Best Practice

Vissim Analysis of Diverging Diamond Interchanges

Wisconsin Department of Transportation

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Overview

This document describes the current best practices for the traffic analysis of Diverging Diamond Interchanges (DDI). It consists of a high-level overview of software and the issues that may arise from a deterministic approach before detailing Vissim-specific elements of a microsimulation analysis and the difference between a proof-of-concept analysis and a calibrated design-quality model.

This document references the following manuals and software packages:

- Highway Capacity Manual 6th Edition
- Highway Capacity Software (HCS) 7.9
- Synchro 11
- Vissim 2020 and 2021

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1 TRAFFIC ANALYSIS SOFTWARE SELECTION

Ramp terminal spacing and interchange interactions with the adjacent street network and nearby intersections is key to understanding the effectiveness of a DDI design at any one location. For this reason, it is strongly recommended to use a microsimulation package that allows for flexibility in both geometry and traffic control devices. For WisDOT, the preferred package at this time is Vissim, a microsimulation modeling software distributed by PTV America. Vissim has the flexibility to accurately replicate geometry, traffic control, and driver behavior. This flexibility allows users to the atypical and site-specific design common in a DDI. When performing preliminary analysis on a project site, Vissim should be used to confirm the lane configuration required based on the traffic volumes and performance.

While the Highway Capacity Manual 6th Edition (HCM) includes DDI analysis in Chapter 23 – Ramp Terminals and Alternative Intersections, there are noted shortcomings with the use of this methodology for DDIs in practice. Limitations of the methodology include:

- Poor performance in oversaturated conditions
- Inability to compare impacts of the DDI versus other interchange options on entrance ramp merging areas
- Inability to develop or confirm signal timing for arterial progression
- Inability to account for significant lane utilization imbalances for upstream and downstream decision points as well as cross sections greater than four lanes at the crossover. [1]
- Highly generalized travel speed performance for segments between ramp terminals [2]

1.1 Synchro Considerations

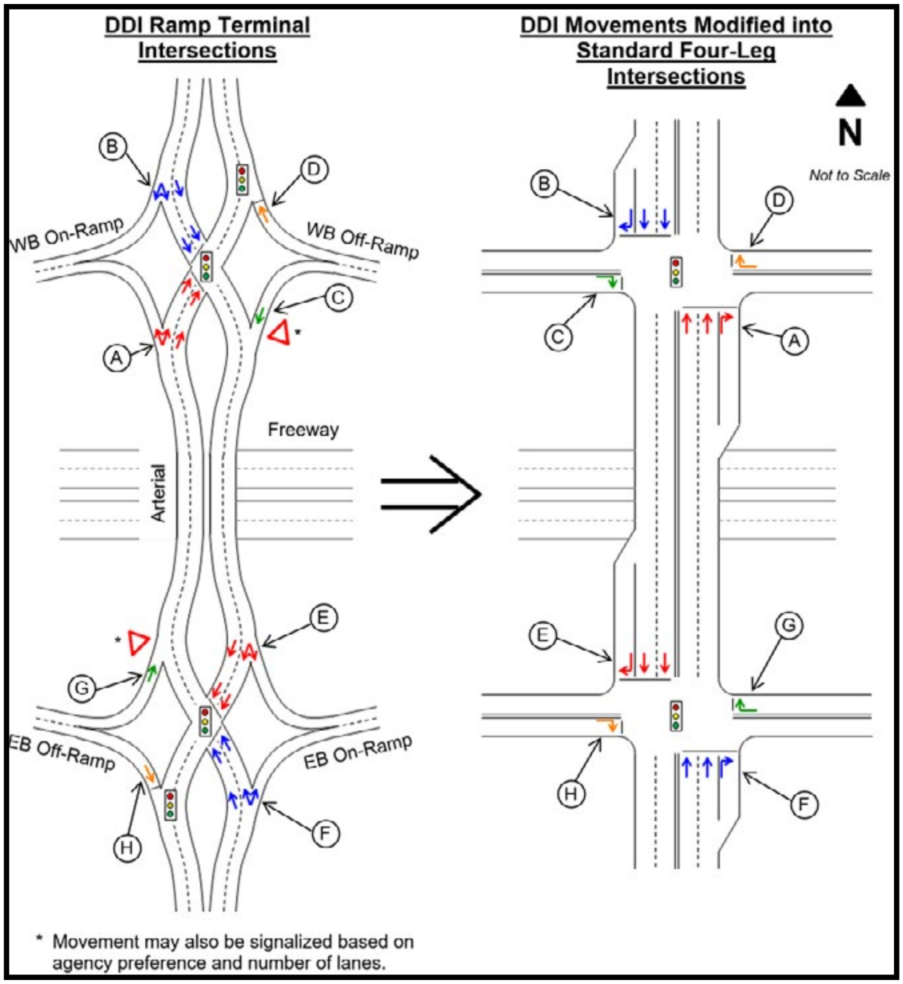
Analysis of a DDI in isolation with no nearby intersections or access points can be performed in Synchro, though this would require careful thought and consideration (see Section 3.2, Modeling Area Extents). HCS and other software that emulates HCM methodology will only be capable of analyzing DDI performance at a very high level. HCS and Synchro do not handle the effects of traffic platoons except in a very general way. Additionally, Synchro does not handle merging and weaving accurately. Synchro treats each DDI ramp terminal as five intersections as opposed to one. Cluster Editor is required to be able to signalize the off ramp turning movements. The most critical shortcoming of utilizing Synchro/SimTraffic for DDI analysis is the inability for the software to allow modeled vehicles to anticipate movements in advance and thus alter lane utilization on multilane movements to reflect downstream decisions. For basic capacity of a DDI, Synchro or HCS should be used with caution as the results may be misleading as they will not account for the influence of nearby intersections and decision points.

Also note that Synchro's built-in optimization of cycles and splits will not function due to phase numbering. DDI phase numbering is another hurdle for Synchro analysis. Synchro allows coordination of phases 2 and 6, or 4 and 8 (opposing through movements along a roadway). At the crossing signals of a DDI, Synchro does not allow phases 2 and 6 to both occur at the signal since they would run concurrently at a typical intersection but are opposing movements at DDI ramp terminals. One of the two directions must be renumbered. Once one movement is renumbered, Synchro is no longer able to generate the time/space diagram for that direction.

[1] HCM 6th Edition, Exhibit 23-25
[2] In order to compare travel times as a measure of effectiveness, the methodology adds in the time by simply accounting for out of direction travel distance and speed limit. It does not account for less than ideal progression or the impact of queues within the intersection influence area.

Synchro can be used for high-level testing of a DDI through manipulation of the software by creating two "regular" intersections as shown in Figure 1. Set the two crossing through movements as conflicting through movements. Set turning movements from the ramp in the DDI as the left turn movement in Synchro, so they that can run at the same time as the DDI through movement that the turn is concurrent with in the DDI configuration. Adjust the saturation flow rate to between 1650 and 1800 vehicles per hour per lane (vphpl). This will allow a proof-of-concept-level calculation of the cycles and splits that would be a starting point for the signal timing input into simulation.

FIGURE 1. MANIPULATION OF DDI MOVEMENTS INTO STANDARD FOUR-LEG INTERSECTIONS



Note that as more DDIs are implemented in each area, the driver population may become more accustomed to travel patterns at DDIs and, depending on the design speed, use of higher saturation flow rates may become more justifiable in the future.

1.2 SimTraffic Considerations

One shortcoming of Synchro analysis is the inability for a deterministic analysis to consider influences of progression and platooning that are critical to a DDI. While SimTraffic could be used to assess platooning and progression along an arterial corridor, SimTraffic does not accurately model the DDI's operations.

Operations of a DDI in microsimulation are dependent on an accurate control of speed and lane utilization. SimTraffic uses point-to-point vehicle routing that might not accurately depict operational concerns or lane utilization and progression at a DDI. It also cannot preclude "U-turn" movements at an interchange nor can it model driver behavior of cars lining up to make the movement after the first intersection. The importance of this intelligence is covered in greater detail in Vissim Modeling.

1.3 Other Considerations

While some operations analyses of interchanges are limited to the ramp terminals, it is also important to use the same model to cover merging areas at freeway entrance ramps. As discussed in section 3.9.2.3 (Freeway operations), DDI impacts to the freeway mainline are best captured in a model containing the entire interchange as opposed to performing a separate merge analysis using HCM methods. The HCM methodology for merging or weaving analysis does not account for differences in the way various interchange types or signal timings release entrance ramp traffic to the freeway. This omission can conceal significant differences between interchange options and must be accounted for in high volume locations where freeway operations are a concern. The DDI provides more time for left turning traffic to enter the freeway resulting in less platooning and a more uniform flow of traffic entering from a DDI when compared to other diamond-type interchanges. Depending on congestion levels on the subject freeway on which the interchange is being considered, these impacts may play a role in selecting the best option.

2 DDI LANE CONFIGURATION CONSIDERATIONS

Initial lane configurations can be determined via a combination of turning volumes, progression with adjacent signals, and storage requirements. For volumes, a general rule of thumb is 750 vphpl for through movements and 600 vphpl at ramp turns. Turning movements are lower because of a reduced speed and queuing considerations. These numbers can be adjusted if there is an imbalance in traffic direction. For example, the through movement could handle more than 750 vphpl if the opposite movement has very little demand due to increased green time that could be provided for the heavier movement.

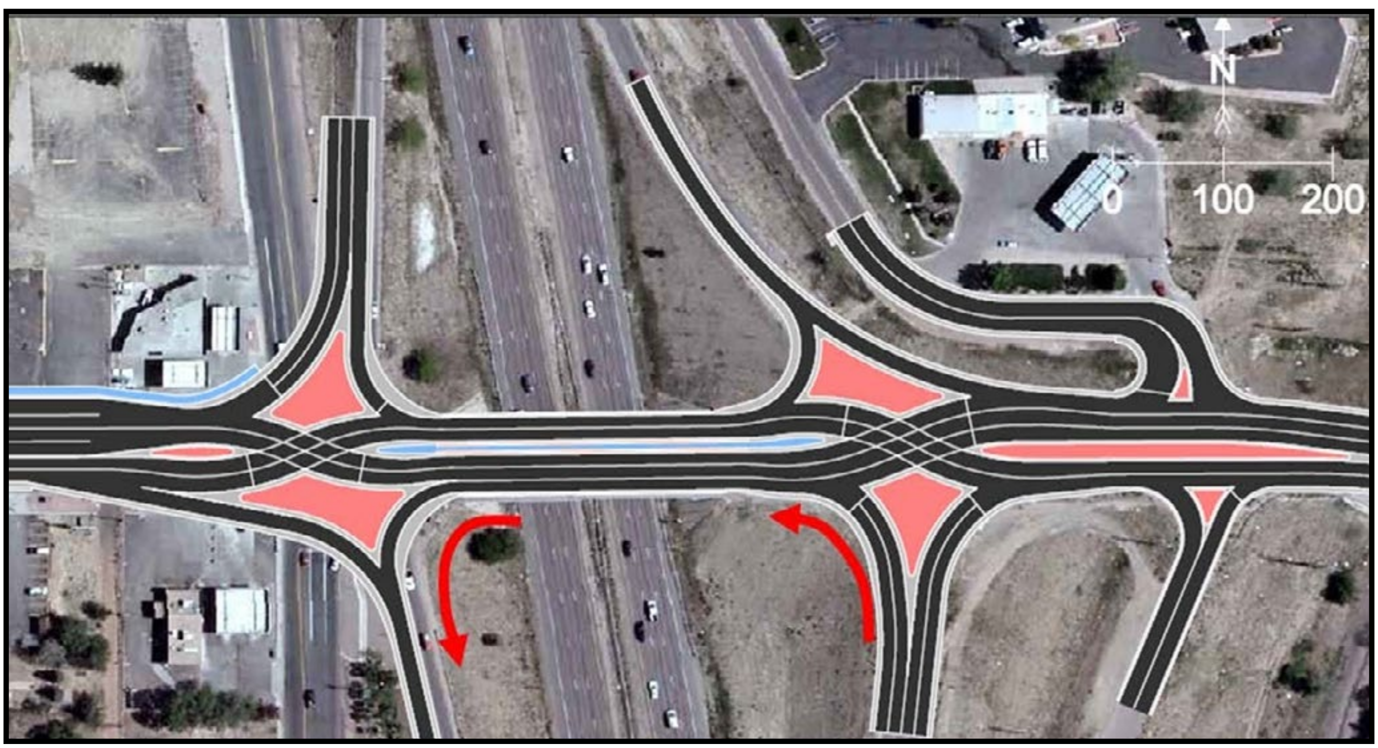
Additional lanes might be necessary beyond those needed to handle traffic demand. These might be due to additional downstream storage requirements or lane continuity and progression throughout the interchange and adjacent intersections.

2.1 Off-Ramp left-turns

Left turns from the exit ramps should be signalized in the following situations:

- Significant pedestrian volumes are present and pedestrian accommodations are located on the outside and not in the median within the interchange core
- More than one turn lane from the ramp
- A weaving section is created between the ramp terminals due to lane imbalances or auxiliary lanes (Figure 2)

FIGURE 2. MOVEMENTS CAUSING POTENTIAL WEAVING ISSUES



At a DDI, the signalization of the left turn movement can use the same criteria as signalization of the right turn, but signalization of all movements should be considered on a site-by-site basis. Left turns do not need to be signalized, but often are for driver expectancy reasons. Left turn on red can be allowed but is dependent on state specific statutes regarding turns from one-way streets to one-way streets.

2.2 Off-Ramp right-turns

Unless the right turn from the exit ramp leads to its own (add) lane, this movement should be signalized. As DDIs become more prevalent, the right turn from the exit ramp can be handled with yield control or with right turn on red. The state of the practice makes the application of right turn on red a jurisdiction-specific decision. This also applies to how and whether dual right turns from a DDI should be allowed to turn on red from one, both, or neither lane. The WisDOT Traffic Signal Design Manual (TSDM) details the requirements for free flow, yield, or signal control of right turns at signalized intersections.

Right turns from the exit ramp may not need to be signalized if the turning lane becomes an add lane or has its own acceleration lane. This type of treatment should only be considered when there are no nearby decision points, such as driveways or turn lanes, as this will create a weaving conflict. Origin-destination, turning and through movement volumes, and intersection spacing downstream of the ramp terminal should be considered when determining if the right turn should be signalized. Undesirable weave conditions may develop downstream of the interchange if there is a significant right turn volume attempting to immediately turn left outside of the interchange, for example. Signalizing the right turn from the off ramp will eliminate concerns for substandard weave lengths but may require providing an additional turn lane to maintain acceptable operations. Signalizing right turns from the entrance ramp is also a more desirable design from a bicycle and pedestrian standpoint.

3 VISSIM MODELING

The following section assumes that the reader has a moderate to advanced familiarity of Vissim software.

3.1 Reference files/background image

It is important that the background image used to model any proposed DDI design is the correct scale and is reproducible. If any adjustments are made to the design in CAD, the background image should be able to be recreated at the exact same scale and position to minimize any rework in Vissim. A good workflow is to create a print border in CAD with a known scale and coordinate position that will not be moved or deleted.

Having an accurate design to base the Vissim model on plays a critical role in the model performance. Speeds, spacing, stop bar placement all play critical roles in the development of signal timing. Similarly, the location of ramp turns is directly related to signal timing and clearance intervals. The Vissim model should match the geometric design as much as possible to accurately model anticipated performance.

3.2 Modeling Area Extents

The Vissim model needs to include adjacent elements such as intersections or driveways that influence either the platooning of traffic flow into the DDI or impact the lane utilization within the DDI. For example, an intersection downstream with a heavy left turn volume may result in traffic within the core of the interchange or on the turning movement from the ramps heavily favoring the left lanes of those movements to such a degree that it impacts capacity or significantly increases queueing. Lane configuration at the interchange, a single right turn lane to the entrance ramp for example, may force more vehicles to skew to the right lane at an upstream traffic signal to the point where the right lane of that intersection may fail.

At a minimum, it is recommended that any signalized intersection within 1500 feet of the DDI ramp terminals be included within the Vissim model. Unsignalized access points with volumes over 100 vehicles per hour (vph) that are within 1000 feet should also be included.

3.3 Inputs

Input links should be coded based on the following guidelines; however, it should be noted that these are just starting points and links can be lengthened based on queuing or error messages for unmet demand or lane changing.

- 1-lane inputs – 500-1000 feet
- 2-lane inputs – 1500-2,000 feet
- 3-lane inputs – 3,000+ feet
- Freeway links – 5,000+ feet at a minimum

These distances will allow traffic on input links to develop some platooning as they approach study elements, but more importantly, lane utilization adjustments can be made by vehicles as they maneuver into appropriate lanes for downstream decision points.

3.4 Routing

Static vehicle routing should be developed in the form of an origin-destination matrix with all decision markers located 10 feet from the input link and all destination markers located at the ends of external links. Routing should always be based on an input and output link in order to accurately model lane utilization.

Point-to-point routing should never be used.

3.5 Links/Connectors

Set default emergency stop and look back distances on urban link types to 50 and 1500 feet [3], respectively, with "per lane" box checked. These can be globally changed in the link list view. These values represent a good starting point and can be modified based on site specific geometry or modified during calibration. Figure 3 and Figure 4 illustrate these settings.

FIGURE 3. CONNECTOR SETTINGS DIALOG BOX

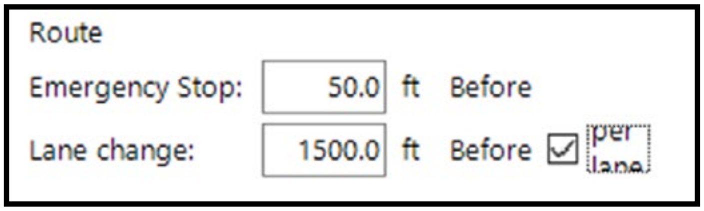
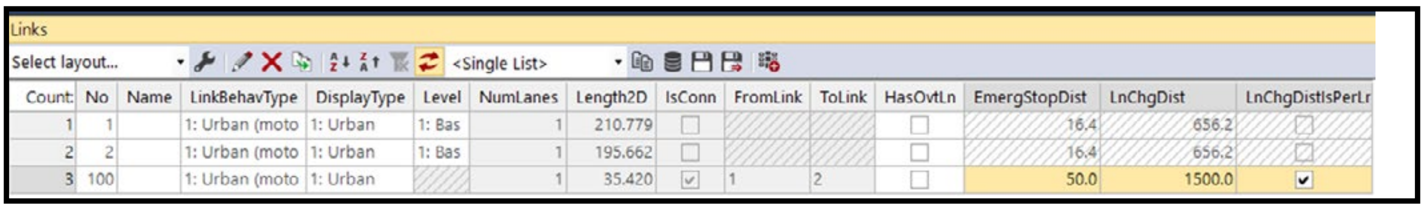


FIGURE 4. CONNECTOR LIST VIEW



Links

Select layout... <Single List>

Count	No	Name	LinkBehavType	DisplayType	Level	NumLanes	Length2D	IsConn	FromLink	ToLink	HasOvtLn	EmergStopDist	LnChgDist	LnChgDistIsPerLn
1	1		1: Urban (moto	1: Urban	1: Bas	1	210.779	☐			☐	16.4	656.2	☐
2	2		1: Urban (moto	1: Urban	1: Bas	1	195.662	☐			☐	16.4	656.2	☐
3	100		1: Urban (moto	1: Urban		1	35.420	☑	1	2	☐	50.0	1500.0	☑

Freeway off-ramps should be coded as "freeway" link display and behavior until turn/storage lanes develop, at which point those should be coded as "urban", as shown in Figure 5. Connectors at this transition should be coded as "urban". Freeway on-ramps should be coded as "freeway" after departing the arterial. Connectors at this transition should be coded as "freeway".

FIGURE 5. FREEWAY DIVERGE LINK TYPE

[3] Lane change distances within the interchange must be long enough that a movement downstream of the interchange can be anticipated by a vehicle on the exit ramp. For example, if a vehicle on a northbound exit ramp wants to head west, then turn right at the intersection 500' west of the west terminal of the DDI, the lane change distance for the entry into that westbound right turn bay must be long enough that if the northbound left turn is a dual lane turn, that vehicle would choose the right lane in anticipation of that turn.

Freeway entrance ramps should be coded as freeway. (See Figure 6.) Merging areas on ramps should be coded from painted gore to end of taper (see Figure 7 and Figure 8) and use “no lane change right” to prevent vehicles from changing lanes into the merging lane. Emergency stop distance will likely need to be increased based on length of the taper to control where vehicles will stop when trying to change lanes. In example below, emergency stop could be set to approximately 100 feet.

FIGURE 6. ENTRANCE RAMP LINK TYPE

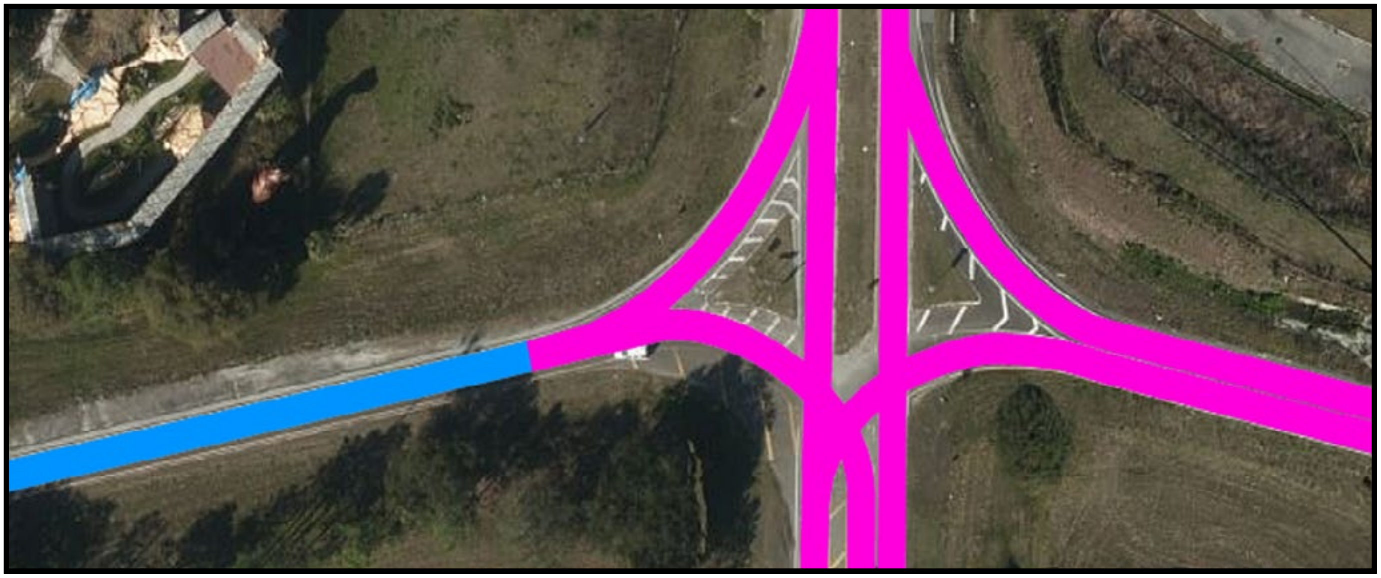


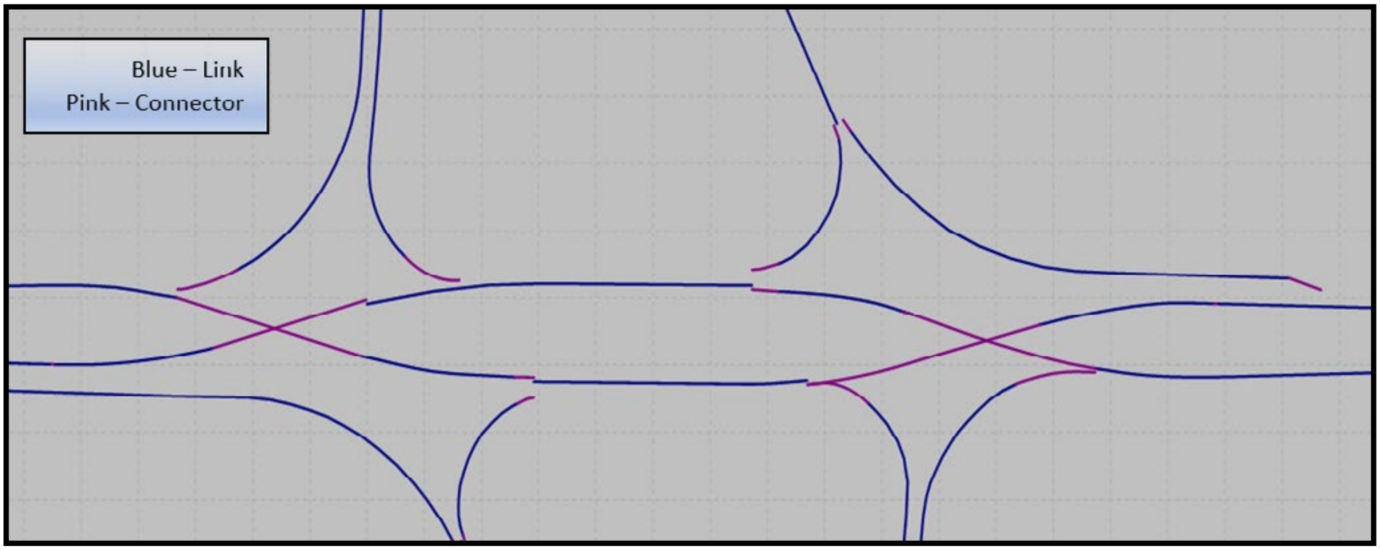
FIGURE 7. SIMPLE LINK/CONNECTOR VIEW SHOWING COMBINED LINK LAYOUT

FIGURE 8. LINK/CONNECTOR VIEW SHOWING “NO LANE CHANGE” SETTING

For DDIs, the areas in which merging or crossing conflicts occur should be coded with connectors. Figure 9 shows how links and connectors are distributed at a DDI. This will make conflict areas easier to code if they are needed. Minimize the extent of the connectors whenever possible and make sure the ToPos value is 0.

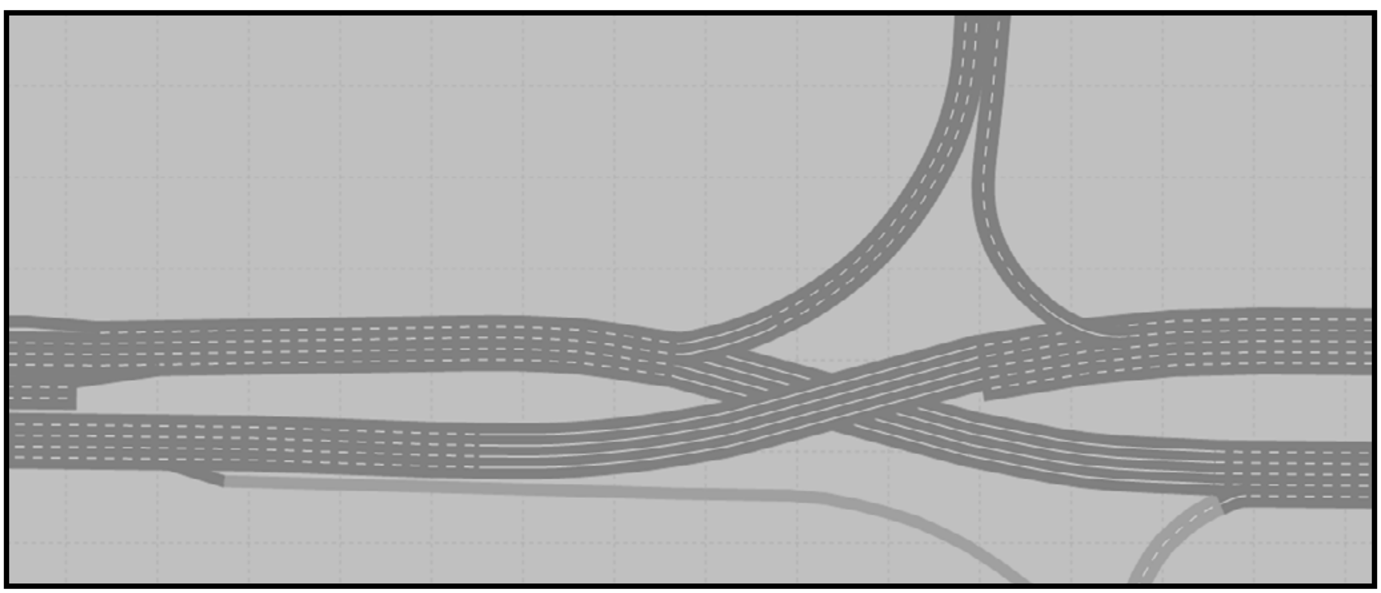
Use "no lane change" on all multilane connectors through these conflict areas.

FIGURE 9. LINK AND CONNECTOR CONFIGURATION AT A DDI



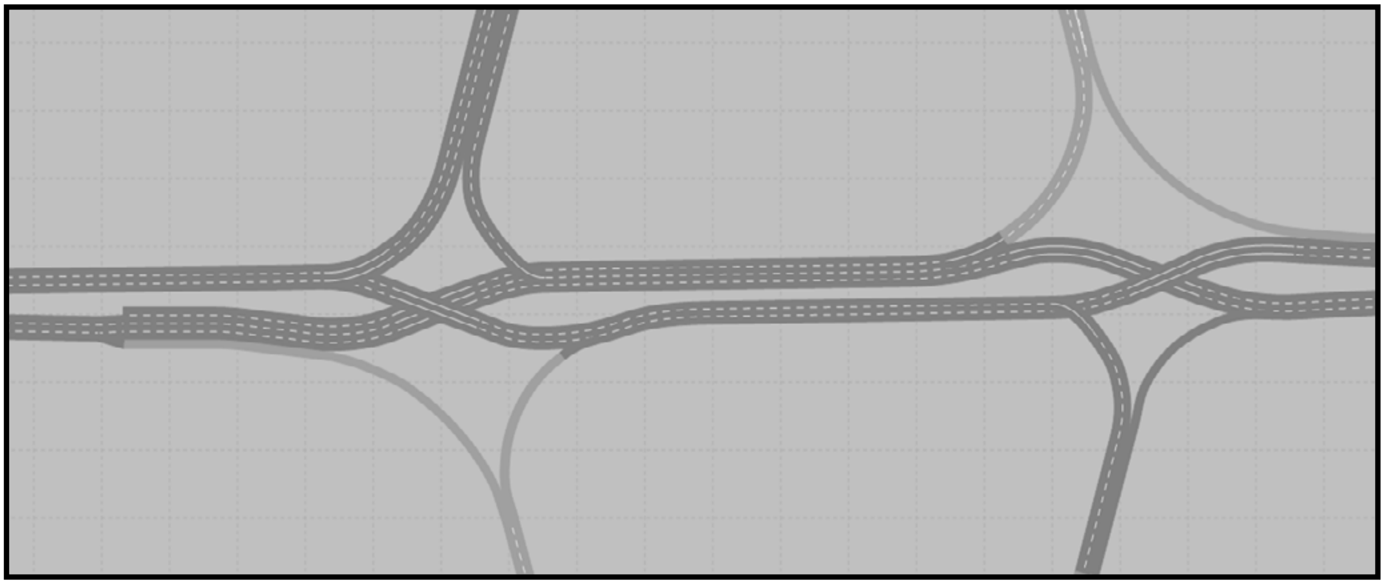
Code crossroad right turn storage bays with separate links whenever possible. Exceptions to this rule include shared thru/turning movements or locations with unique geometry where separate turn bays are not possible to code. Figure 10 shows a Vissim model of a DDI with the right turn coded as a separate link.

FIGURE 10. DDI MODEL WITH RIGHT TURN



Left turns to the ramps of a DDI are not coded as separate links even when they are turn only lanes once inside the interchange core. Figure 11 illustrates how the left turn lane is coded in this situation.

FIGURE 11. DDI WITH LEFT TURN LANE DEVELOPED OUTSIDE OF THE CROSSOVER INTERSECTION



For ramp turns, code left and right turns as separate links as far as possible upstream based on geometry. Refine if need be based on observations of drivers in the animation. Figure 12 shows how the on ramp uses two different links to separate the left turns and the right turns.

FIGURE 12. DDI RAMP TURN WITH SEPARATE LINKS

3.6 Running speed vs turning speed

3.6.1 Design Speed

The design speed of reverse curves for through movements should be governed by posted speed on the approaching roadway. The design speed of curves should be less than the design speed of the approaching roadway. This speed reduction should be no greater than 15 mph and preferably only 10 mph.

Speed differential greater than this may pose a safety risk for off-peak drivers and may increase the likelihood that vehicles leaving the roadway as they enter reverse curves experience speeds that are too fast for the curvature. The first Missouri DDIs (I-270 and Front Street in Kansas City and I-44 and MO 13 in Springfield) had a through movement design speed of 25 mph with posted approach speeds of 40 mph. At early DDIs, a slower design speed was also examined, but a traffic simulation showed that the high percentage of trucks in the vehicle stream with a 20 mph speed began to impair the operations of the interchange.

DDIs can be used with approach speeds greater than 40 mph; however, this increases the design speed of reverse curves and significantly increases the footprint as the median width increases to accommodate the higher speed reverse curvature.

The key elements of a DDI are interrelated, further enforcing the fact that DDIs are very site-specific in their design characteristics. While the overall concept remains the same from one to another, specific measures, such as design speed, radii of reverse curves, median width, etc., may vary significantly from one location to another.

The design speed of curves coming from the ramps need not be high. At a standard diamond interchange, these ramp movements are essentially stop condition type movements. Turning speeds of 10 mph would be acceptable, but more likely than not, design speeds will be governed by traffic operation requirements as well as design vehicles. Turning speeds for DDIs are typically in the 10 to 20 mph range. The Front Street DDI in Kansas City has dual left turn lanes from the ramps that are designed to accommodate side-by-side WB-67 trucks turning at 10 to 15 mph. The University Parkway DDI in Sarasota, Florida has 25 mph design speeds for all turning movements.

3.6.2 Desired Speed Distributions

Unlike typical roadways, at and within DDIs, observed speeds are usually within 5 mph of the design speed. Where terminals are spaced far apart, vehicles do speed up within the core of the DDI to 5 or so mph faster than the reverse curvature.

Desired speed curves should reflect local driver behavior on typical roadways relative to posted speed limits. Apply the same distributions to DDI elements based on the design speed of curvature as mentioned above.

For turns from the exit ramps, do not apply “normal” left and right turn speeds to these movements. They are likely a larger radius than turns at a typical standard diamond interchange. Apply the speed that matches the radius of curvature for each lane.

For multilane turns from the ramp and even through the crossovers (particularly if the crossover design speed is 25 mph), it is recommended that cars and trucks use different speed distributions. Trucks are likely to navigate these movements more slowly when heavy traffic is present.

Table 1 shows the recommended values for desired speed distributions not covered by the WisDOT-specific Vissim speed distributions. Based on the WisDOT speed distributions, past national experience has shown that speeds along the through movements of a DDI would be most closely replicated by determining the design speed of the DDI curvature and using the posted speed that matches that design speed in Table 2.

TABLE 1. SUPPLEMENTAL RECOMMENDED BASE DESIRED SPEED DISTRIBUTIONS

NUMBER	FACILITY OR SPEED FUNCTION	POSTED SPEED (MPH)	MINIMUM SPEED (MPH)	MEDIAN SPEED (MPH)	MAXIMUM SPEED (MPH)
20	20 mph (use for turns)	20.00	18.00	20.00	27.00
25	25 mph (use for turns)	25.00	20.00	27.00	40.00
100	Reg Right Turns	-	9.00	-	12.00
101	Sharp Right Turns	-	6.00	-	9.00
102	Wide Right Turns	-	15.00	-	19.00
200	Reg Left Turns	-	15.00	-	19.00
201	Sharp Left Turns	-	10.00	-	13.00
202	Wide Left Turns	-	17.00	-	22.00
300	U-Turn	-	5.00	-	8.00

TABLE 2. WISDOT DEFAULT DESIRED SPEED DISTRIBUTIONS

				WisDOT Speed (mph)			
Index	Posted Speed	Facility Type	Vehicle Type	Min	50th	85th	Max
1	70	All	PC	60.0	74.3	79.5	90.0
			HV	55.0	67.0	71.8	80.0
2	65	All	PC	55.0	71.4	75.6	85.0
			HV	55.0	64.1	67.9	80.0
3	55	Freeway	PC	50.0	64.6	72.4	80.0
			HV	45.0	59.2	65.0	70.0
4	55	Expressway	PC	50.0	59.9	65.6	75.0
			HV	45.0	54.9	60.6	70.0
5	55	2-lane rural	PC	50.0	59.9	64.5	70.0
			HV	45.0	54.9	59.5	65.0
6	50	Freeway	PC	45.0	62.4	69.3	80.0
			HV	45.0	57.0	61.9	70.0
7	50	Non-Freeway	All	45.0	52.8	58.2	65.0
8	45	All	All	40.0	48.3	55.0	65.0
9	40	All	All	35.0	43.4	49.5	55.0
10	35	All	All	30.0	42.5	47.4	50.0
11	30	All	All	25.0	33.9	38.9	45.0
12	25	All	All	20.0	30.9	34.6	40.0

3.6.3 Crossroad Speeds

Place the Desired Speed Decisions (DSD) and Reduced Speed Areas (RSA) on top of each other just prior to the apex of the first curve encountered [4]. If spacing between terminals is greater than 750' or so, an additional DSD can be placed just upstream of the PT of the last curve before the core tangent. If this additional DSD is used to speed up within the core, place another pair of DSDs and RSAs at the end of the tangent to drop running speeds down for the second crossover. Place a final DSD upstream of the PT of the last curve of the DDI to return vehicles to the arterial speed.

3.6.4 Ramp Speeds

Place a DSD downstream of the exit gore to speeds more appropriate for the interchange. This will require judgement and can vary based on the length of the ramp. Setting a DSD near the exit gore to the DDI's design speed may make traffic travel unrealistically slowly if the ramp is very long.

Place an RSA at the apex of the turn that is at least 25-30 feet long that is matched to the design speed for that turning radius. A DSD will be needed on the crossroad tangent just after the end of the connector from the ramp turn to bring vehicles up to the desired speed within the DDI.

For turns to the entrance ramps, ensure that the RSA placed at the apex of the turn is matched to the speed appropriate for the radius of the turn. Place a DSD at or near freeway speed near the PT of the curve.

3.7 Conflict Management for Off-Ramp Turns

Visual inspection of the microsimulation model is recommended to address potential issues at the off-ramp left and right turns. Signal timing, using delay and trail green phases, can help mitigate potential conflicts in simulation. Once the model has been set up, run the animation, and observe whether the first turning vehicles from the ramps yield to the last of the platoon from the through movement leaving the crossover. A conflict area may be required to mitigate any observed repeated behavior of turning traffic in the model colliding with the through traffic.

Priority rules are also preferred to prevent blocking behavior that results when traffic cannot clear the intersection due to downstream queuing. Priority rules used for blocking should have a maximum speed set for 3 mph as a starting point.

[4] The reasoning behind the colocation of RSAs and DSDs has to do with where DDI curvature is located relative to the links and connectors. Typically, an RSA stretched across either the apexes of the curves or through the curves would work at a DDI, the reverse curves take place across multiple link and connector elements. Vissim will throw an error is DSDs are placed too close to the end of links and RSAs should really be used throughout the sections where speeds are slowest.

3.8 Signal Timing

3.8.1 General Timing Considerations

Synchro generates optimized signal timings based on a performance index. It is recommended that Synchro be used to create a good starting point for the signal timings of adjacent intersections, but not the DDI ramp terminals. Timings for a DDI are not well handled by Synchro so it is essential that optimization is performed by the traffic engineer.

The primary conflicting traffic at the two crossing crossover intersections (the opposing through movements on the crossroad) are typically signal controlled. Signals within the DDI are two-phase signals, regardless of whether turning movements to and from the ramp are also signalized. The two-phase operation allows for shorter cycle lengths and decreases lost time per cycle. The DDI movement, that will be coordinated with adjacent signals, will not always be the through movement. It may be the turning movement from the ramp. Careful attention should be given to traffic distribution at the interchange to determine which movements should receive priority.

A good starting point for DDI timing is to set the cycle length to either a full or half cycle of the adjacent signals and set the splits to slightly favor the direction heading away from the interchange (the westbound direction at the west terminal and the eastbound direction at the east terminal). The goal with DDI timing is progression of traffic in both directions. Coding of the traffic model to reflect the proper speed approaching, within, and departing the interchange is therefore critical as it will impact the proper development of offsets.

There are two schools of thought on DDI cycle lengths. Shorter cycle lengths result in less queuing per cycle. This may come at the expense of ideal progression on the arterial, particularly if major signalized intersections are nearby. Longer cycle lengths make progression easier but can create significant queuing. Longer cycle lengths have less lost time overall as the phases change less frequently.

3.8.2 RBC Settings

When creating ring barrier controllers (RBCs), set the Frequency value (upper right corner) to 10. This allows the controller to be called 10 times per second (similar to the simulation resolution). If this value is left at the default Frequency of 1, the controller is only called once per second and any timings that are not whole numbers, e.g. an all red time of 1.5 seconds, will be rounded down. This may cause unintended behavior of the traffic signal and create vehicular conflicts when transitioning between phases.

3.8.3 Preferred Number of RBCs

During the concept development phase, it is recommended to put each ramp terminal on its own controller. This allows for more flexibility under actuated control in practice and may be of benefit in off peak hour analysis.

There is a perceived inability of signals at DDIs to “rest on green.” During off-peak hours, signals at standard diamond or single point interchanges can rest on green for both directions of the crossroad. When no traffic is detected on the ramps, no phases for the ramps are triggered and the crossroad can flow without interruption. While the DDI signals cannot rest on green for both cross street through movements simultaneously since their paths cross twice, the signals can be deployed in a manner that emulates resting on green. Each signal phase that accommodates cross street traffic approaching the DDI should be set to rest on green. Signal phases that accommodate traffic within the core should be set to trigger only if presence is detected. This may require changes in detector placement to prevent left turns onto the entrance ramp from triggering an unnecessary phase change. If the spacing between the terminals is large, this may also require advance detection within the interchange core.

A second consideration is that it may be desirable, based on project-specific traffic patterns, to have only one of the ramp terminals running in coordination with a nearby corridor while the other terminal could run fully actuated or in coordination with the corridor on the other side of the freeway. This scenario is common when the arterial travel pattern is primarily to and from the freeway with little through traffic.

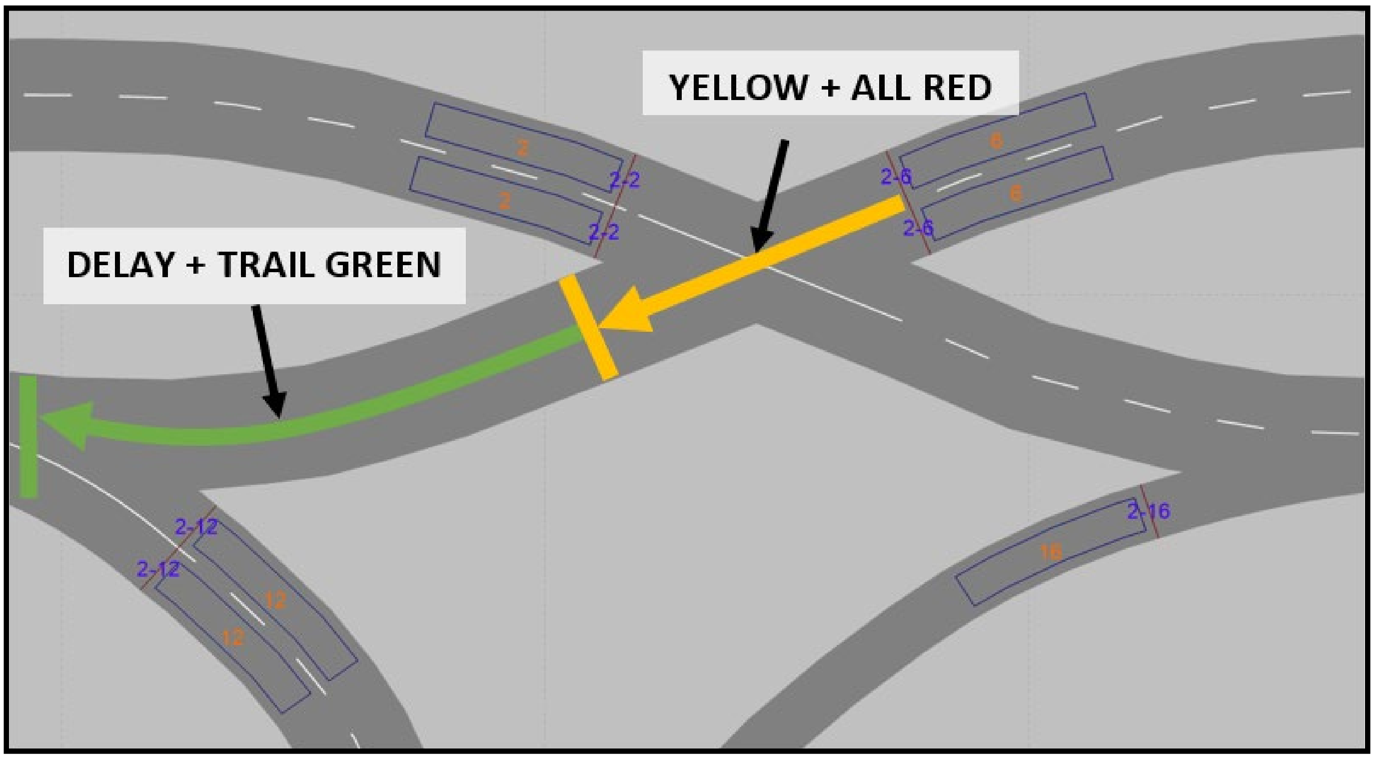
During Vissim modeling, it is much easier to develop signal timing under various traffic patterns when the terminals have separate RBCs. (See section 3.9.1, Progression and Coordination.)

3.8.4 Yellow/All-Red and Delay/Trail Green timings

During design-level signal timing, the signal phasing must include delaying the start of the green phases leaving the ramps to allow for clearance of the previous phase. Additionally, the end of the green phases for turn movements leaving the ramps may be extended past that of the through movements and into the all-red phase of the crossover intersection. This delay and green extension will be different for each interchange and will be based on geometry of the turns from the ramps. Do not use a single, longer clearance time for all signal heads as this will significantly degrade the efficiency of the signal.

The yellow and red times for each intersection should be calculated, in the standard fashion, for the conflict area of the crossover intersection. The delay and trail green time should be calculated based on travel time and the additional distance from the end of the main conflict area to the end of the conflict area with the turn from the exit ramp. These two distances are shown in Figure 13.

FIGURE 13. DDI YELLOW, ALL RED, DELAY, AND TRAIL GREEN CALCULATION

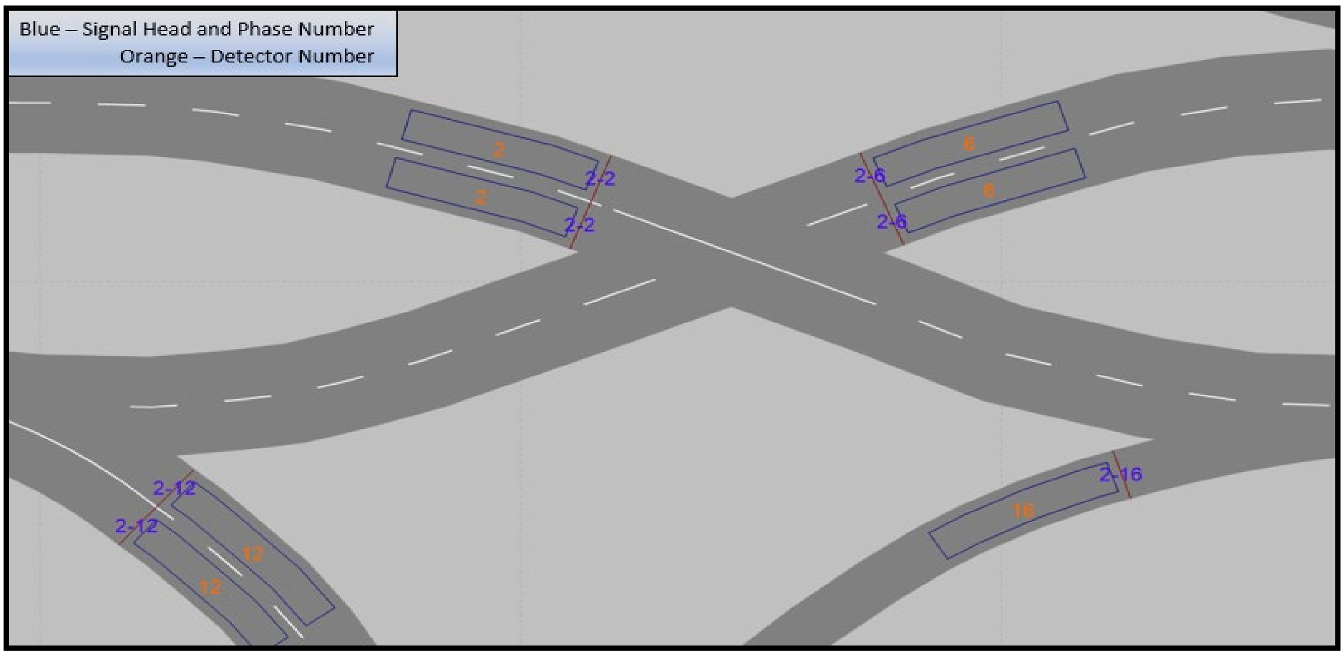


Within the RBC interface, delay and trail green can only be applied to an overlap phase. The overlap should have the corresponding through movement as its parent phase. The yellow time for the overlap will be different than the parent phase because the approach speed is assumed to be lower. The all-red time is not required as the conflict area is well downstream of the opposing parent phase's signal head.

The delay green value is not restricted. However, the trail green value, when added to the overlap phase's yellow and all-red time, cannot exceed the yellow and all-red time of the parent phase. If this timing is not coded properly, the signal will fall out of coordination, the delay and trailing function will not work properly, and the program (Vissim and the RBC editor) will not trigger an error, warning, or any indication that an error exists. The resulting signal malfunction can only be detected through observation of the model animation.

Figure 14 shows a sample numbering scheme used for signal heads and detectors.

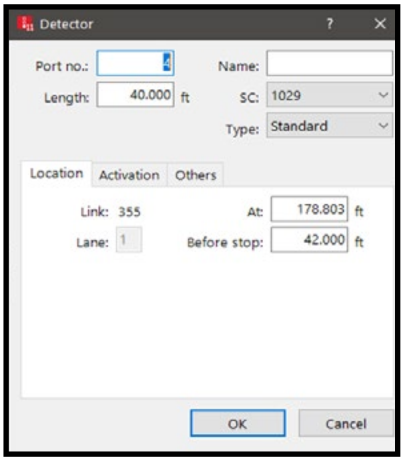
FIGURE 14. SIGNAL HEAD AND DETECTOR NUMBERING EXAMPLE



3.9 Stop Bars, Signal Heads, and Detectors

Stop bar detection should be coded for all movements and detector length should be set to 40 feet. The leading edge of the detector should be placed 2 feet behind the location of the signal head or RTOR stop sign (for right-turn only lanes). The detector position can be set using the "before stop" value in the detector window (see Figure 15). Setting this value to 42 feet will place the rear of the detector at 42 feet or the front of the detector 2 feet from the stop bar.

FIGURE 15. DETECTOR SETTING DIALOG BOX



Advanced detectors should be set to a length of 10 feet. Stop signs with RTOR settings should be used for all right turns where RTOR is allowed. Signalized right-turn only lanes do not require signal heads and should be coded with RTOR stop signs only. If visualization is needed later for animations, signal heads can be added and turned "off" to not influence traffic operations results while still showing the signal in animation view. RTOR stop signs for right-turn only lanes should be coded at the stop bar and approximately even with nearby signal heads.

Dual or triple right-turn only lanes should be coded as a RTOR on only the outside lane. A RTOR stop sign should be coded for lane 1 (right-most lane) and a signal head should be coded for the remaining lanes. RTOR for dual or triple movements may require adjustments during calibration to make drivers less aggressive. These adjustments include increased headway/gap acceptance for conflict areas/priority rules, or longer stop time distributions for the stop sign.

3.9.1 Progression and Coordination

Signal progression at a DDI can be challenging due to the two-phase nature of the signal phase coding. Progression along the crossroad corridor may require adjacent four-phase signals to utilize lagging left turns for some approaches allowing the green bands to shift, better accommodating the DDI. Ideally, the adjacent intersections would be converted to two-phase signals, by implementing innovative intersection designs as well. Restricted crossing U-turn intersections (RCUTs) are ideal as the two directions of the crossroad can run independently. In such a scenario, crossroad progression through a DDI can be seamless.

Progression between the two DDI terminals is site-specific and will depend on traffic patterns, turn movement volumes and speeds. Recognize that at some locations, progression from a ramp turn may be preferable to progression along the crossroad. Also recognize that at some locations, coordination between the two ramp terminals may not be necessary.

DDIs are unique in one critical way that drives signal timing and progression. With two-phase operation, the core of the interchange is always being fed with traffic. Either the through movement or the left turn from the ramp are receiving a green signal at any given time, providing a constant stream of traffic into the interchange core. Timing is always driven by the need to manage the space within the interchange core as overflow, or queues backing up beyond the middle segment of the DDI will cause interchange operations to degrade.

3.9.2 Recommended Measures of Effectiveness (MOEs)

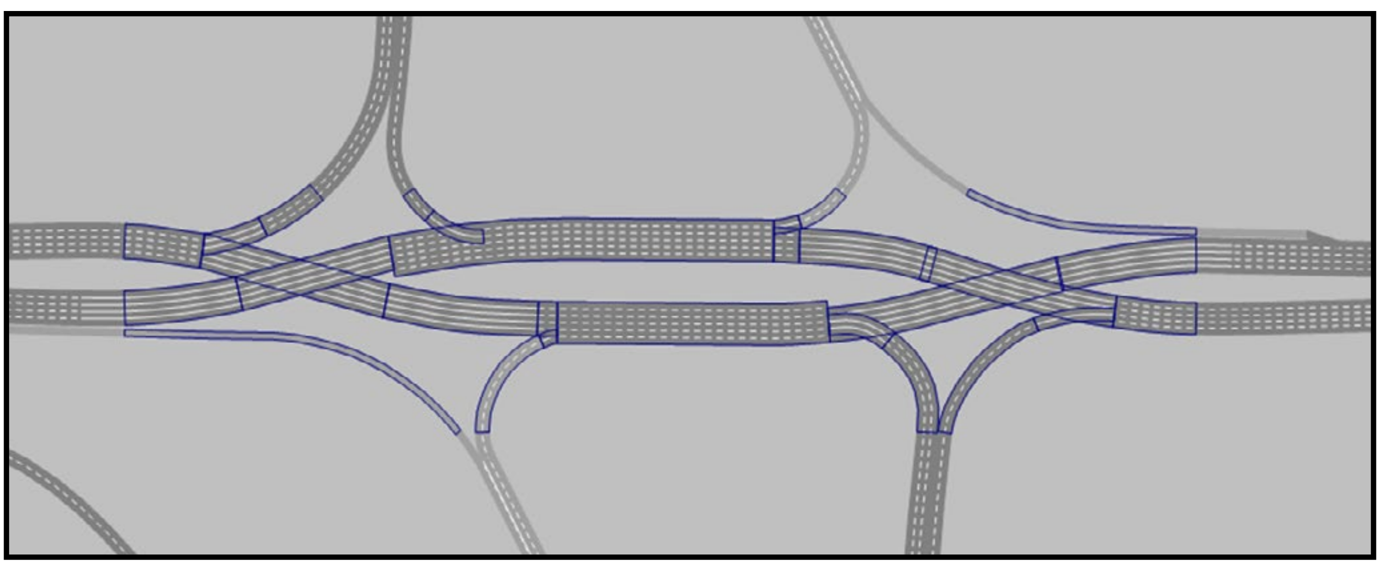
It is important to consider a few things when setting up the Vissim model for output processing:

- Is a comparison with other interchange options necessary?
- Will any other options have free flowing ramp movements such as a loop?
- Is the freeway at or near capacity?

3.9.2.1 Number of nodes and placement

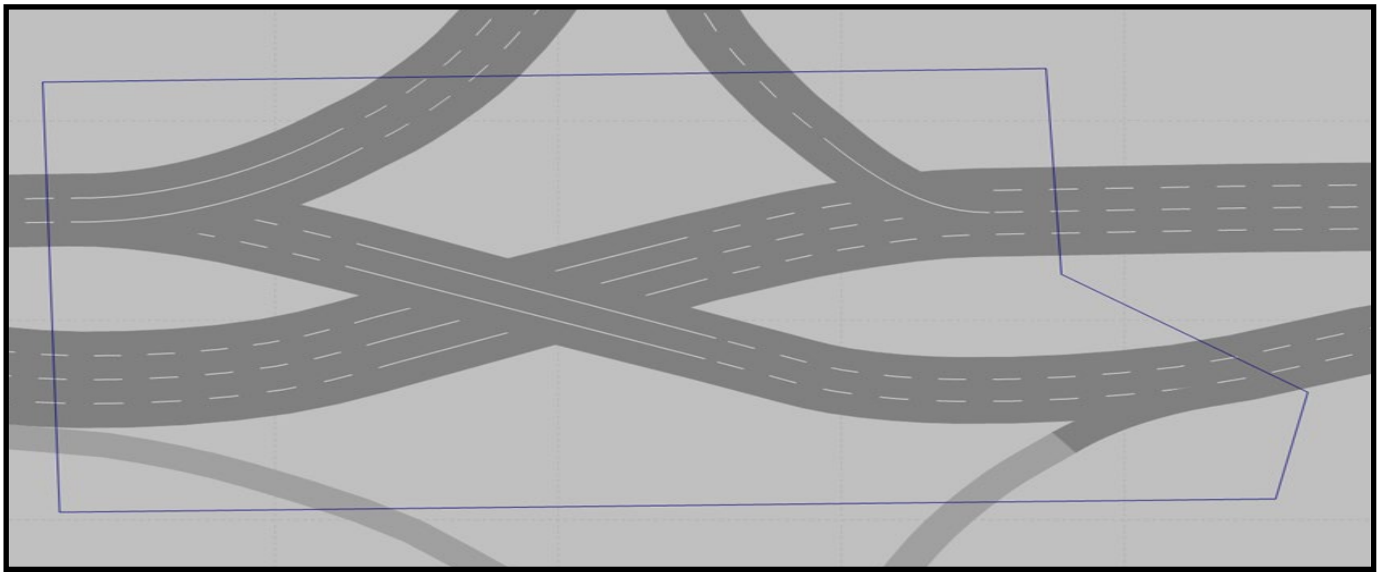
If other interchange options will be considered, a segment node should be placed that includes both ramp terminals. Make sure to remove the freeway links as they would otherwise skew weighted results and would require manual removal from Vissim's node output. Figure 16 shows a single segment node placed over the entire interchange.

FIGURE 16. DDI WITH A SINGLE SEGMENT-BASED NODE



If a DDI is only to be compared to other diamond-type options, a polygon node for each terminal is appropriate. Figure 17 shows a polygon node placed at a DDI ramp terminal and crossover intersection.

FIGURE 17. NODE PLACEMENT AT A DDI



3.9.2.2 Travel time

Using Vissim's travel time corridors are the ideal way to provide comparative output when some movements have free flowing elements. This could include a partial cloverleaf interchange, for example, where the northbound to westbound ramp is served by a free-flowing loop and encounters a signal at the southbound ramp terminal.

Travel time corridors' beginning and ending points should be placed at whatever geographically identical locations that are shared between options and will offer the most direct comparison between interchange concepts.

3.9.2.3 Freeway operations

Turn on link evaluation for the links before, during, and after the ramp merge to compare impacts to freeway flow. It is important for comparison of interchange types with one entrance ramp as different interchange concepts deliver traffic to the entrance ramp with different densities. This difference can be significant in freeway performance as the freeway approaches capacity or where the entrance ramp volume is at or above 1700 vphpl.

3.10 Calibration

Calibration is fundamental to the creation and use of a microsimulation model for design-level analysis. When determining storage bay lengths and design details, calibration is required. When calibrating for a project that will become a DDI, it is important to consider what calibration parameters will carry over from the available existing condition information such as a standard diamond interchange configuration. Calibration parameters influence driver behavior in terms of speed, headways, and lane utilization, to name a few variables. Lane utilization resulting from a driveway or other turn movement from the interchange will carry over in the form of connector look back and emergency stop distances. Variables impacting driver aggressiveness such as lane changing behavior, desired speed distributions, and start up lost time and headway (which affect saturation flow rate) at signals will also carry over. With that in mind, parameters from nearby projects could be used to adjust proof-of-concept level analysis when used in developing and refining lane configurations in lieu of a traditional calibration effort. Even without the use of regional parameters and leaving most variables in the software default value (except for those variables specifically mentioned earlier in this document) will provide a much more accurate and defensible starting point for DDI lane configuration than deterministic analyses.

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