Calibration and Field Validation of Four Double-Crossover Diamond Interchanges in VISSIM Microsimulation

Bastian J. Schroeder, Ph.D., P.E.*
Assistant Director, Highway Systems, ITRE
Tel.: (919) 515-8565; Email: Bastian_Schroeder@ncsu.edu

Katayoun Salamati, Ph.D.
Post-Doctoral Research Scholar, ITRE
Tel.: (919) 515-9349; Email: Katy_Salamati@ncsu.edu

Joseph Hummer, Ph.D., P.E.
Chair, Civil and Environmental Engineering, WSU
Tel.: (313) 577-3790; Email: joseph.hummer@wayne.edu

1) Institute for Transportation Research and Education, N.C. State University
   NCSU Campus Box 8601, Raleigh, NC 27695-8601

2) Department of Civil and Environmental Engineering, Wayne State University
   5050 Anthony Wayne Dr. Detroit, MI 48202

Submitted for consideration for publication and presentation at the 93rd Annual Meeting of the Transportation Research Board, January 12-16, 2014

Word Count: 5,016 text words plus 2,500 for figures/tables (10*250) = 7,516

Revised Submission – November 2015

* Corresponding Author
ABSTRACT

This paper presents calibration and validation results for modeling Double-Crossover Diamond (DCD) interchanges in a microsimulation environment. Using the VISSIM simulation tool and detailed field data collected at four operational DCDs in the United States, the paper describes modeling challenges, calibration steps, and validation results in the form of delay, travel time, and queuing estimates. DCD interchanges are rapidly being deployed across the United States, accelerated by their ability to process high volumes of especially left-turning traffic at interchanges, at a greatly-reduced construction cost over other interchange alternatives. In the absence of an analytical methodology for evaluating these interchanges, simulation presently represents the only option for evaluating the operational performance of DCDs. While other research has previously applied simulation to DCD evaluation, this paper is able to present detailed validation results from field data collected at four fully operational DCDs in the US. The results show that the operations of DCDs can largely be replicated in a simulation environment, but that care needs to be taken in properly setting speed and routing decisions throughout the DCD network. The analysis further showed that validation is more readily achieved over an extended route analysis, with increasing difficulties for short segment validation. The validation of field-measured queues proved challenging due to definitional differences between simulated and field study results. Overall, the results of this paper demonstrate the feasibility of satisfactory calibration of simulation tools to enable the operational performance evaluation of DCD interchanges.
INTRODUCTION

Alternative intersections and interchanges have become popular alternatives for addressing congestion problems at nodes in the United States. The Alternative Intersection and Interchange Report (AIIR) produced by the Federal Highway Administration (FHWA), identifies several potential configurations, including guidance on geometric design, and to some extent operational analysis. The Cap-X tool produced by FHWA even allows a high-level operational assessment of various intersection and interchange forms through a methodology based on critical movement analysis. But while that tool is useful in a planning context, there currently exist no detailed analytical methods for evaluating and predicting the operational performance of alternative intersections and interchanges. As a result, many analysts turn to microscopic traffic simulation – an analysis approach that is widely recognized to require careful calibration and validation to result in realistic performance estimates.

Among the alternative intersection and interchanges, the Double-Crossover Diamond Interchange (DCD), also referred to as a Diverging Diamond Interchange (DDI), has become increasingly popular as a cost-effective treatment to replace over-capacity diamond interchanges. The DCD is able to process interchange traffic very efficiently, especially for locations with high left-turn demands to and from the freeway. The operational benefit of the DCD is rooted in a direction crossover of the mainline traffic of the arterial street, that switches through and left-turning traffic from the right to the left side in advance of the interchange (right turns veer off before the crossover). After the switch, left-turn traffic from the freeway, and left-turn traffic to the freeway are able to move through the interchange using a simple two-phase signal and a free-flow movement, respectively. This operational benefit, combined with high cost-effectiveness of the DCD (stemming largely from the ability to use existing bridge structures in most cases), have resulted in increased adoption of the DCD design in the US. At the time of this writing, over a dozen DCDs have already been constructed, with many dozens more in the planning, design, and construction stages.

Due to the unique geometric configuration of the DCD, and unconventional signal timing and traffic patterns, traditional analysis methods like those in the Highway Capacity Manual presently do not allow for the evaluation of DCDs. Consequently, many analysts have turned to microsimulation to predict the operations of new and planned DCDs, but generally without the ability to collect field data at this very recent interchange configuration. As a result, most simulation analyses lack detailed calibration and validation with empirical data. This paper presents a detailed calibration and validation approach to replicate the field-measured performance of four operational DCDs in the United States.

BACKGROUND AND LITERATURE

The DCD was first introduced in the U.S. by Chlewicki, who published the idea of the Double Crossover Diamond (DCD) interchange, which he called the diverging diamond interchange at the time (1). In a Synchro macroscopic evaluation, he found that the DCD was superior in operations to the conventional diamond, producing, for example, 27 second average delay per vehicle, compared to 80 seconds for a conventional diamond (1). Since that first introduction, the DCD has gathered significant attention and research, including driver perception and human factors studies (2), and (limited) design guidance in the Alternative Intersections/Interchanges Informational Report (3).
While the initial deterministic analysis approach in (1) proved feasible to some extent, it was soon recognized that simulation tools may be more appropriate for DCD evaluation; at least until a formally established method becomes available. The signalized intersection methodologies in the Highway Capacity Manual (HCM) (4) are largely intended for isolated intersections, and are not suitable for the DCD design. While the new urban streets procedures in the 2010 HCM (4) allow the analyst to better estimate progression effects between adjacent intersections, the methods fall short of explicitly estimating the dynamic traffic patterns at the DCD. The HCM recognizes its limitations and refers to the use of alternative (simulation) tools to truly estimate these dynamic impacts (5). Potential operational characteristics at the DCD not handled by HCM methodologies include:

- Queuing on the links between the two cross-over signals,
- Demand starvation at signalized approaches leaving the DCD,
- Queue blockage of left-turn on-ramp movements on shared lanes,
- Impact of reverse curves on speed patterns and progression,
- The presence of pedestrian movements, and especially unsignalized pedestrian crossings at the channelized lanes at the DCD,
- The presence of on-street bicycle movements, or
- The interaction between freeway and arterial traffic with potential queue spillback effects.

In addition to improved operational evaluation, a simulation analysis provides four-dimensional visualization of traffic patterns and roadway geometry, an invaluable asset for communicating operations and geometry of the relatively new DCD configuration to a non-technical stakeholder audience.

Consequently, a variety of studies have applied simulation to DCD evaluation. Bared, et al. (6) and Edara, et al. (7) conducted a more extensive VISSIM simulation-based evaluation of the DCD and predicted similar operational benefits over the traditional diamond. Their research showed that the DCD was far better at the higher levels of demand than the simple diamond. A few researches attempted to model the operations of DCD in microsimulation software. Maji et al. (8) used VISSIM to compare the capacity and level of service analyses of DCD from VISSIM with Critical Lane Volume (CLV) methodology. They applied both CLV method and VISSIM simulation to evaluate a possible DCD at I-270 and MD 85 in Maryland. Maji et al. found that in addition to CLV methodology, a calibrated simulation model is needed for a detail traffic and operations analysis of DCD (8).

It is recognized that a simulation analysis requires a well-calibrated and validated model to give confidence in the validity of the simulated traffic patterns. Resources including the FHWA traffic analysis toolbox (9) provide guidance to analysts for using simulation tools and emphasize calibration as a critical modeling component. What constitutes a perfectly calibrated model is still the subject of much debate in the simulation modeling community. Perhaps the most appropriate way to express whether a simulation model has been properly calibrated is through an error probability function as proposed by Bayyari et al (10) and Sacks et al (11):

$$\Pr\left(\left|\text{Field MOE} - \text{Simulation MOE}\right| < \alpha \right) \geq \beta.$$ ...... Equation 1

Where: $\alpha$ represents a tolerable error threshold and $\beta$ the desired confidence level.
Thus for example one can declare a micro-simulation model successfully calibrated if there is at least a 90% probability that the mean speed difference between the field measurement and simulation model estimate is less than 3 mph. Additional detail on methods for calibration are described in literature sources (12, 13, and 14) and are also stressed in a forthcoming chapter on simulation studies in the ITE Manual of Transportation Studies (MTS) (15). That source describes recommended data items for calibration and validation and links those to empirical field data collection methods discussed throughout the MTS.

Since DCD interchanges are still relatively new in the U.S., the availability of detailed field data for DCD evaluation is limited. As a result, noticeable knowledge gaps related to DCD operations and simulation exist, including:

1. Some of the research on operations has used a small set of demand scenarios, non-simulation traffic modeling, or suboptimal signal timing.
2. None of the simulation studies of the DCD conducted to this point has been able to use a model calibrated to DCD field conditions.

**OBJECTIVE AND SCOPE**

The objective of this paper is to present an approach for calibrating the operational performance of DCD interchanges in microsimulation, and to validate key performance measures from empirical data collected at four DCD interchanges in the U.S. The paper illustrates key configurations when setting up a simulation model for DCDs and aims to demonstrate that an acceptable validation match can be obtained in the simulation.

The simulation tool VISSIM (16) was used for all analyses, although other tools are available to perform similar analyses. The team selected VISSIM for this project because its link-connector structure allows a great degree of flexibility in network coding. Node-based simulation tools are likely less appropriate for DCD modeling since the crossover nodes do not fit within the standard intersection paradigm. However, no claims are made here that VISSIM is the only viable simulation analysis tool for DCDs, nor that node-based simulators cannot be adapted to work with the DCD design.

This paper is not intended to explore and test operational improvements of the DCD interchange through modified geometry, signal timing, etc. It is also not within the scope of this paper to compare the DCD configuration to alternative interchange forms. The modeling was applied to a total of four DCD interchanges, which are shown in Figure 1.

1. The Bessemer Street at US129 DCD in Alcoa, TN is an underpass interchange with a three-lane arterial street cross-section.
2. The Missouri-13 at Interstate-44 DCD in Springfield, MO is an overpass interchange with a four-lane arterial street cross-section.
3. The National Avenue at US-60 DCD in Springfield, MO is an overpass interchange with a six-lane arterial street cross-section.
4. The Dorsett Road at Interstate I-270 DCD in Maryland Heights, MO is an underpass interchange with a five-lane arterial street cross-section.

TRB 2014 Annual Meeting

Paper revised from original submittal.
a) Bessemer Street, Alcoa, TN  

b) MO13, Springfield, MO  

c) National Ave., Springfield, MO  

d) Dorsett Rd., Maryland Heights, MO  

Figure 1: VISSIM Screenshots of the Four DCD Models
CALIBRATION AND VALIDATION APPROACH

This section describes the general calibration and validation approach for the four DCD interchanges in VISSIM. For the purpose of this discussion, calibration refers to modification of inputs into the simulation tool, while validation refers to the verification of simulation outputs with field-observed performance measures.

Calibration Factors

The key calibration factors that serve as inputs into the simulation are:

1. **Origin-Destination volumes** at the DCD interchange and adjacent signals;
2. **Look-Back Distances** from route decision points to control lane positioning;
3. Field-measured *free-flow speeds* through the DCD interchange, as well as geometrically-constrained free-flow speeds at the crossover and for turning movements; and
4. Field-implemented *signal timing* schemes as obtained from field controller settings at the DCD and adjacent signals.

Interchange O/D route percentages can be estimated relatively easily from turning movement counts at the two cross-over signals, if the percentage of interchange U-turns is known (or assumed to be zero). If the analyst chooses to include adjacent signals in the evaluation of the DCD (which is desirable), it is preferable to estimate a global O/D matrix of the entire corridor. Synthesizing an O/D matrix to include adjacent intersections can be more cumbersome, but may be approximated by assuming a proportional allocation of the volumes of an upstream origin to all downstream destination. In the case of VISSIM, the “combine routes” can be used to accomplish this, or alternatively, the O/D may be estimated externally to the simulation. Figure 2-a illustrates the concept of O/D routing for the Dorsett Road DCD showing 13 O/D pairs to cover the DCD interchange and adjacent signals along the arterial street.

In addition to the O/D volume and routing set-up, many simulation tools employ the concept of a look-back distance, which is the distance upstream from a diverge point at which simulated vehicles are affected by the diverge and initiate any necessary lane changes. In VISSIM, this is referred to as the Lane Change Distance (LCD). In field observations of DCD interchanges it was frequently observed that drivers pre-position themselves well in advance of the DCD interchange for downstream turning movement. This phenomenon was especially pronounced for left-turning movements from arterial to freeway, where the lane utilization at upstream signal was highly impacted by downstream turning percentages. Consequently the look-back distance for these movements needs to be specified in a way that it extends through the upstream signals. Figure 2-b illustrates the look-back distance concept for the Dorsett Road DCD.
For calibration, speeds at DCD crossovers were observed to be well below the free-flow speeds on tangent sections of the arterial. It is therefore recommended to use speed reduction zones to control free-flow speed at critical segments through the DCD. Table 1 shows the calibrated speed control decisions used at the crossover, as well as turning movements at the four modeled interchanges. Notice that the speed at the segment between crossovers has also been observed to be less than the speed limit. All speed distributions were modeled as normal distributions in VISSIM.
Table 1 Field-Measured Speed Parameters for DCD Sites

<table>
<thead>
<tr>
<th>Interchange</th>
<th>Crossover Speed (mph)</th>
<th>Turning Speed (mph)</th>
<th>Bridge Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-13</td>
<td>24.0</td>
<td>3.5</td>
<td>15.0</td>
</tr>
<tr>
<td>National Ave</td>
<td>25.0</td>
<td>3.0</td>
<td>21.0</td>
</tr>
<tr>
<td>Bessemer St</td>
<td>26.0</td>
<td>2.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Dorsett Rd</td>
<td>26.0</td>
<td>3.0</td>
<td>23.5</td>
</tr>
</tbody>
</table>

Accurate speed modeling is especially important for newly-opened DCDs, where drivers may not yet be comfortable with the geometry. The (free-flow) speed inputs are considered the key differentiating factor between models for the transition and after periods (in addition to potential work zone friction in transition, and signal timing adjustments in the after period).

To accurately model signalized control of the DCD interchange, the analyst needs to explore whether the interchange is modeled with one versus two controllers. The selected tool should employ signal control logic that is flexible enough to allow modeling of two-controller two-phase signal control, as well as four phases on a single controller. Figure 3 shows a standard coding scheme of the DCD with eight phases, which can be implemented in the field with one or two controllers. In addition to the eight numbered phases, the diagram shows four overlap phases as letters A through F. These overlaps are used to tie together multiple phases (e.g. overlap A corresponds to phases 1 plus 2).

Figure 3 Eight-Phase DCD Timing Scheme with Four Overlaps at National Ave. site
The signal phasing shown in Figure 3 can work within an actuated-coordinated scheme if two controllers are used, and coordination offsets can be manipulated separately at each controller. If a single controller is used in the phasing scheme in Figure 3, the signal typically runs pre-timed to assure proper progression through the interchange. Alternatively, the DCD can use a single controller, but employ overlap phases to implement a relative offset between the two crossover signals. The controller offset is then used to coordinate the DCD with adjacent signals. The team further observed simpler single-ring configurations, as well as more complicated four-ring configurations.

Validation Parameters

The three key validation parameters used in this evaluation are:

1. **Interchange travel times**, as defined by travel time segments through the two DCD signals (through routes), as well as left-turning routes through the DCD (to and from the freeway);
2. **Route travel times**, as defined by travel time segments through the DCD and adjacent signals for through movements, left-turns from freeway to arterial, and left turns from arterial to freeway; and
3. **Comparison of average and 95th percentile queue lengths**, estimated from maximum queue lengths on a per-cycle basis.

The interchange travel time includes the two DCD signals and any queues immediately upstream of the DCD. The route travel time segments include at a minimum the adjacent signals upstream and downstream of the DCD. For left turn routes, the travel time segments start or end at the top of the freeway off-ramp or on-ramp, respectively.

The travel time data were collected from extensive travel time runs during field visits to all four DCD interchanges. For all runs, a floating car technique was employed to assure the travel time vehicle is representative travel stream. For the queue measurements, cycle-by-cycle queues were observed through manual observation in the field on a per-lane basis. The detailed operational results of the field studies at these four DCDs are documented in (17). A summary of field-measured travel times for the longer route travel times for the through routes, including a listing of sample size, is shown in Table 2. It is noted that the corresponding sample size for the left-turn movements is approximately half that of the through routes.

<table>
<thead>
<tr>
<th>Interchange</th>
<th>Movement</th>
<th>AM Peak Period (sec)</th>
<th>PM Peak Period (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg.</td>
<td>StdDev.</td>
</tr>
<tr>
<td>MO-13</td>
<td>South to North</td>
<td>147.6</td>
<td>37.2</td>
</tr>
<tr>
<td></td>
<td>North to South</td>
<td>123.6</td>
<td>21.0</td>
</tr>
<tr>
<td>National Ave</td>
<td>South to North</td>
<td>189.6</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td>North to South</td>
<td>165.6</td>
<td>37.2</td>
</tr>
<tr>
<td>Bessemer St</td>
<td>East to West</td>
<td>158.4</td>
<td>34.8</td>
</tr>
<tr>
<td></td>
<td>West to East</td>
<td>159.0</td>
<td>22.2</td>
</tr>
<tr>
<td>Dorsett Rd</td>
<td>East to West</td>
<td>169.2</td>
<td>46.8</td>
</tr>
<tr>
<td></td>
<td>West to East</td>
<td>175.8</td>
<td>36.6</td>
</tr>
</tbody>
</table>
MODELING RESULTS

This section presents the VISSIM modeling results and a comparison of the modeling results to field-observed data. Table 3, Table 4, and Table 5 summarize the results for the three validation performance measures across all sites, in terms of the percent difference of VISSIM minus field data, relative to the field-observed data. A negative percent difference thus corresponds to a lower estimate in VISSIM relative to the field.

Interchange Travel Times

The interchange route results in Table 3 show some routes and sites with a very close match with less than 10% error, while other errors are higher. While these differences may seem higher than more commonly-accepted calibration targets in the 15-20% range, it should be considered that the interchange routes are relatively short, resulting in potential large percent difference despite small absolute differences. It should also be noted that these short travel times are highly dependent on vehicle arrivals in red vs. green phases. At the DCD interchanges, which are typically part of a coordinated signal system, travel times for arrivals in green can be significantly shorter than travel times in red.

Table 3 Interchange Travel Time Segment Summary

<table>
<thead>
<tr>
<th>Movement</th>
<th>Bessemer St.</th>
<th>MO13</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Through</td>
<td>S-N / E-W</td>
<td>48%</td>
</tr>
<tr>
<td>Route</td>
<td>N-S / W-E</td>
<td>-16%</td>
</tr>
<tr>
<td>Left from</td>
<td>S-W / E-S</td>
<td>36%</td>
</tr>
<tr>
<td>Arterial</td>
<td>N-E / W-N</td>
<td>-11%</td>
</tr>
<tr>
<td>Left from</td>
<td>W-N / N-E</td>
<td>-24%</td>
</tr>
<tr>
<td>Freeway</td>
<td>E-S / S-W</td>
<td>45%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Movement</th>
<th>National Ave.</th>
<th>Dorsett Road</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Through</td>
<td>S-N / E-W</td>
<td>-3%</td>
</tr>
<tr>
<td>Route</td>
<td>N-S / W-E</td>
<td>-1%</td>
</tr>
<tr>
<td>Left from</td>
<td>S-W / E-S</td>
<td>-17%</td>
</tr>
<tr>
<td>Arterial</td>
<td>N-E / W-N</td>
<td>71%</td>
</tr>
<tr>
<td>Left from</td>
<td>W-N / N-E</td>
<td>80%</td>
</tr>
<tr>
<td>Freeway</td>
<td>E-S / S-W</td>
<td>-16%</td>
</tr>
</tbody>
</table>

For the simulation results, it can be expected that the travel time observations include an adequate sample of both arrival types – proportional to the effective green to cycle length ratio (g/C) on the DCD approach. However, for the much smaller field sample size, it is more likely that a truly representative sample was not obtained.
Route Travel Times

In the second validation exercise, the short interchange travel times were expanded to include the adjacent intersections upstream and downstream of the DCD. It is generally expected that the validation results would be improved for longer routes, which is evident in the results shown in Table 4.

Table 4 Route Travel Time Segment Summary

<table>
<thead>
<tr>
<th>Movement</th>
<th>Bessemer St.</th>
<th>MO13</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Through</td>
<td>3%</td>
<td>17%</td>
</tr>
<tr>
<td>Route</td>
<td>-18%</td>
<td>-21%</td>
</tr>
<tr>
<td>Left from</td>
<td>6%</td>
<td>-9%</td>
</tr>
<tr>
<td>Arterial</td>
<td>26%</td>
<td>24%</td>
</tr>
<tr>
<td>Left from</td>
<td>-13%</td>
<td>5%</td>
</tr>
<tr>
<td>Freeway</td>
<td>-30%</td>
<td>-4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Movement</th>
<th>National Ave.</th>
<th>Dorsett Road</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Through</td>
<td>-5%</td>
<td>-3%</td>
</tr>
<tr>
<td>Route</td>
<td>-18%</td>
<td>5%</td>
</tr>
<tr>
<td>Left from</td>
<td>1%</td>
<td>4%</td>
</tr>
<tr>
<td>Arterial</td>
<td>10%</td>
<td>-12%</td>
</tr>
<tr>
<td>Left from</td>
<td>73%</td>
<td>30%</td>
</tr>
<tr>
<td>Freeway</td>
<td>6%</td>
<td>-1%</td>
</tr>
</tbody>
</table>

The results of the longer route travel times generally show a much improved match between VISSIM and field data. This is expected because cycle-by-cycle arrival patterns and low sample sizes are likely to have less of an impact across a larger distance. Especially the through travel time routes show a match within 10% for ten scenarios across the four sites, with five additional scenarios having less than 20% error, and the highest error being only 21%. For the left turns, most of the 32 scenarios showed an error within 25%, with only five scenarios having a larger error. In fact, 20 of the 32 left turns had an error less than 15%.

These results show a lot of promise that simulation can be used to evaluate and predict the performance of DCD interchanges in a corridor context. Figure 4 shows bar chart comparison of the VISSIM vs. Field route travel time comparison for all movements at all four sites. The bar charts show the average route travel times, as well as error bars drawn at one standard error. The standard error is defined as the standard deviation divided by the square root of the sample size, and is used to show both negative and positive variation about the means.
Figure 4: Route Travel Time Comparison

1  12
Figure 4 shows for Bessemer Street that the route travel times for all simulated routes match the field-observed average within 30% or better. In fact, several routes match within 10% difference in means with the field data. For MO13, the route travel time estimates show a match within 25% for all except one route between VISSIM and field-observed data. The one outlier is a yield-controlled movement of the west-to-north left turn from freeway to arterial, which showed very low delay in the (low sample) field data, as drivers happened to arrive during times with little opposing flows.

For National Avenue the biggest error is evident for the north-to-east left turn onto the freeway, which shows 73% and 30% error in the AM and PM peak, respectively. A clear challenge in the left-turn analysis is the sample size, which in this case only showed three travel time runs in the AM Peak period for the north-to-east movement, and four runs in the PM peak. For comparison, the field sample size for the PM peak through routes was 13 and 15 observations for the northbound and southbound movements, respectively. For the through routes on the arterial, the VISSIM travel times match within 15% error.

Finally, for the Dorsett Road the route travel times show a close match with field data. The through travel times match the field observations within less than 10% error, with most turning movements showing less than 25% error. The exception is the north-to-east movement described above, but even here the error is contained to 13% and 37% in AM and PM peak, respectively.

Queue Validation

The final data element gave a look at queuing patterns. Queue lengths are a very challenging metric to validate because (a) field measured vehicle queues need to be compared to distance-based queues (in feet) from simulation, (b) queue lengths are highly sensitive to arrival patterns, progression, and random variation in traffic, and (c) queue lengths are expected to show high variability across the peak hour. In an effort to overcome the first challenge, the field-observed vehicle queues were multiplied by an assumed spacing of 21.2 feet per vehicle to convert the queue-length to an approximate distance in feet. That assumed spacing corresponds to the car-following setting used in VISSIM, and specifically the stand-still vehicle spacing. The other two issues are more challenging to overcome. All three considerations are likely explanations for observed differences in queue length estimates from field study and simulation, which are summarized in Table 5 for the 95th percentile cycle-by-cycle queue lengths.

The VISSIM estimated queue lengths are in most cases lower than the corresponding field data with an average difference of 30 to 70% less than field-observed data. The authors attribute the majority of these differences to definitional discrepancy between field queues and observations gathered from VISSIM, and generally places less weight on these results than the travel time findings. For reasons mentioned above, queue lengths are generally very difficult to validate, and the definition differences are recognized by national guidance documents like the 2010 Highway Capacity Manual.
Table 5 95th percentile Queue Length Results Summary

<table>
<thead>
<tr>
<th>Movement</th>
<th>Bessemer St.</th>
<th>MO13</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>West/North Inbound</td>
<td>30%</td>
<td>8%</td>
</tr>
<tr>
<td>West/North Outbound</td>
<td>-35%</td>
<td>67%</td>
</tr>
<tr>
<td>East/South Inbound</td>
<td>-21%</td>
<td>-4%</td>
</tr>
<tr>
<td>East/South Outbound</td>
<td>19%</td>
<td>-36%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Movement</th>
<th>National Ave.</th>
<th>Dorsett Road</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>West/North Inbound</td>
<td>-37%</td>
<td>-39%</td>
</tr>
<tr>
<td>West/North Outbound</td>
<td>-81%</td>
<td>-35%</td>
</tr>
<tr>
<td>East/South Inbound</td>
<td>-55%</td>
<td>-77%</td>
</tr>
<tr>
<td>East/South Outbound</td>
<td>-70%</td>
<td>-76%</td>
</tr>
</tbody>
</table>

DISCUSSION

Model Inputs and Set-Up

One of the biggest challenges with simulation studies in general is the set-up of the base network and accumulation of all necessary inputs. With VISSIM’s link-connector structure and the availability of high-resolution aerial photographs, drawing the DCD network proved to be a very straightforward activity, with only few obstacles encountered.

The simulation tool was readily used to replicate the crossover geometry and all turning movements. One minor challenge was related to the geometry of the various lane adds and drops at the DCD signals, where links needed to be coded as wide segments that include through and turning lanes, to assure that lane changes could happen across an extended distance. In other words, the merge and diverge lanes on the arterial were coded consistent with VISSIM guidance on how to code freeway merge and diverge areas. This practice proved to be important in replicating field observations, and is preferred over coding exclusive left-turn lanes as separate links from through traffic, which would have limited merging behavior to a single (connector) point.

For modeling speed inputs into VISSIM, the team relied on its extensive field data collection effort, and had at its disposal detailed free-flow speed measurements for turning movements, through the DCD crossovers, and between the two DCD intersections, which proved to be critically-important inputs into the simulation.

The team also collected Origin-Destination turning movement counts, which proved essential in coding DCD volume inputs. A challenge related to volume input originated from the adjacent signals, and the need to include their turning movement counts in a synthesized O/D matrix for the entire modeled corridor. From field observations it was evident that drivers pre-positioned well in advance of the DCD turns, which required routing information to be provided well in advance to the simulated vehicles. The team expects that it will be very difficult to adequately replicate DCD operations in a simulator tool that is...
limited to node-based routing. The overall O/D estimation proved straightforward with VISSIM’s build-in
*combine routes* feature; although an external matrix estimation tool could have been used as well.

The use of O/D routing, as well as long lane-change distance settings was important to replicate field-
observed unbalanced lane utilization at the external DCD signals. Even though no formal analysis of lane
utilization was performed, the team confirmed traffic patterns through visual calibration.

One challenging aspect in coding the DCD interchanges was replicating the at times complicated
signal control strategies of the DCDs, which use various combinations of rings, barriers, overlap phases,
and dummy phases. With its Ring-Barrier-Controller (RBC), VISSIM could readily be used to replicate
all four DCD timing schemes despite their differences. While all four DCDs operated on a single
controller, the phasing scheme ranged from a single ring with five phases (two overlaps) to a four-ring
design with fourteen phases. Other than an initial learning curve in understanding the four different
signalization schemes, VISSIM’s RBC controller correctly replicated field controller settings.

Overall, the VISSIM input and coding process proved highly effective and accurate in replicating the
unique geometric, operational, and signal timing parameters observed at the four DCD interchanges.

**Calibration and Validation – Lessons Learned**

The team had at its disposal a detailed and comprehensive field data set consisting of extensive field
GPS travel time runs, as well as cycle-by-cycle back-of-queue measurements. But while the field data
was much richer than for many previous attempts at validating DCD VISSIM models, it also proved to be
very challenging in designing an “apples to apples” comparison between simulation and field data.

One key challenge for travel time runs was to reconcile differences of one-hour VISSIM simulation
results over ten iterations with every vehicle delivering one data point, with more sporadic GPS data
collected over multiple peak hours over multiple days. For example, while the team assured an adequate
sample size of field runs for a peak period, the actual time stamps for the GPS runs oftentimes covered
multiple hours in the morning peak, while VISSIM was used only to model the 60-minute peak (plus a
warm-up period). The team was therefore faced with tradeoffs between having a homogeneous (short-
duration) data set, versus assuring an adequate sample size of field travel time runs.

Ultimately, the team decided to focus its analysis on a two-hour peak period, and place higher
emphasis on the standard deviation and confidence intervals of both VISSIM and field travel time data.
The results generally showed a better match for the through routes, which the team attributes to a large
extent to a larger sample size for those movements. For left-turn routes, smaller sample sizes proved to be
biased by coincidental arrival patterns, where for example the GPS trajectories from the freeway
happened to arrive at the DCD left turn always during green, while VISSIM showed the full distribution
of arrivals in red and green.

The challenge of arrival patterns and relatively small sample size proved most challenging for the
shorter interchange segments, and it proved difficult to reconcile highly variable travel time results across
short routes that are highly sensitive to arrivals in red versus green. Nonetheless, the interchange travel
times showed acceptable performance across most scenarios. For the longer route travel time, the
validation effort proved to generate significantly matches with field data.
For queue data, queue measurements in simulation versus field data are difficult to compare as documented in the HCM2010 and elsewhere, as definitions, aggregation intervals, and data units differ across the two. Further, queues are generally considered a challenging validation metric, because of very high variability and a high sensitivity to changing arrival patterns from cycle to cycle. Despite these challenges, the simulated queue results of average and 95th percentile back-of-queue proved to be within an order of magnitude of the field-observed results. The error was generally negative, to where actual queues were 30-70% larger than the simulation results. This error is larger than for other performance measures, but is at least partly attributed to definitional differences in queue measurements, where field-measurements are taken in vehicles, while VISSIM provides queue length in feet. The field measurements were converted by assuming an average vehicle spacing of 21.2 feet per VISSIM settings. But if field vehicle spacing in queues was closer to say 30 feet, or if larger vehicles were common in the field, the resulting error would be much reduced.

CONCLUSION

This paper presents calibration and validation results for modeling Double-Crossover Diamond (DCD) interchanges in a microsimulation environment. The results show that the operations of DCDs can largely be replicated in a simulation environment, but that care needs to be taken in properly setting speed and routing decisions throughout the DCD network. The analysis further showed that validation is more readily achieved over an extended route analysis, with increasing difficulties for short segment validation. The validation of field-measured queues proved challenging due to definitional differences between simulated and field study results.

While simulation models of DCDs have been plentiful, this is the first source with detailed field data and validation across multiple sites, movements, time periods, and performance measures. From these results, the team proposes to focus the validation activities for DCDs on travel time estimates, with a preference to longer routes when possible. Any field data collection needs to assure a sufficient sample size of travel time data, and should consider that the simulated volumes are often representative of only one hour of observation. Consequently, travel times may need to be measured within the same hour over multiple days, rather than over a multi-hour period on one observation day. Model volume inputs should be based on origins and destinations at the model perimeter, and routes should be configured across the network (rather than node-based routing). The analysis further recommends coding approaches to the DCDs as wide multi-lane segments, similar to freeway merge/diverge areas, to allow free lane selection by drivers. The corresponding look-back distances for lane-changes also need to be calibrated carefully to mirror imbalanced lane utilization in the approach of the first crossover.

In closing, this paper demonstrated the ability of VISSIM to model DCD interchanges, and replicate field-observed performance for the most part. The modeling guidance and lessons learned from this paper are considered to be very important for analysts hoping to model the DCD in a simulation environment, as many nuances of DCD performance are not necessarily represented correctly without careful set-up of the various model parameters.
ACKNOWLEDGMENT

The study on which this paper is based was funded by the Federal Highway Administration. The authors would like to thank FHWA for their support throughout this project, along with the cities of Alcoa, TN, Springfield, MO, and Maryland Heights, MO for their support and assistance in data collection. All opinions expressed in this paper are the views of the authors, and do not represent the official views of FHWA.

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