appropriate lane for their turning movements
- Dotted lines or "turkey tracks" to guide crossroad traffic through the crossover intersection
- Directional arrows in each through lane on the approach side and departure side of the crossover intersection

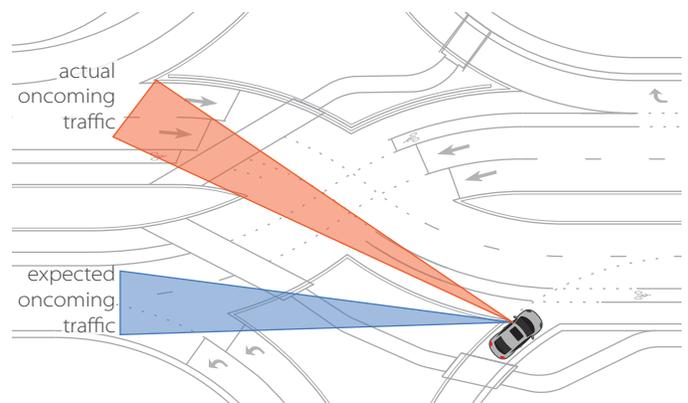
Overhead signing should be used to direct drivers from the crossroad approaches through the interchange. "Do Not Enter" and "Wrong Way" signs should be provided to warn drivers not to enter the wrong leg of the crossover intersection. Also, sign placement should avoid the inside of left turn on-ramp movements in order to avoid signs being run over by the tracking of semi-tractor trailers. See Exhibit 4-6 for typical DDI signing.

Additional signs and pavement markings warning drivers to avoid blocking the crossover intersections may be required under some circumstances; however, this should not be the case for initial installation if the DDI was properly designed. If regular intersection blocking is anticipated, the DDI may not be an appropriate alternative for the intended location.

Line of Sight and Glare Screening

Lines of sight for conflicting traffic movements do not always meet driver expectations at a DDI, as described in Exhibit 4-7. Since these lines of sight differ from driver

exhibit 4-7: lines of sight



The need for glare screening depends on the design geometry of the application. Line of sight diagrams should be used to determine glare screening needs in areas where the headlight paths of opposing vehicles may intersect. This is often a particular concern in retrofit scenarios where crossover lanes often line up directly opposite of opposing approach lanes. Line of sight between opposing crossroad through movements at crossover intersection stop bars will dictate the extent of glare screening required at those locations and beyond. At distances further away from the crossover intersections, headlight glare can still be significant when vehicles are directly aligned with each other as they approach the intersection. See Exhibit 4-8 for an illustration of how a concrete wall barrier in the eyebrow area can reduce this problem.

Roadway and Lane Width

UDOT design standards for shoulder width should be followed within the DDI. A wider than minimum shoulder is recommended where appropriate, to better accommodate stranded vehicles and bicycle use.

UDOT discourages the reduction of shoulder widths and lane widths across structures despite recognizing the necessity to reduce shoulders in retrofit applications. Lane widths should be a minimum of 12 feet wide, unless a design exception has been granted. While designing crossover lanes, designers should apply the same guideline and standards, such as those for lane widths, curves, and striping, established by UDOT for conventional intersections.

UDOT design standards recommend minimum 12' wide travel lanes, especially for receiving lanes. Under special circumstances, such as right-of-way/utility conflicts, UDOT has approved the use of 11' and 11.5' wide through lanes through the design exception process. Lanes narrower than 12' are not recommended at a DDI, especially in areas that are confined by medians. UDOT also recommends left and right turn lanes be a minimum 12' wide, and wider if possible. While some DDIs in Utah have been designed with receiving lanes as narrow as 12', this design has been recognized as undesirable for future DDI designs. Particularly in cases where right and left turns converge simultaneously, the receiving lanes should ideally be 16' wide and no narrower than 14', as shown in Exhibit 4-9. Special consideration should be given to the design of turning radii and striping for receiving lanes to best keep vehicles in their correct lanes.

exhibit 4-9: ddi receiving lanes

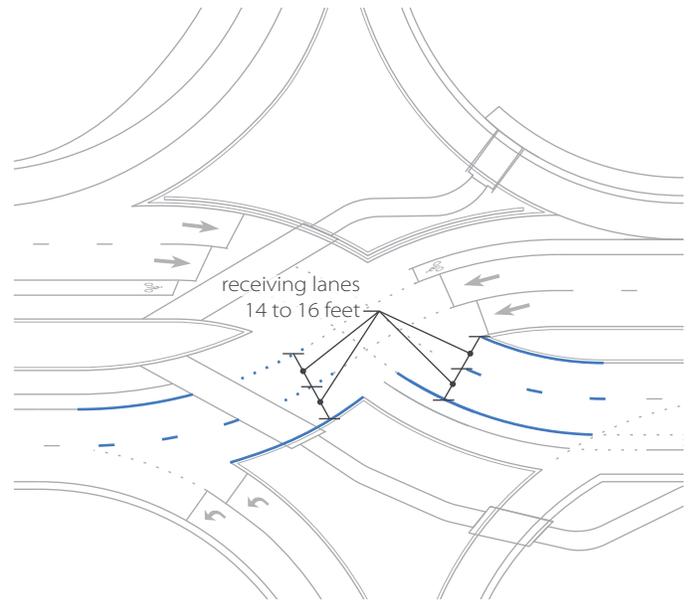


Exhibit 4-10 illustrates a cross-section showing various lane widths and other dimensions at a DDI. In cases where the DDI crossroad passes under the highway at the interchange additional lane width may sometimes be secured by adjusting the slope protection under the structure and/or replacing it with retaining wall.

The design of left turn and right turn lanes/storage, like traditional intersections, is based on the operational needs and traffic demands of the respective turn movements. Designers should consult the project traffic engineers evaluating the DDI for specific lane requirements and lengths.

Turn Radii

A key feature of the DDI is the crossover intersection, which typically contains back to back reverse curves. Naturally, the radius of a crossover curve is a function of the design speed and cross slope, as shown in Exhibit 4-11. For a 25 mph design speed and cross slopes ranging from -2% to 2%, the minimum horizontal curve radii on crossovers range between 167' to 198'. Tangent sections between reverse curves are not required by UDOT, but may be desirable based on design geometries, lines of site, and travel speed. Designers should exercise care in selecting design radii to ensure that they properly account for adverse cross slope so that friction coefficients are not exceeded in areas where the road slopes towards the outside of the curve.

exhibit 4-10: ddi cross section

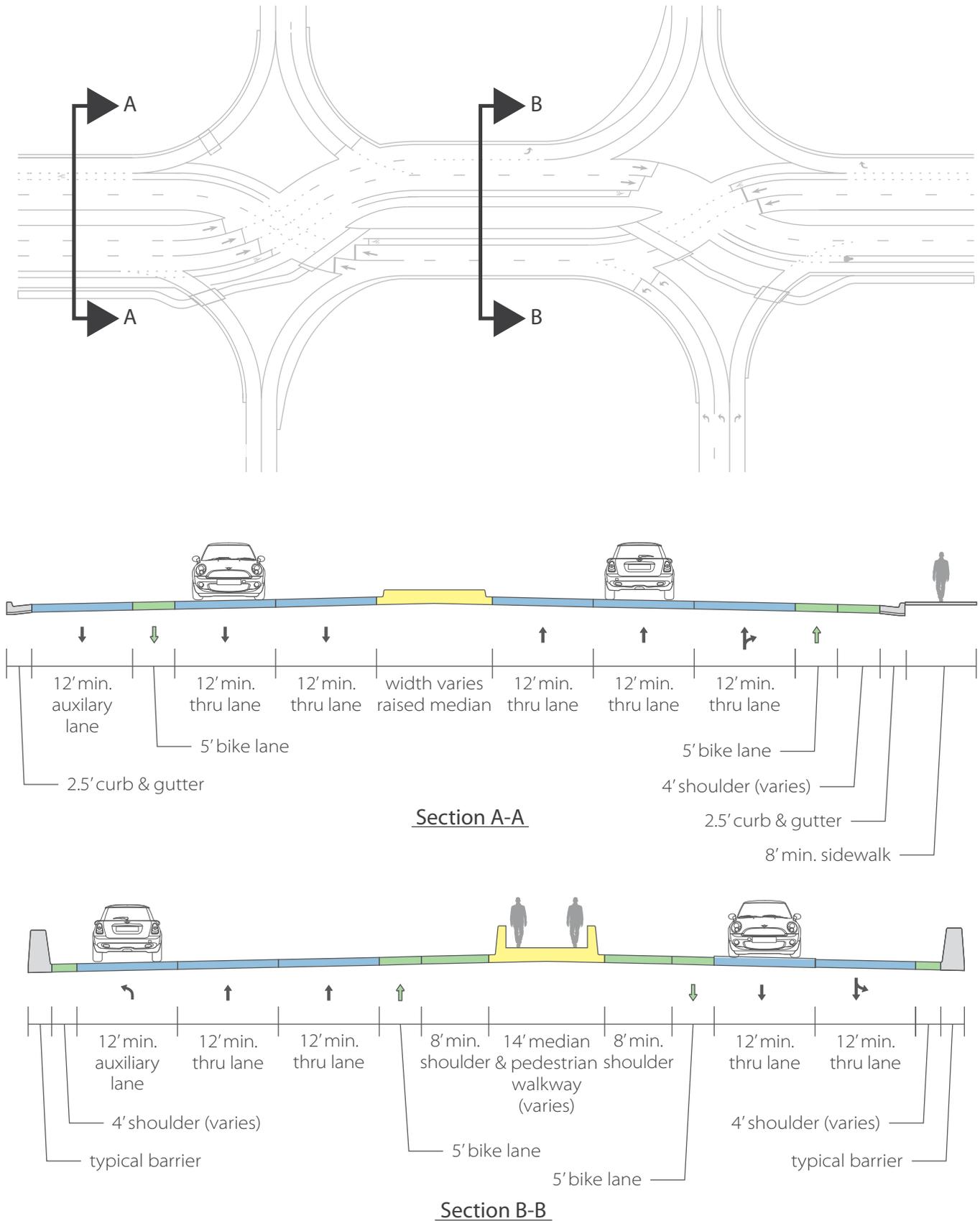


exhibit 4-11: urban speed table

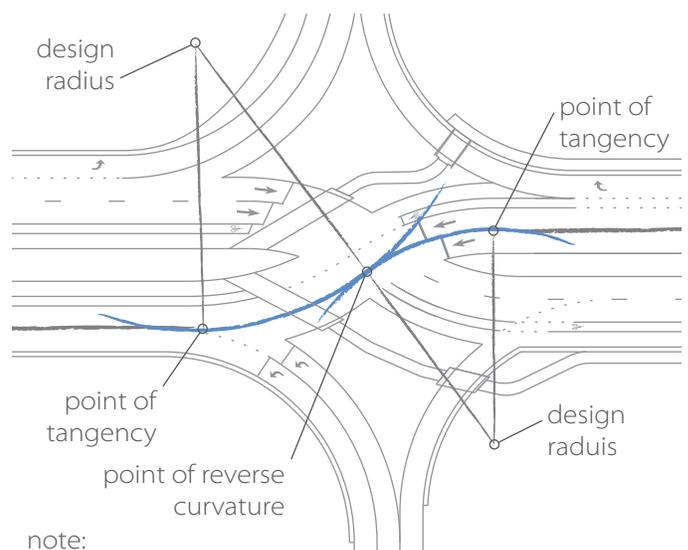
e (%)	Green Book Provided Minimum Radii ←							→ Calculated Minimum Radii			
	15 mph R (ft)	20 mph R (ft)	25 mph R (ft)	30 mph R (ft)	35 mph R (ft)	40 mph R (ft)	45 mph R (ft)	50 mph R (ft)	55 mph R (ft)	60 mph R (ft)	65 mph R (ft)
-4.0	54	116	219	375	583	889	1,227	1,667	2,241	3,000	4,024
-3.0	52	111	208	353	544	821	1,125	1,515	2,017	2,667	3,521
-2.8	51	110	206	349	537	808	1,107	1,488	1,977	2,609	3,435
-2.6	51	109	204	345	530	796	1,089	1,462	1,939	2,553	3,353
-2.4	51	108	202	341	524	784	1,071	1,437	1,903	2,500	3,275
-2.2	50	108	200	337	517	773	1,055	1,412	1,867	2,449	3,201
-2.0	50	107	198	333	510	762	1,038	1,389	1,833	2,400	3,130
-1.5	49	105	194	324	495	736	1,000	1,333	1,754	2,286	2,965
0.0	47	99	181	300	454	667	900	1,190	1,551	2,000	2,561
1.5	45	94	170	279	419	610	818	1,075	1,391	1,778	2,253
2.0	44	92	167	273	408	593	794	1,042	1,344	1,714	2,167
2.2	44	91	165	270	404	586	785	1,029	1,327	1,690	2,134
2.4	44	91	164	268	400	580	776	1,016	1,310	1,667	2,102
2.6	43	90	163	265	396	573	767	1,004	1,293	1,644	2,071
2.8	43	89	161	263	393	567	758	992	1,276	1,622	2,041
3.0	43	89	160	261	389	561	750	980	1,260	1,600	2,012
3.2	43	88	159	259	385	556	742	969	1,245	1,579	1,984
3.4	42	88	158	256	382	550	734	958	1,230	1,558	1,956
3.6	42	87	157	254	378	544	726	947	1,215	1,538	1,929
3.8	42	87	155	252	375	539	718	936	1,200	1,519	1,903
4.0	42	86	154	250	371	533	711	926	1,186	1,500	1,878

notes

1. computed using superelevation distribution method 2 from the aashto 's a geometric design of highways and streets, 6th edition (green book)
2. superelevation distribution method 2 utilizes equation 3-10 and f_{max} values listed in exhibit 3-15 of the green book
3. values for speeds 15 to 45 mph match values from exhibit 3-16 of green book.

Designers should apply design vehicle turning templates at crossovers and other locations to verify that paths of simultaneously (if dual lane) traveling vehicles (including the design vehicle) don't overlap or run over channelization features. In applications with multiple turning lanes, the turning templates should show that side-by-side design vehicle operation is possible, with particular attention paid to run out lengths or trailer tracking on the inside of the turn. This has been a particular problem for large trucks making left turns at on-ramps which has nearly universally resulted in inside scarring and signs being knocked over. The apex of reverse curves may also require wider lanes to accommodate the side-by-side movement of WB-67 vehicles. In addition, designers should consider the effects of radii size to help slow vehicles traveling at speed upon entering the crossover area. Designers should also consider wider (14' to 16') receiving lanes for left turn vehicles at the crossover intersection and at ramp terminals.

exhibit 4-12: reverse curve design



note:
tangent sections between reverse curves are optional but should be considered based on design speed, crossover angle, and lines of sight

The turn radii requirements of simultaneous vehicles should consider local laws and guidance for large trucks, which are required to turn left in the outside-most lane for multi-lane movements in Utah. This could potentially reduce turn radius requirements. Designers should verify through use of design vehicle turning templates that adequate turning radii are provided for all turn movements at a DDI.

In the case of a DDI at a skewed approach, it may be necessary to pull back the stop bars on the adjacent approach to accommodate the left turn path of a design vehicle. In that case, angled or staggered stop bars may help optimize the approach vehicle storage. While conventional intersections also require angled stop bars to accommodate left turning vehicles, the issue is exacerbated at a DDI due to the fact that the displaced left turn lane is located even closer to the receiving lanes. To allow uninterrupted flow of right turn vehicles in free right or left turn lanes, UDOT prefers a 25'-55'-25' compound radius per the AASHTO Green Book.

Median Use and Mountable Curb

A DDI typically has seven medians to channelize traffic through the intersection (Exhibit 4-13). Three successive medians (in the middle of the DDI crossroad facility)

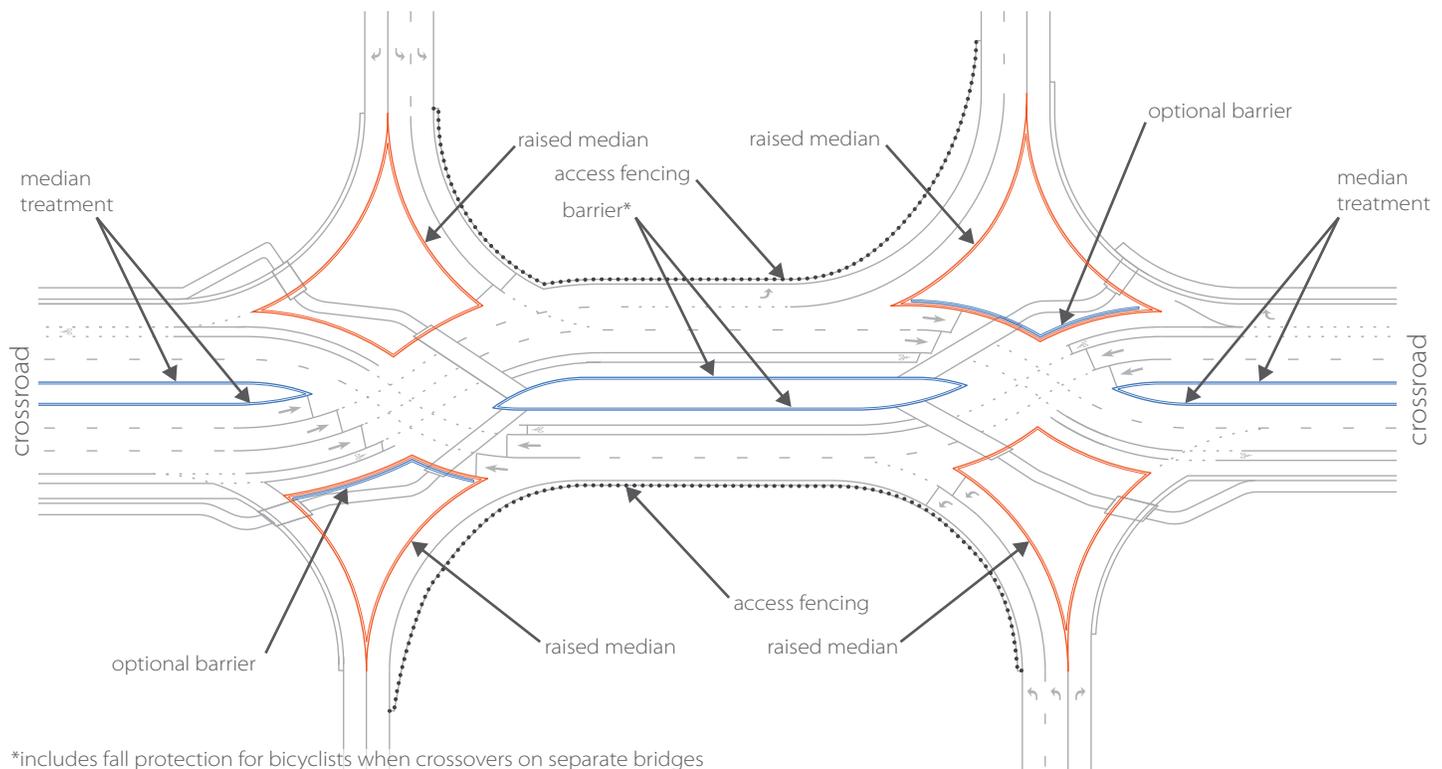
separate opposing through movements. Four medians (two at each crossover intersection) separate and channelize movements at the crossover intersection and the ramps.

The expensive right-of-way acquisition common to urban settings has encouraged minimizing DDI roadway width. Consequently, UDOT has used in some cases back-to-back B5 curbs for DDI medians on past retrofit projects. Since this configuration results in narrow medians with reduced visibility, all medians should be equipped with reflectors (now defined in the UDOT Standard Drawings) to improve median visibility. However, such a configuration is now discouraged, since it would not allow for center median use by pedestrians.

To help solve the common problem with inside scarring on left turns at on-ramps, it may be wise to place channelizing curbs closer to the striped lanes in order to encourage reduced turn speed for large vehicles. Curbs in this area should also be mountable and signs should be moved to the other side of the curve in order to reduce maintenance costs from curb scarring and sign replacement.

Barrier on the through lane side of the on-ramp islands (sometimes referred to as the "eyebrow") should help direct and channelize through traffic into the correct lanes

exhibit 4-13: ddi median & barrier



*includes fall protection for bicyclists when crossovers on separate bridges

without unnecessarily restricting lines of sight that allow drivers to protect themselves from collisions with conflicting movements. Consequently, barrier placement in these areas should be strategic and sparing.

UDOT requires concrete wall barrier on the central median in order to channelize lefts and protect pedestrians. This barrier should be 42" higher than the adjacent pavement grade and may not need to enclose the entire median in order to effectively protect pedestrians and channelize lefts. It will need to be designed for transitions to wheelchair ramps in areas with pedestrian connections.

Lane Merges

For lane merges in the DDI crossover approach area, adequate taper lengths should be provided as per current design standards. Designers should also bear in mind that designing to minimum standards is not always necessary, or even desirable. In areas where multiple lane merges and/or complex weaving movements occur at a DDI, additional merge distance may be appropriate where not prohibited or constrained by other physical geographic or design constraints.

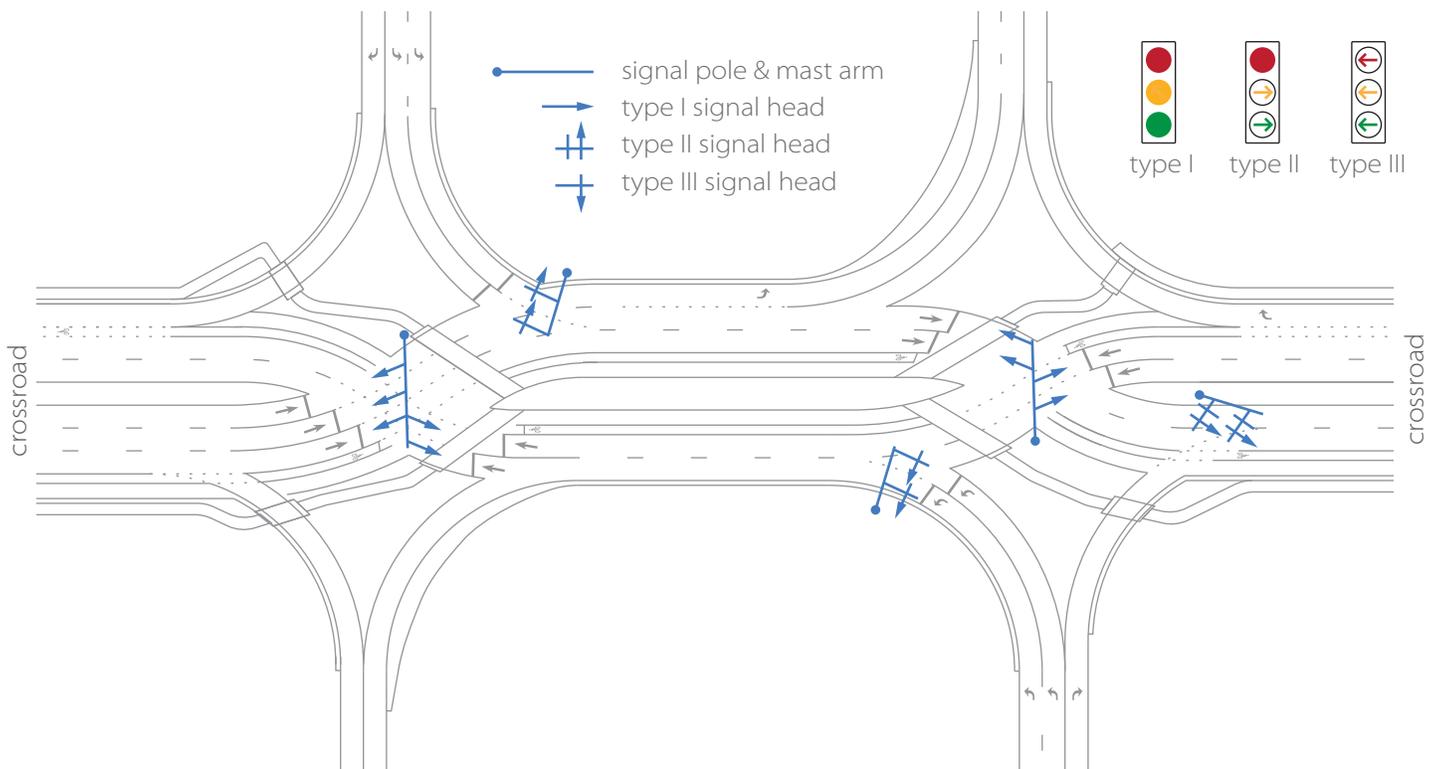
Signals and Lighting

Signal design at a DDI should adhere to the same standards for traditional intersections, as defined in the Utah MUTCD and UDOT's *Design of Signalized Intersections: Guideline and Checklist*.

Both crossover intersections should be operated by a single controller and have battery backup. Appropriate planning should occur to ensure that phasing, overlaps, and channels are correctly assigned and able to operate in the cabinet and controller of choice. The control cabinet should be strategically placed so intersections can be seen while maintenance and timing adjustments are performed in the cabinet. Designers should also ensure that sufficient hardware is provided to control the detectors and signals at the intersection.

With the exception of permissive right turn on red movements, traffic signals for ramps should have arrow signal indications directing traffic rather than a ball indication. Other signals in the interchange may or may not have arrow signal indications depending on the design. Where left turn on red movements are recommended, supplemental signage should be installed to allow left turns on a red arrow. See Exhibit 4-14 for a typical signal installation.

exhibit 4-14: ddi signal locations



Two-phase operation may or may not be optimal depending on the goals of the interchange. Consultation with the UDOT Traffic Management Division should be undertaken to determine the necessary signal phasing for optimal operations.

The DDI priority movement coordinated with adjacent signals will not always be the through movement. Careful attention should be paid to the traffic distribution at the interchange to determine which movements should receive priority.

Traffic operations at a DDI may require changes to the signal timing of adjacent traffic signals since the crossover intersection signal operation cannot serve two opposing crossroad through directions at the same time. Since only one direction at a time may pass through each DDI crossover signal, the platoon effect to adjacent signals is staggered. This may negatively impact adjacent signal progression and traffic coordination patterns. Therefore, adjacent traffic signals should be made part of any operational analysis, and depending on the impacts, it may be advisable to analyze additional signals away from the interchange.

Arterial coordination through a DDI is still possible even with platoon staggering, but careful evaluation and

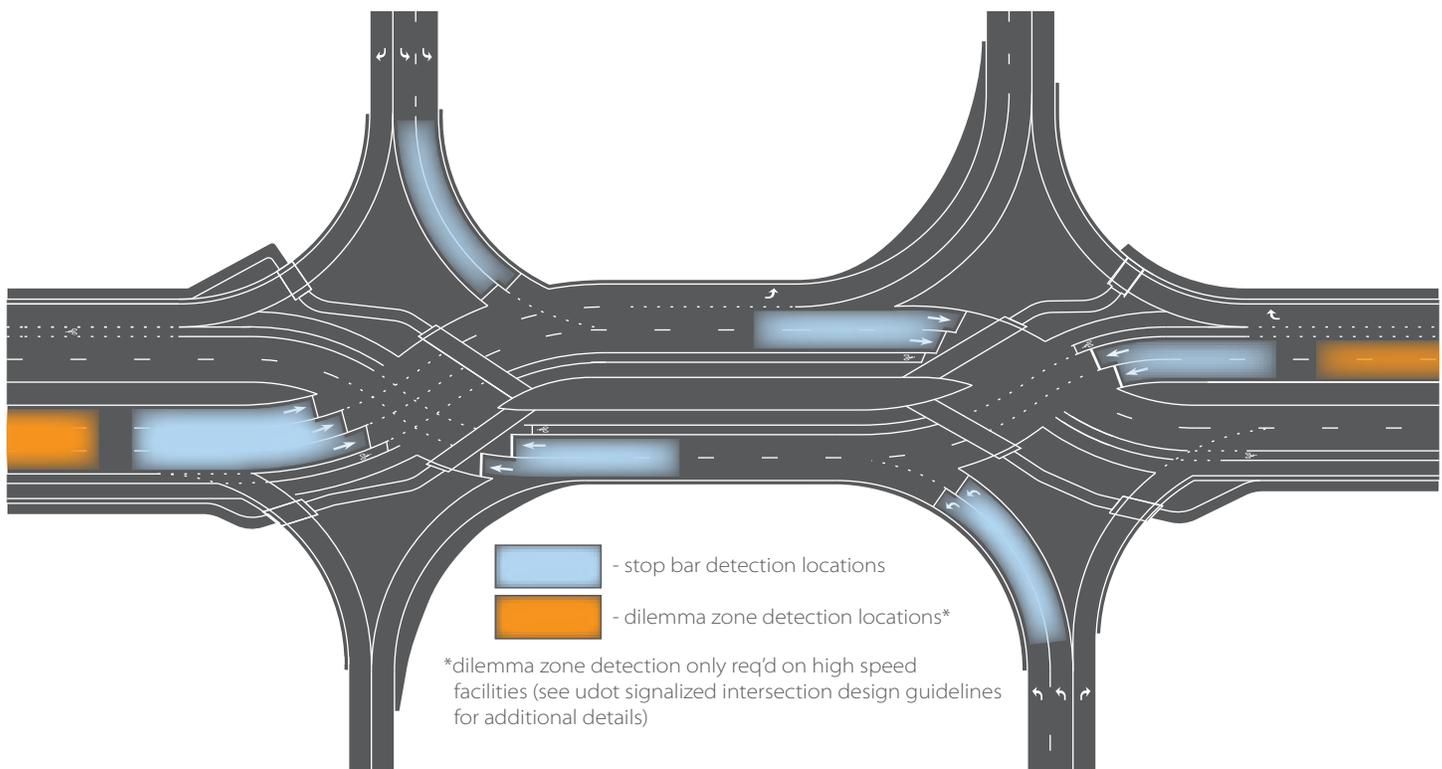
implementation will likely be required to optimize progression in both directions. Progression can be maximized through the design of the crossover distance. Consultation with UDOT Traffic Management Division can help find the optimal design.

Manual development of time-space diagrams and field adjustment of signals should be expected. Greater distance between crossover intersections and the adjacent intersections allows for more flexibility in the coordination of the DDI with adjacent intersections. Regardless of the strategy used, queue lengths at the DDI must not extend into upstream intersections.

Signal spacing of at least 1320 feet should be implemented between the crossover intersections and adjacent signals, per UDOT Administrative Rule R930-6. A VISSIM model should be constructed to determine if proposed spacing and phasing of adjacent intersections will provide adequate operation.

Lighting at the DDI should be designed with considerations similar to a conventional intersection. At the main intersection, the luminaires should illuminate receiving lanes of traffic, stop bars, and the crosswalks. Luminaires should also be provided to illuminate DDI crossovers and the area between the crossover and main intersection.

exhibit 4-15: ddi signal detection locations



Illumination at pedestrian refuges and crosswalks should be considered based on the interchange lighting warrants provided in UDOT's *Roadway Design Manual of Instruction*.

Signal Warrants

Signal warrant analyses may be performed for DDI ramp terminals where a DDI is replacing an existing interchange with un-signalized ramp terminals, or where a new interchange is proposed. If an existing interchange that is being retrofit with a DDI has already been signalized, UDOT recommends signalizing the DDI without performing a signal warrant analysis.

Despite the guidance to perform warrant analyses with DDIs, the results of a signal warrant effort should be approached with caution as traditional warrant analysis criteria do not correlate directly to the DDI. For example, the Utah MUTCD warrant analysis refers to the sum of the two major approaches (the major and minor approach volumes) to be used for signal warrant evaluation. At a DDI, the major and minor approaches being considered are different than the volumes used for other interchange types because they represent the opposing directions of the same crossroad. As such, each volume is really only a part of the total volume for the major approach, and thus really only represent one direction of flow when compared with traditional warrant analysis. This fact can cause traditional warrant analysis to underestimate the need for signals at DDI crossover intersections. Consequently, until the Utah MUTCD addresses this issue, a conservative approach should be taken toward signalizing by defaulting to signalization unless there are compelling reasons not to signalize.

The Utah MUTCD clearly states that the satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic signal control; however, the Utah MUTCD does not expand on other conditions that may contribute to the decision. Specifically, the Utah MUTCD does not specify justifying factors like queue lengths, delays, and interference with adjacent signalized intersections. Due to these and other factors, crossover intersections at DDIs should be signalized unless an engineering study shows that an alternative control will provide adequate operation in context with adjacent intersections.

For example, if warrants 1 or 2 are not met solely because of insufficient volume on the major approach, it is suggested that the highest volume of the major approach be increased by up to 50 percent before summing the two

major approaches again. If warrants are still not met, a signal could be justified based on an operational analysis that demonstrate the necessity of the signal for adequate operation of the interchange. Another consideration might be the presence of upstream signals, which could allow a warrant for interruption of continuous flow to be met.

Signalizing Ramp Movements

Signalizing movements to and from the ramps can yield a number of benefits:

- Merging and weaving within the interchange is eliminated, reducing the need for auxiliary lanes
- Each conflict point within the interchange is protected by a signal
- All pedestrian crossings are signal protected

The designer should give special consideration to signalizing ramp movements at a DDI under certain conditions, such as:

- Significant pedestrian traffic
- Significant ramp traffic combined with periodic pedestrian traffic
- Ramp volumes that require more than one entrance or exit lane
- Traffic patterns that encourage merging and weaving operations within or near the interchange

The above list is not comprehensive and is based on agency experience and engineering judgment. For instance, it may be desirable to signalize the off-ramp right turn for added safety, as drivers tend to look to the wrong side of the street (near instead of far side) for approaching traffic either turning right on red, or turning right under a yield condition.

Left turns from the ramp, if signalized (and off-ramp right turns, if signalized) should have their green phases delayed by a few seconds to allow the through movement to clear before the green is given. Signalization of all movements should be considered on a site-by-site basis. As of 2013, permissive left turns on red are allowed at DDIs if signed to allow it.

Bicyclists, Pedestrians, and Disabled Persons

Because of the unconventional movements and crossing distances at DDIs, positive guidance is necessary for non-vehicular traffic to move safely through the intersection, the primary groups being bicyclists and pedestrians. The operational and safety needs of both groups should be considered in the design of a DDI. Pedestrian facilities

must also meet current Americans with Disabilities Act (ADA) standards for accessible design. UDOT recommends providing pedestrian safety fencing on the outside of all elevated DDI structure regardless whether pedestrians navigate the interchange on the inside or the outside of the interchange.

Designers should further consider that at least two types of bicyclists exist: bicyclists who ride on roadways or in bike lanes with vehicular traffic and prefer to ride there, and bicyclists (which may include children) who use active transportation paths. Bicyclists in roadways are typically comfortable riding along with vehicular traffic and performing many of the same movements. Engineers should consider bike lanes (5-foot minimum width) through the interchange for these cyclists. Other bicyclists who choose to follow the active transportation paths through the intersection could cross through the intersection in a multi-stage crossing process together with pedestrians.

On high speed facilities, consideration should be given to physically separate bike lanes from vehicular traffic by a barrier or to simply prohibit bicycle use altogether. For example, bike routes from the DDI crossroad to the highway or interstate facility are not usually provided since bike access is not allowed on these facilities.

Where the DDI crosses over a grade separated facility with an elevated pair of unconnected structures, a 5-foot safety buffer should be provided adjacent to any fall hazard. If 5 feet is not available, a 42-inch barrier with fencing may be provided to protect cyclists from fall hazards.

Refuge Islands

Refuge islands are required for pedestrians to make the multi-stage crossing movements that a DDI requires. For pedestrians crossings utilizing the median island of the DDI, some stages of the crossing movements will be signalized (at the crossover intersections) and others may require crossing free or permissive turn movements (right turning movements to/from interchange ramps).

If provided, pedestrian push buttons for signalized movements should be located on the refuge islands. By using push buttons to initiate a pedestrian phase or by crossing in crosswalks that require turning vehicles to yield to pedestrians, pedestrians cross interchange turn movements as they typically would at traditional intersections.

In designing refuge islands, engineers should consider the size of the island and its ability to accommodate the

number of pedestrians crossing the approach per signal cycle. In addition, the island should ideally shield pedestrians, recreational bicyclists, and wheelchair bound pedestrians from vehicle traffic without obscuring their view of traffic or the driver's view of pedestrians, bicyclists and the disabled.

When a central pedestrian corridor is provided on the center median, it should be at least 11 to 14 feet wide. Fourteen-foot wide is the minimum necessary to allow for snow removal of half the width while allowing the other half to be used as temporary storage. Widths less than 14 feet may require complete snow removal out of the interior of the interchange, which may not be practical.

Designers should also pay special attention to drainage near refuge islands, especially in retrofit scenarios. The existing roadway crown and the placement of barrier in these areas can create ponding areas that will need to be addressed.

Designers should consider items within the AASHTO design methodologies when considering the placement of pedestrians including:

- Pedestrian free flow condition
- Positive feedback to drivers or channelization
- Stopping sight distance.

Snow Removal and Median Drainage

Snow removal from the travel lanes of a DDI has been a difficult design consideration for DDIs in Utah. The multiple (and sometimes narrow) channelizing medians, combined with additional movements outside of the normal intersection footprint, complicate operations for snow plow drivers. Consequently, snow removal operations should be coordinated with maintenance staff to ensure that design meets the needs and operation of maintenance staff.

Plowing operations tend to push accumulated snow storage to the right shoulder on the outside of the roadway. While this works well for traditional intersections, in a DDI, plowing to the right actually means that snow is pushed onto the center median since the crossover puts the center median to the right of traffic. Consequently, center medians should be designed to accommodate both snow storage and drainage, and should be grade to retain runoff within the median so that saturation and refreeze does not become a problem. In areas where center medians are not provided, plow blades may need to be turned to the left at the crossover intersection in order to through accumulated snow to the left, or outside, of the interchange.

exhibit 4-16: ddi snow removal

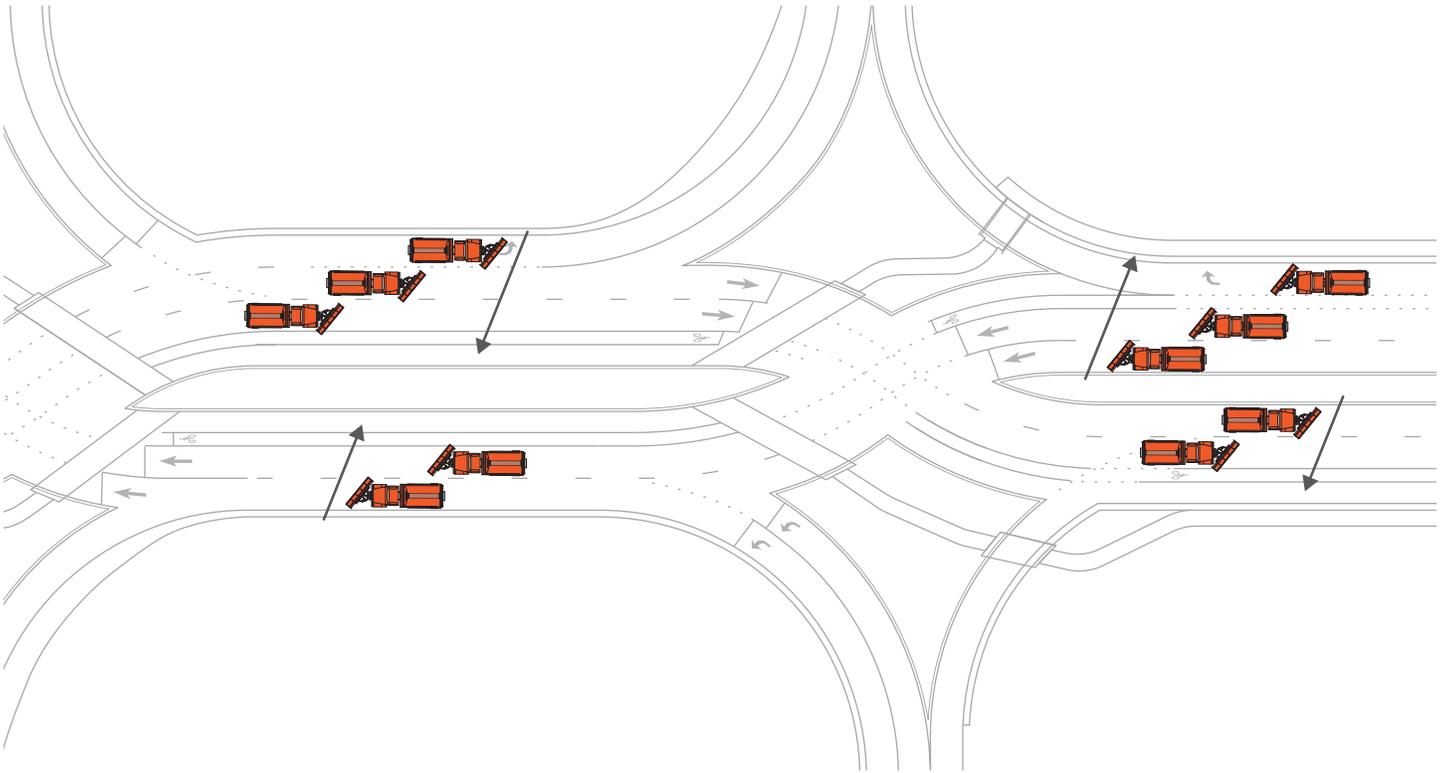
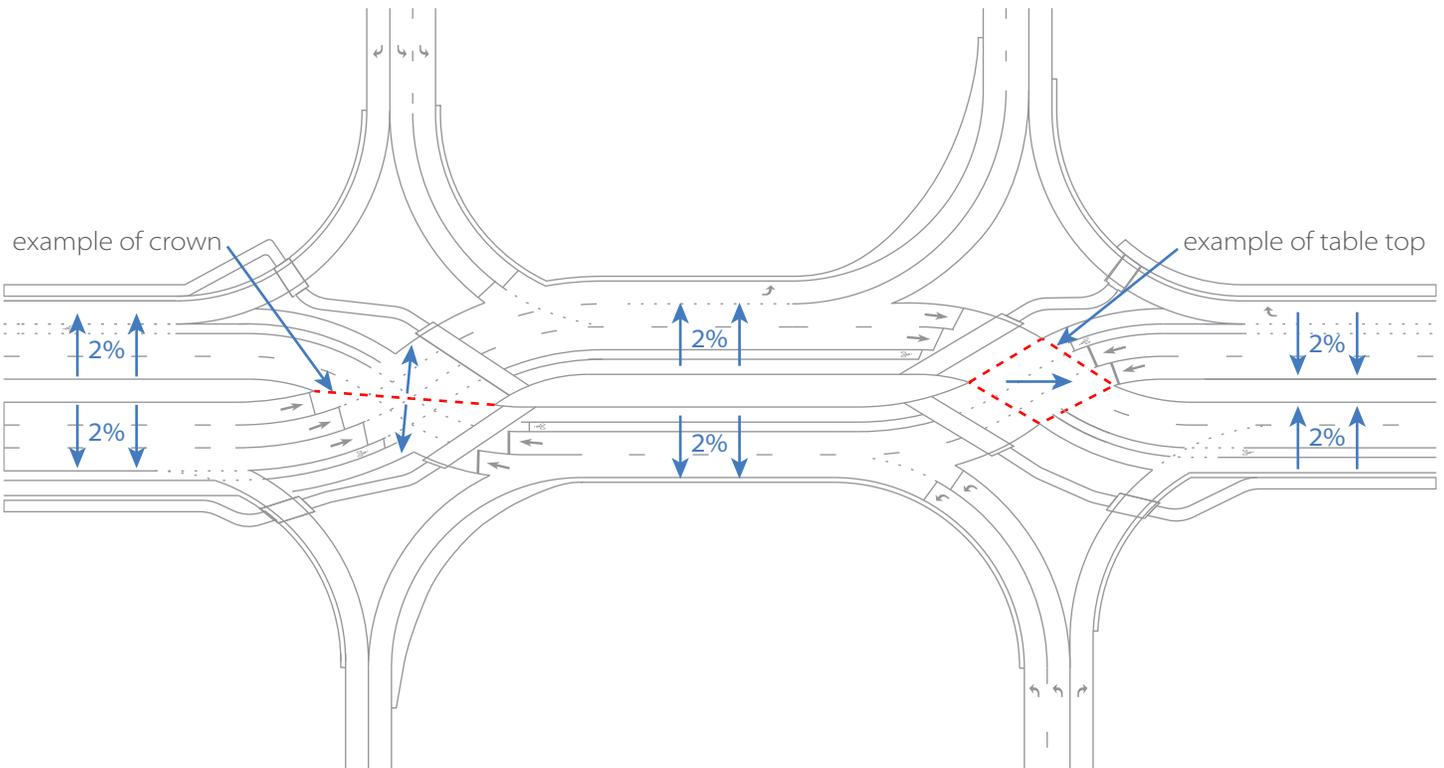


exhibit 4-17: ddi crown and table top grading



The snow removal operation at a DDI is illustrated in Exhibit 4-16.

Given the high cost of right-of-way acquisition, construction, and maintenance associated with providing median treatments wide enough to store snow, designers have typically elected to minimize median footprints within the DDI. However, reducing median footprint should never compromise the safety of pedestrians who are using the median.

Drainage is extremely important at a DDI and needs to be pro-actively addressed. In such cases where medians or other paved space wide enough for snow storage are utilized, drainage should be proactively managed with grading and inlets to drain water out of the traveled way. In a DDI various lane groups (e.g. travel lanes, displaced left turn lanes, and bypass right turn lanes) are separated by raised medians making it difficult to drain surface water appropriately. The addition of storm drains along the raised medians may be necessary to remove excess water from the roadway.

Exhibit 4-17 provides examples of crown and table top drainage that can accommodate drainage to the outside or to the central median of a DDI.

Federal Processes

It is not the purpose of this guideline to address the specifics of IACR, NEPA, and other federal regulatory processes, however due consideration should be given to those requirements as part of the design process so that design and construction schedules are not adversely affected.

exhibit 4-18: ddi design lessons learned

1	Pedestrian fencing on both sides of bridge
2	Designer should compare posted speed of crossroad and mainline with DDI design speed within limits of DDI design speed
3	Ensure widths under overhead structures are adequate for proposed DDI lane configuration
4	Check overhead bridge clearance taking into account road crowning, changes to drainage and new pavement thickness
5	Ensure there is sufficient distance between intersections adjacent to DDI to allow vehicles to naturally find their target lane
6	Properly line up ramp lanes with DDI receiving lanes
7	Don't assume existing drainage will be adequate when converting an existing interchange to DDI
8	Conduct proper horizontal alignment checks and ensure curves meet design speeds
9	Conduct proper vertical alignment checks and mitigate any visibility issues that may affect driver expectancy, especially when dipping under grade separated
10	Use concrete wall barrier in eyebrow section (strategically & sparingly) to reduce perception of driving into oncoming traffic and vehicle glare at night
11	Carefully evaluate signing and striping to ensure adequate guidance is provided without overwhelming the driver with too much information
12	Pay special attention to intersection angles and eyebrow design
13	Pay special attention to location of signal poles, clear zones, and concrete wall barrier (even temporary locations)
14	Consider pavement operations beforehand to reduce hand pours, cold joints, expansion joint patterns, orientation of reinforcing steel, etc.

SECTION 5 DDI IMPLEMENTATION & CONSTRUCTION

Construction Contracting Method

UDOT has constructed DDIs using both traditional Design-Bid-Build (DBB) delivery and the alternative delivery method of Design-Build (DB). Depending on the project goals, the construction manager general contractor (CMGC) alternative delivery method would also be acceptable to the department. Although UDOT does not restrict the method of project delivery (subject to being appropriate for the goals of the project), it is important to recognize that each of these methods has its own strengths and weaknesses. To date, DBB delivery has primarily been utilized by UDOT for smaller DDI retrofit projects where the DDI had already been specified as the preferred alternative. DB delivery has been used on much larger projects (e.g. I-15 CORE, Access Utah County) where UDOT defined overall goals instead of specific solutions. In these cases the Department used the DB delivery process to manage

exhibit 5-1: st. george ddi construction



risk and encourage innovation. As a result, successful DB teams proposed the DDI as an alternate technical concept (ATC) that reduced cost and schedule while meeting project goals. Contracting method is a particularly important consideration with regard to managing the risks associated with Maintenance of Traffic (MOT), which—along with opening a DDI to traffic for the first time—represent some of the biggest challenges to opening a DDI, and especially when converting another interchange type to a DDI.

In determining what contracting method to use in constructing a DDI (or any other improvement for that matter) it is important to understand a few key differences between DBB, DB, and CMGC contracting. These contracting methods are explained further in UDOT’s materials on Innovative Contracting.

Maintenance of Traffic

Maintenance of Traffic (MOT) during DDI construction is critical to its implementation. Safe and efficient movement of traffic through DDI construction zones maintains positive

public perception while limiting impacts to businesses and the traveling public. Converting an existing interchange to a DDI is single-handedly the largest challenge to be faced when developing a DDI. This challenge is further complicated if all movements must be maintained during the conversion process. Consequently, it is advisable to understand which movements are crucial and which can be temporarily closed or re-routed to facilitate construction.

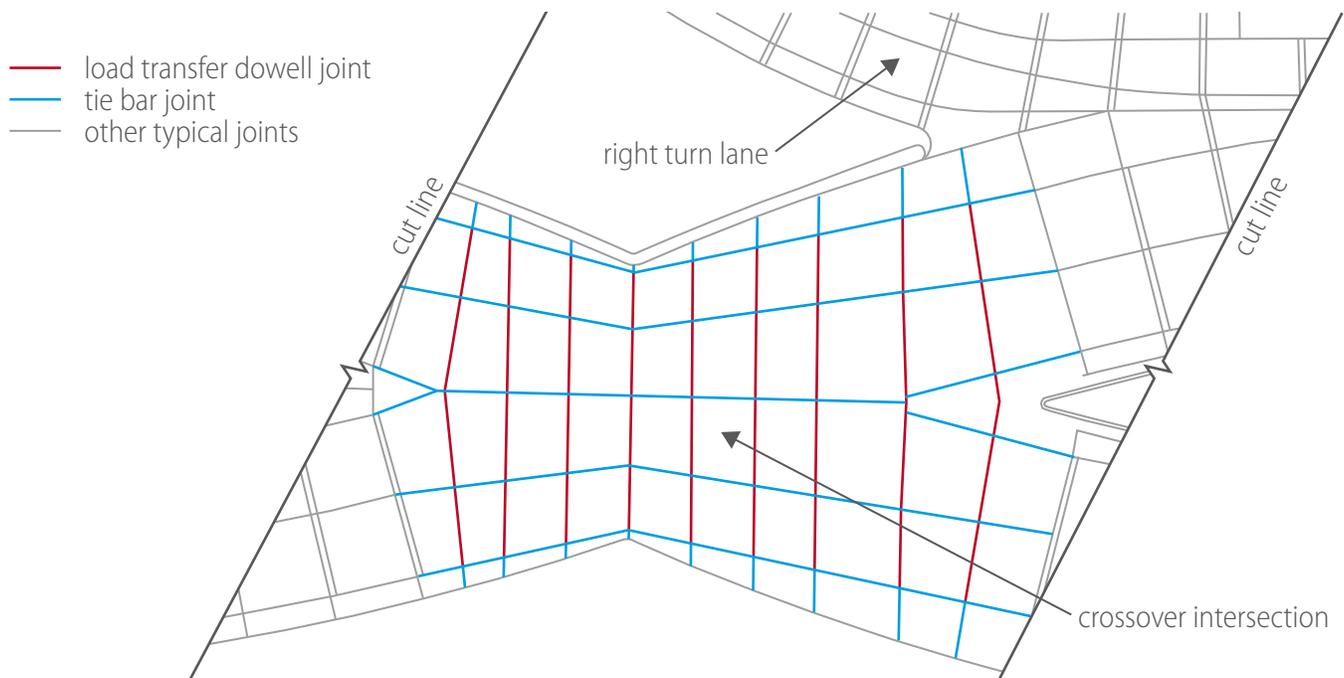
As parts of the work zone are completed, some movements can be opened incrementally, which allows drivers to become familiar with the permanent routing configuration one or two movements at a time. In certain cases this incremental approach may have advantages to implementation, while in other cases it may be preferable to open it up to traffic all at once.

The footprint and the operational characteristics of a DDI both hold some constructability advantages that allow expedited construction times for retrofit designs and that utilize crossovers to impact only one side of the DDI at a time for MOT. MOT strategies that use the crossovers during construction also provide the added benefit of getting

“The whole difference between construction and creation is exactly this: that a thing constructed can only be loved after it is constructed; but a thing created is loved before it exists.”

— Charles Dickens

exhibit 5-2: pccp sample joint layout



the public familiar with DDI movements in advance of opening the intersection.

UDOT has successfully used innovative construction methods such as accelerated bridge construction (ABC) to minimize traffic impacts during the construction of DDI structures. In constructing UDOT’s first DDI at American Fork Main Street and I-15 (Pioneer Crossing), the DDI design footprint required the construction of two new bridges. These bridges were much smaller than a typical SPUI structure and could be built adjacent to the existing structure. This allowed traffic to maintain use of the original bridge while constructing the first structure for the new DDI. Subsequently, traffic was transferred to the new bridge in order to demolish and replace the original structure.

The reverse curvature of the crossover intersections can pose unique paving problems during the construction

of MOT transitions including issues such as reconciling the grade, slope and surface treatments of temporary pavements with the final pavement grades, slopes, and surface treatments. To resolve these concerns at Pioneer Crossing, designers and construction personnel worked together to develop an efficient and minimally impactful paving strategy that would accommodate necessary MOT phasing, expedite the work, and provide for efficient traffic flow. This collaborative effort accounted for construction activities such as pouring medians, striping, and signal transitions which typically occur with night work over single nights or weekends. While strategies appropriate for some DDI projects might not be directly applicable to others, there are some common themes that should be considered for MOT at all DDIs:

1. DDI MOT Phasing is complex and requires careful planning with considerations for business access, mul-

exhibit 5-3: ddi construction lessons learned

1	Carefully consider and plan out conversion of an existing interchange to DDI
2	Evaluate options such as total closures, partial closures, and phased MOT before construction starts
3	Insist on a strong public involvement effort to communicate MOT during construction ahead of making traffic pattern changes
4	Don't take for granted drivers will immediately become accustomed to new traffic patterns overnight; a phased approach under MOT can be very useful
5	Align signal heads over travel lanes as much as possible, especially when using temporary signals on span wire
6	Keep temporary pavement markings refreshed during construction and subsequent MOT/phase shifts
7	Be cognizant of existing ghost lines and how they may interfere with driver's guidance at the crossover intersection
8	Plan carefully for the MOT phasing and placement of signals, lighting, drainage structures, and other appurtenances.

multiple MOT sequences, interstate closures, temporary signals, and flaggers as signal controllers.

how they may interfere with driver's guidance at the crossover intersection.

2. Evaluate options such as total closures, partial closures, and phased MOT before construction starts. ABC methods of structure construction can help minimize closures associated with structural construction.
3. Collaboration of MOT with impacted business owners and the general public is critical so that businesses can remain open/viable and so that the public feels well served during the construction period. Insist on a strong public involvement effort to communicate MOT during construction prior to making changes in traffic patterns.
4. MOT phasing can be useful to familiarize drivers with the new traffic patterns of a DDI if MOT phases are set up to mimic some of the final DDI movements.
5. Align signal heads over travel lanes, especially when using temporary signals on span wire and when utilizing unconventional traffic movements.
6. Keep temporary pavement markings refreshed during construction, including all subsequent MOT phase shifts. Be cognizant of existing ghost lines and

7. Be aware of surface treatments. For example, the polymer overlay delineation (or deck treatment) for structures should extend all the way to stop bars instead of changing surfaces right before the signal. Similar friction coefficients in key braking zones improve safety.
8. Careful planning should occur for the MOT phasing and placement of signals, lighting, drainage structures, and other appurtenances. It is not uncommon for permanent DDI signal foundations to be in the middle of an existing intersection prior to converting to a DDI.

Opening a New DDI

With the introduction of new concepts like the DDI, it is important to make a positive first impression and avoid early confusion with premature openings. Transitioning signals and opening a DDI for operation without fully completing construction work is not advised, despite the inevitable pressure from contractors to do so. Items that have regularly been missing at intersection transition/turn-on include: missing or non-operational signal detection, improper signal head placement, incomplete striping and

exhibit 5-4: ddi opening day checklist

Roadway	1	<input type="checkbox"/>	Mast arm mounted and other signage must be installed as per the design
	2	<input type="checkbox"/>	Medians and channelizing islands must be constructed as designed
	3	<input type="checkbox"/>	Pavement markings must be provided as designed
	4	<input type="checkbox"/>	All construction equipment must be removed from the intersection
	5	<input type="checkbox"/>	All travel lanes and driveways must be opened to traffic and cleared of any debris
	6	<input type="checkbox"/>	Any preexisting pavement markings must be cleared from the intersection before restriping
	7	<input type="checkbox"/>	Construction of sidewalks and curb ramps must be complete
Signal & Lighting	8	<input type="checkbox"/>	Signal poles and mast arms as specified must be installed and grounded at designed locations
	9	<input type="checkbox"/>	Specified signal heads must be installed and aligned as shown in the design, and tested
	10	<input type="checkbox"/>	Pedestrian push buttons and signal heads must be installed as designed, and tested
	11	<input type="checkbox"/>	Specified signal detection must be installed at appropriate locations, tested and operational
	12	<input type="checkbox"/>	Specified controller cabinet must be tested at the TOC, have all equipment, and operational
	13	<input type="checkbox"/>	All aspects of signal timing must be tested and approved by signals engineer
	14	<input type="checkbox"/>	Conflict monitor and MMU must be configured, tested, and approved by signals engineer
	15	<input type="checkbox"/>	CCTV, priority, and preemption equipment must be installed as designed, and functional
	16	<input type="checkbox"/>	Design specified luminaires must be installed and operational
	17	<input type="checkbox"/>	Signal must be connected to the TOCs ATMS network
Signing	18	<input type="checkbox"/>	All signing must be provided as designed
	19	<input type="checkbox"/>	Any preexisting conflicting signing must be removed
UDOT Approval	20	<input type="checkbox"/>	Contractor must ensure conformity with UDOT's Innovative Intersection Specification
	21	<input type="checkbox"/>	Contractor must get approval of the UDOT resident engineer and signals engineer before the signal turn-on. This includes completion of the UDOT Signal Turn On Checklist.

pavement markings, missing signs, incomplete sections of critical roadway or sidewalk, and missing pedestrian call features. These omissions are not trivial, but can cause inefficient DDI operation on opening day and sometimes for extended periods of time. They also can lead to safety related issues by contributing to driver confusion that endangers all road users and have sometimes resulted in close calls for potentially life threatening collisions. Additionally, opening a DDI before completing construction risks setting a poor precedent and expectation on how the interchange and intersections should operate, particularly with regard to prohibited movements, as well as generating myriads of complaints and generally tarnishing the public perception of UDOT's opening day execution.

The engineer in charge of the DDI implementation should make sure that all traffic control devices are in place and tested prior to transitioning signal systems and opening a new DDI for public use. A checklist covering required items for signal transition and intersection opening is provided in Exhibit 5-4 to help engineers in charge hold contractors accountable for the completion of these items prior to intersection opening.

It is also advisable that the official opening take place during off-peak hours during a weekend. This allows the project team and UDOT to take the opportunity to tweak signal timing, pavement markings, and/or signing prior to the Monday morning AM peak. It is much easier to deal with making slight changes during light traffic conditions than during peak weekday traffic.

Regardless of what day the DDI is opened, it is imperative that UDOT staff be on site during the initial days of operation to ensure optimal operation of the interchange. Close coordination with the UDOT Traffic Management Division is required to help with DDI implementation.

Signal Detection

Properly functioning detection is critical for efficient traffic operations at a DDI, like most signalized intersections. For DDI and non-DDI approaches, stop bar detection is usually provided to monitor the presence of vehicles and extend the green time for through and turn movements. Advanced, dilemma zone detection for through lanes on higher speed facilities is recommended and operates as it does at typical intersections. At crossover locations, advanced radar detection is used for the crossover

exhibit 5-5: sr-92 retrofit ddi

SR-92 & I-15 (2009)



SR-92 & I-15 (2012) - DDI retrofit



movements. This allows signals to run free, for the green time to be extended to serve demand, or to call the opposing phase in order to clear trapped vehicles crossover lanes. Exhibit 4-15 depicts the typical detector influence areas for the DDI.

In addition, it is important to test detection (regardless of the type of detection used) before opening a new signal to traffic to help assure accurate operation at opening so as to not confuse drivers with non-operational movements.

Signal Timing Guidance

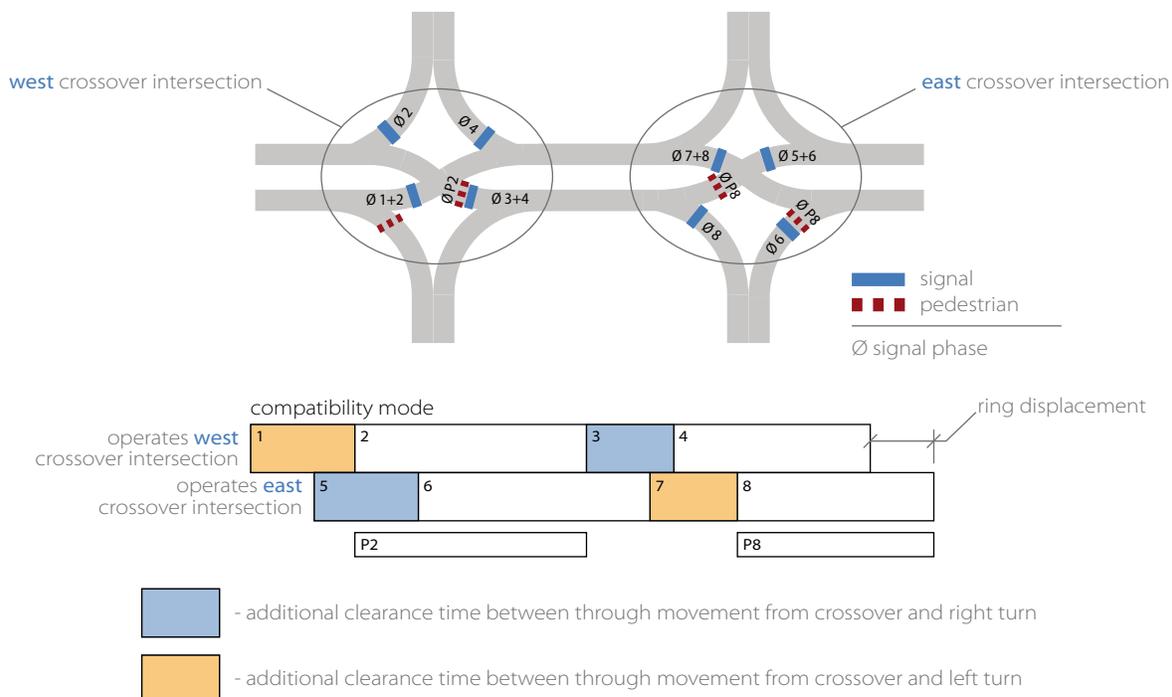
In order to provide the flexibility necessary for efficient DDI operation, the use of advanced signal technology is crucial. Intersection operations for a DDI can take advantage of overlaps to optimize coordination between crossover signals and to run certain turn movements concurrent with crossovers. Overlaps allow several non-conflicting phases to operate simultaneously, even when the phases cross the barrier in the NEMA ring and barrier structure. Adequate hardware is necessary, that will accommodate the necessary phases and overlaps, for the DDI to operate efficiently and as intended.

Even though the signal timing strategy may vary, the basic DDI signal timing principles that drive efficiency

of operation remain the same. At the DDI, efficiency in signal operation is achieved through simple two-phase signalization that prioritizes either the through movements and on-ramp traffic, or the off-ramp traffic. On occasions where ramps are signalized, UDOT also uses a three phase signal strategy to minimize weaving. To accomplish perfect coordination between crossover movements and adjacent signals, strategic overlaps and timing are implemented.

UDOT has also found that shorter signal cycle lengths tend to work better than longer ones (the shorter the better). In attempting to implement short cycle lengths, however, it is important to consider the potential effects on coordinated corridors. These coordinated corridors often have cycle lengths ranging from 100 to 150 seconds per cycle. On coordinated corridors with longer cycle lengths, it may be wise to use cycle lengths at the DDI that are half that of the coordinate corridor (half-cycle lengths), or to run the DDI signals as free. While these strategies may disrupt corridor progression part of the time, they will also minimize that disruption by sending multiple DDI platoons through to downstream intersections for every coordinated corridor cycle, thus minimizing overall delay and ensuring that coordinated movements serve as much

exhibit 5-6: ddi signal phasing diagram (2-phase)



traffic as possible without forcing the DDI into longer and more inefficient cycle lengths.

Exhibit 5-6 provides an example of the UDOT signal timing strategy for through and on-ramp prioritization, and for off-ramp prioritization (offset modification is the key differentiator). Contact the UDOT Traffic Management Division at (801) 887-3710 for assistance with signal timing implementation in Utah.

Pedestrian Timing

Pedestrian crossing strategies at DDIs may involve signalized crossings that run at the same time as the crossover through movements. These strategies differ from conventional interchange crossing patterns and should be addressed to provide clear direction for pedestrians and casual bicyclists. These may include flashers for pedestrian crossings of free movements, and adjusted minimum green times to allow crossings at signalized movements with very short signal cycles.

SECTION 6 COMMUNICATIONS AND PUBLIC INVOLVEMENT

Change Is Hard

UDOT’s public involvement mission statement is “to capture the public’s vision and sense of need by establishing an ongoing dialogue that is collaborative, respectful, and timely.” In order to capture, gain, or win “the public’s vision and sense of need” on the question of innovative interchange treatments such as the DDI, extraordinary proactive efforts are often required to establish the type of “ongoing dialogue” or communications that result in public understanding and acceptance. This is not because the operation and benefits of a DDI are difficult to understand or to prove, but rather because it is human nature to suspect and oppose new ideas until they have been sufficiently proven by time and by trial. Therefore, some level of public opposition should always be expected whenever new ideas introducing change from traditional behavior, including DDIs is introduced.

“Almost everyone shuts down when science becomes too technical; you’ve got to infuse it with entertainment and storytelling to make it effective.”

— Greg Graffin

As more DDIs are built statewide, public education and outreach will become less of a challenge. Until then, public outreach efforts should work to overcome common DDI concerns such as, confusion, unfamiliarity, skepticism, and non-acceptance.

With education comes the opportunity to inform the public of the advantages DDIs provide. Developing strong partnerships with key stakeholders and involving the general public throughout the life of a project can quell frustration and misunderstanding of this potentially confusing concept.

To make innovation seem commonplace enough to minimize public objection and to prove the merit of new or provocative ideas requires thoughtful strategy, careful execution, and persistent effort in developing and implementing a public involvement and communications plan that will address the potential concerns

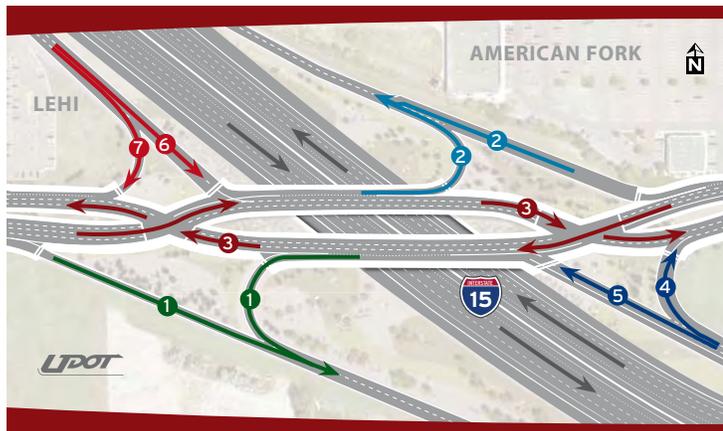
of the affected public. The plan should account for the following:

- Goals
- Measurable objectives
- Concerns and opportunities

exhibit 6-1: static visualization (pioneer crossing)



exhibit 6-2: ddi “business card” flyer (pioneer crossing)



Traveling on American Fork Main Street:

- 1 **Accessing Southbound I-15:** If driving east toward the interchange, get into the far right lane and merge onto I-15. If driving west, get into the far left lane. Continue across bridge and merge directly onto I-15.
- 2 **Accessing Northbound I-15:** If driving east, move into left lane. Continue across bridge and move into left turn lane, which will merge directly onto I-15. If driving west, move to right lane and merge onto I-15.
- 3 **Going Straight:** Using any of the three regular traffic lanes, continue through the next crossing intersection where you will switch back to the right side of the roadway.

Traveling on I-15:

- 4 **Northbound to American Fork:** Stay to the right when the off-ramp divides. Turn right and merge onto Main Street.
- 5 **Northbound to Lehi:** Stay to the left when the off-ramp divides. Turn left and merge directly into westbound traffic lanes.
- 6 **Southbound to American Fork:** Stay to the left when the off-ramp divides. Turn left and merge into eastbound traffic lanes.
- 7 **Southbound to Lehi:** Stay to the right when the off-ramp divides. Turn right and merge directly into westbound traffic lanes.

Visit udot.utah.gov/pioneer to see the DDI in action.

- Key audiences
- Messages
- Strategies
- Tactics
- Scheduling
- Evaluation tools

Budget Proactively

Developing and executing an effective plan requires an appropriately sized budget to “capture” or win over “the public’s vision.”

Consider the following sample questions, pertaining to the location, audience demographics and familiarity with the DDI, as you determine the level of outreach that may be needed:

- How many people are impacted?
- How traveled is the area?
- Is it at a major interchange?
- What are the interchange user demographics?
 - » Are they mostly local or truckers, tourists, etc.?
 - » Are there cyclists and pedestrians who will want access?
 - » How might they react to this type of interchange? Is it advisable to find out?
 - » What do they already know about DDIs?
- Is there another DDI in close proximity that the audience may have driven already?

What then is an appropriately sized budget? Considering the high hurdle to win public opinion on the question of an innovative concept such as the DDI, a public involvement budget two to three times the size of a traditional budget may be needed to accommodate the challenges of communicating and solving grass roots issues. This guidance should not be construed to mean that budgets

must be this high, or that they might not need to be even higher at times given the identification of specific needs. Nevertheless, consideration should be given to the public involvement goals and budget at an early development stage to ensure that the addressing of vital public involvement needs is not restricted simply due to lack of foresight regarding budget. Additionally, budget to address several years of on-going requests from other DOTs and municipalities who are interested in first-ever implementations of innovative concepts should be considered, as should efforts to photographically document pre-construction, during construction, and post-construction conditions of the interchanges for education and messaging purposes.

As an example, the budgets for the Pioneer Crossing and Timpanogos Highway DDI projects were larger than usual because they introduced a first-in-Utah (second in the nation) concept that required extra public education and outreach, including targeting groups far beyond the usual group of “public, businesses, and drivers directly affected” by the construction.

Understand Your Audience(s)

Many project related public involvement and communications efforts automatically assume (in scoping or in execution) that the only audiences to be addressed are the public, the businesses, and the drivers directly affected by the project. With innovative concepts like the DDI, this is certainly not the case. Internal UDOT staff, UDOT leadership, public decision makers, industry leaders, legislators, and municipal leaders all have an interest in the development and implementation of these new ideas. We recommend that all of these parties be considered as stakeholders, and as potential audiences for project communications. In turn, while some audiences have common

needs, each audience may also have distinct needs that complicate or expand public communication efforts and require individualized and unique strategies and tactics.

Demonstrate Public Accountability

Planning efforts and NEPA documents identify a “needs assessment” or “purpose and need” step where project needs and metrics of success are developed. The identification and measurement of these needs is not merely a bureaucratic requirement, but provides an opportunity to identify needs and measures that may be messaged as part of a public information campaign. Without measuring the performance of the innovative concept versus the need that it is intended to serve, there is no closure of the public accountability loop to demonstrate good stewardship over public funds. This accountability to the public is critical to maintaining transparency and building trust and should be included as part of every project that may come under public scrutiny, but certainly for all projects that implement potentially controversial ideas like the DDI. It is an opportunity to demonstrate the merit of concepts like the DDI over time and highlighting actual operating results from application in the field. The positive outcome leads to the DOT’s ability to secure funding for new projects, continue to introduce innovation, and advance the goals of transportation within the State.

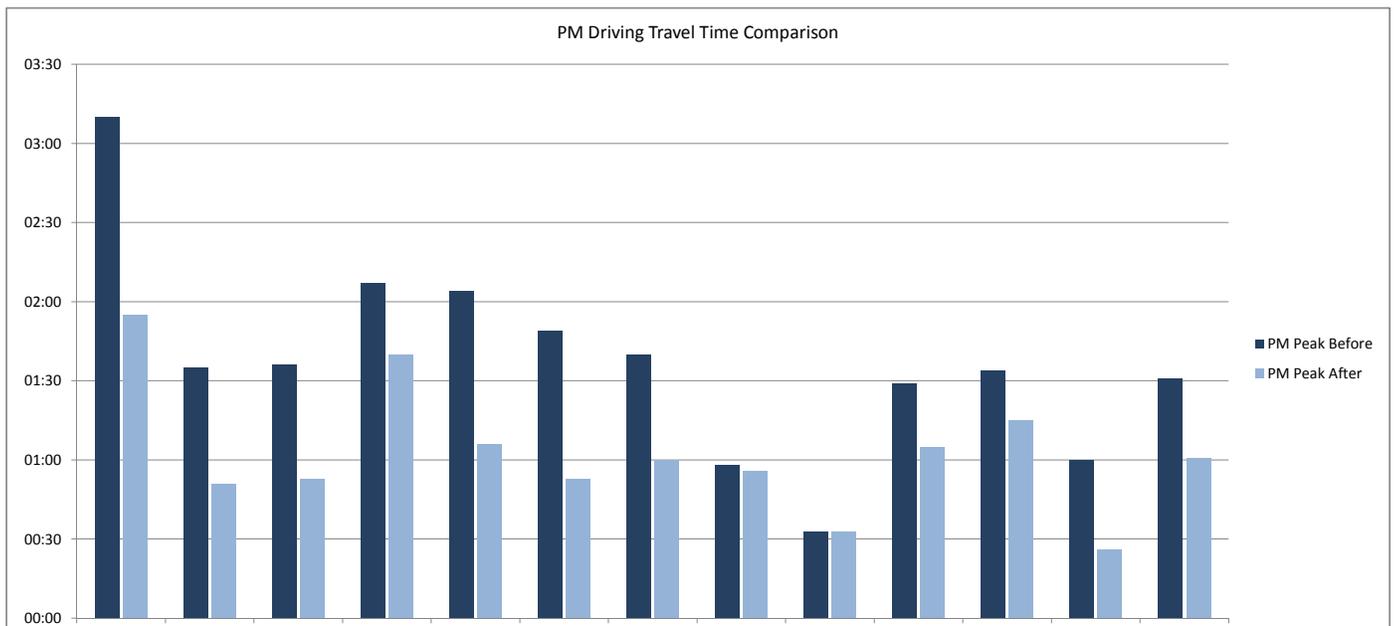
Any potential metric that is used to measure the success of the project (traffic volume, congestion, travel time, safety, economics, etc.) should be measured both

prior to implementation and post implementation (a before/after study). The differential comparison of pre- and post- implementation metrics to modeled efforts and to other project expectations is the essential work required to conclusively demonstrate merit and value to a perceived skeptical public and stakeholder group.

Manage Expectations

In developing value statements about project performance from a before/after study comparison, it is important to select time frames for measurement that will match public expectations. For example, although excellent delay and travel time saving may be anticipated in a future planning year that is 20 to 30 years away, it is important to recognize that a constructed improvement is being evaluated by the public right now. Public opinion will simply not wait 20 to 30 years to pass judgment on whether or not the public justification for the project is being met. Public opinion can develop and harden very quickly absent clear messaging about the value provided. Consequently, when developing and messaging value statements, it is important to clearly demonstrate value that meets the needs of the public as defined by the project. In addition, in circumstances of interchange modification or replacement, set realistic expectations for the value to be expected by using opening day measurements rather than measurements for some period 20 to 30 years down the road. This approach will allow expectations to be exceeded, which enhances the perceived value to the public.

exhibit 6-3: vissim before/after study results



Consider emphasizing the following:

- Increased safety and smooth traffic flow of a DDI. The safety and efficiency of the turning movements may be highlighted to assure the public that the interchange is functional for all vehicles and modes of travel.
- Minimized impact and disruption of service by expediting construction in retrofit interchange situations.
- Lessened cost and adjacent property impacts due to a smaller project footprint, reduced bridge length or width. In a retrofit, the money saved by using existing infrastructure is a message that will resonate.
- Lessened delay through the interchange and accompanied cost savings and trip reliability.

The DDI presents an opportunity to showcase UDOT's innovation to the public at large through traditional and trade media. Coordination with UDOT's Communications Department as well as each Region's public information officer is mandatory for any traditional media outreach.

Distributing the Message

UDOT traditionally uses a web site for projects that are of public interest or that have potentially substantial impacts. In the case of a DDI, a web site can act as a central repository for modeling, simulation, and graphic visualizations that can be easily accessed by the public. Updates on the status of the project, a time line of milestones, dates for public meetings, and other pertinent public information details can be provided in one dedicated location. Any inquiries may be easily referred to this web site and may

exhibit 6-4: pi materials for ddi mot phasing (pioneer crossing)

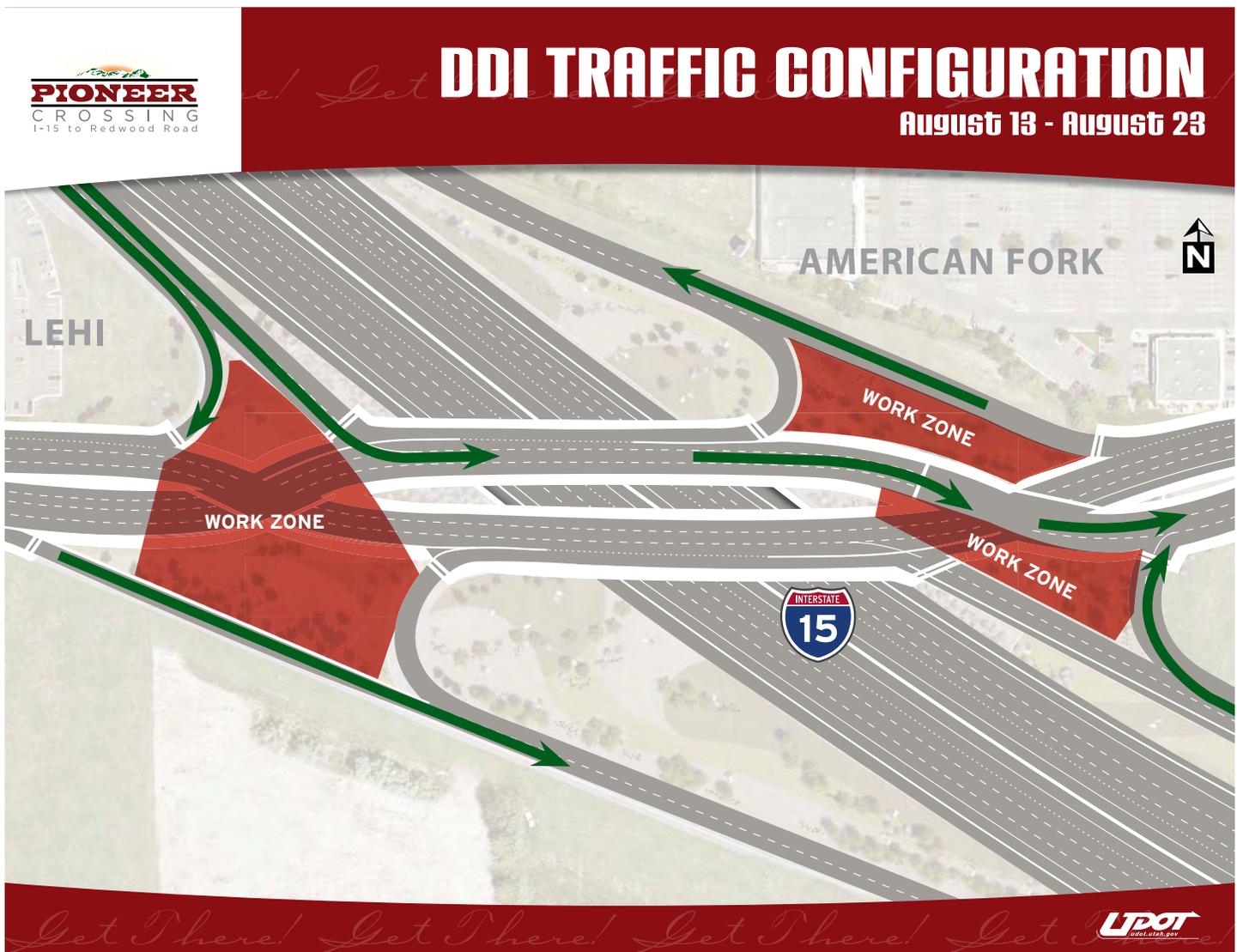
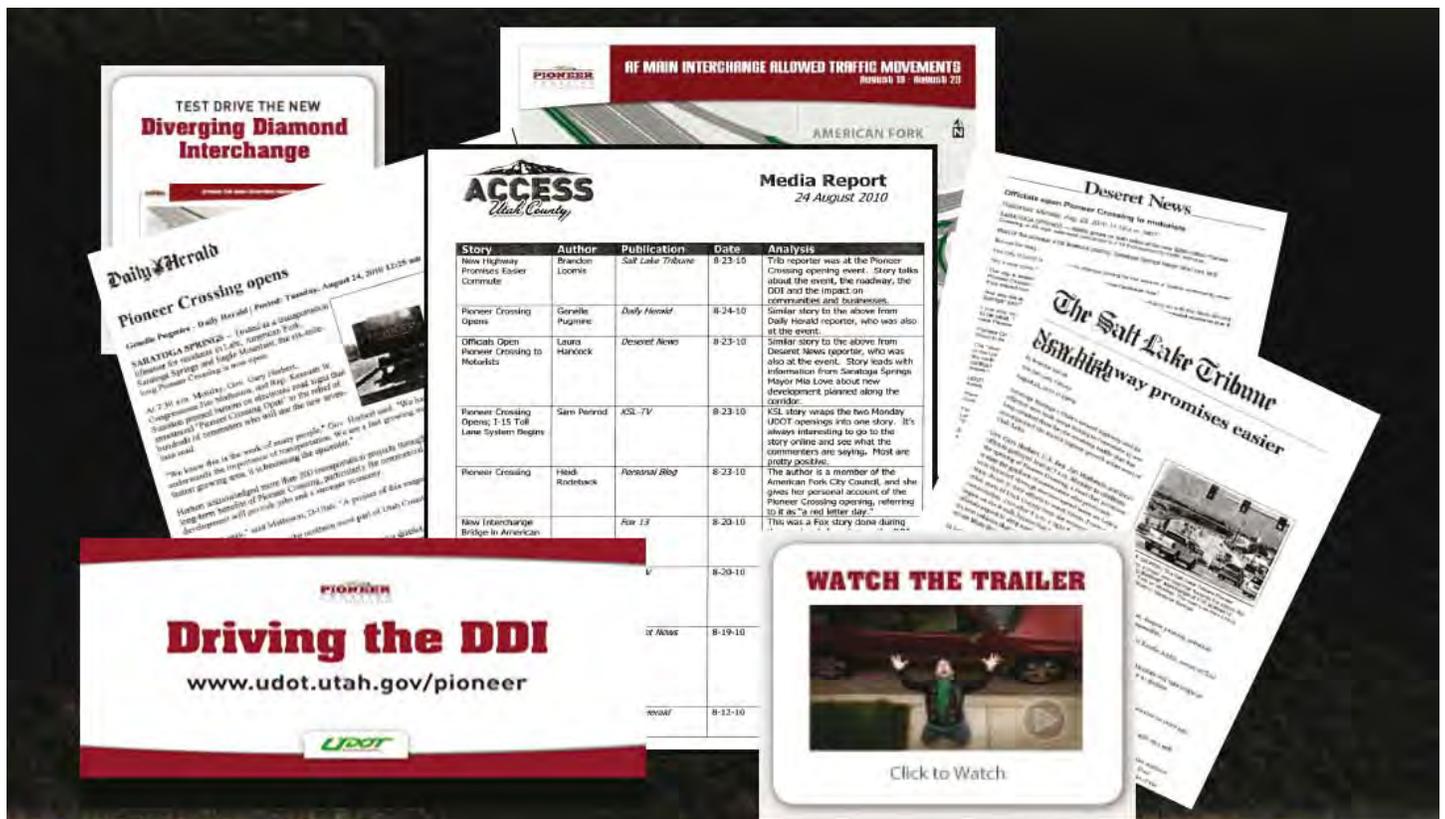


exhibit 6-5: pi materials for pioneer crossing ddi



aid in meeting the public's expectation for involvement during project development and construction.

Recognize that there has been significant and widespread adoption of social media tools, such as Twitter and Facebook that can assist in collecting public comments and providing less formal project information to augment the project web site. It is important to note that social media should be carefully analyzed for its effectiveness and weighed against the time and effort required for this type of tool. UDOT has established social media sites that can be used to post information when a project doesn't warrant its own sites. Please review UDOT's Social Media Policy (<http://www.udot.utah.gov/main/uconowner.gf?n=9966024694955721>) when using this technology.

Social media work best when they are implemented as part of an overall strategy that is complementary to other strategies and tactics – like project hotlines, public meetings, mobile-accessible web pages, and printed project communications. Print, broadcast media and specific mobile applications or apps, should be considered on a selective basis and skillful writing, engaging visuals, and targeted audiences are vital to capture and effectively communicate messages.

Tell an Engaging Story

Distributing facts and figures alone does not engage the public in a way that allows them to grasp, retain, and accurately broadcast critical project messages. The rise of the internet and social media has allowed simple and effective mass communication while simultaneously encouraging a proliferation of messaging that requires strategic differentiation in order to be heard. In developing

exhibit 6-6: ddi animation



effective public messaging, we recommend using the form of the story to broadcast key project messages whenever possible. The use of a story format provides a framework for understanding and resolving problems that facilitates ease of understanding, retention, and communication to others. It is an approach that is particularly well suited to identify problems or project needs and to demonstrate how those problems are resolved by the proposed improvements. The story format may be presented through simulations and animations to enrich traditional displays in order to illustrate the unique traffic movements and benefits of a DDI, including:

- Contrasts between existing and proposed mobility conditions within interchanges, being replaced under a retrofit situation, and
- Movement of non-motorized, pedestrian and bicycle traffic.

The story form personalizes UDOT and other key stakeholders and extends public trust.

The development of a “story” for public messaging should include elements that engage or develop interest with those who see or hear the story. The use of monotone voices and technical jargon, as well as the use of plodding camera movements, and unimaginative visual effects, does not engage viewers nor does it enhance the story telling experience. Consequently, public messaging should include engaging dialogue, simplified messages, dynamic camera movements, and captivating visual effects that reinforce the messages to be communicated. The use of these and other effective storytelling elements will engage viewers in a way that encourages consumption of the entire message and provides greater potential for that message to be retained and shared with others.

On the Pioneer Crossing project (American Fork Main Street) the visual simulation included an instructional animation and a driver’s perspective experience of driving a DDI. (<http://www.youtube.com/watch?v=LqE1Z77ccwQ>) Animations can be used in presentations, online, public meetings, webinars, media stories, and in social media. They should be done during the construction phase when design is mostly determined. Because of the cost of doing an animation, this tactic should be carefully weighed in overall value and potential reach. UDOT Central Communications has an animation calculator to quantify the potential need for an animation on a project.

Public Involvement during Construction

Public involvement during construction is especially critical to communicate traffic changes and time frames associated with the inconvenience of construction. Door-to-door distribution of project communication materials and direct contact to facilitate open lines of communication go a long way toward building trust and confidence between impacted businesses, property owners and UDOT. Ensuring that complaints are initially lodged with those empowered to resolve them allows resolution to occur at the lowest possible level. Variable message signs (VMS) and other location specific broadcast methods are critical to communicate expectations with the traveling public, including outreach for commuters who can’t be reached door-to-door.

Public Perception of the DDI in Utah

Overall, the limited out-of-direction travel, significant congestion reduction, and improved safety of the DDI have been well received by a vast majority of Utah’s traveling public. Public opinion studies indicate over 80% of the public becomes confident with the concept only a short time after opening. And the public seems to like the DDI as well, with 80-90% saying it has improved congestion in the areas where it has been implemented. These initial successes seem to indicate that the concept is working and that public information materials are helping to get the message out effectively.

exhibit 6-7: ddi public opinion

