An Innovative Method for Remotely Fine Tuning Offsets along a DDI Corridor

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**ABSTRACT**

Diverging diamond interchanges are relatively new in the United States, and signal coordination between the crossovers and adjacent intersections is challenging. This paper provides a method for remotely fine tuning offsets for a DDI and its adjacent intersections. The proposed method uses Dynamic Bandwidth Analysis Tool (DBAT) which uses actuated phase times from the signal controller and optimizes the dynamic bandwidth based on that entry data set. The authors used four performance measures to evaluate the proposed method: delay, stop severity index, maximum queue, and high resolution vehicle trajectory plots. The test results confirmed DBAT provides a better offset solution compared to other bandwidth optimization tools that generally optimize *programmed* bandwidth only and do not account for early return to green due to skipped or gapped-out movements. Under the DBAT offsets, delay for the through movements on the corridor decreased by 52.8% in the northbound and 46.83% in the southbound. The average delay reduction over all measured paths for uncongested and congested scenarios was 13.88% and 3.50%, respectively.

In addition, the proposed method and workflow can significantly reduce the offset retiming work process which traditionally requires visiting the study site to observe early return to green and green extension. Normally, this manual process takes more than a day, but the proposed method can be completed in less than an hour without visiting the study site. Furthermore, the proposed method can coordinate any set of movements as well as multiple travel paths. The authors believe that the proposed method and workflow will significantly help both retiming and new timing of arterial signal coordination along DDI corridors and other signal systems.

Keywords: *Diverging Diamond Interchange, Bandwidth, Dynamic Bandwidth Analysis Tool, Dynamic Bandwidth, High Resolution Data*
INTRODUCTION

Diverging diamond interchanges (DDI) are relatively new in the United States. The DDI, also known as a double crossover diamond (DCD), has two signal-controlled crossover points that allow for free flowing left turns and is an alternative to the conventional diamond interchange. This alternative interchange treatment, like most other alternative roadways, is known for reducing the number of conflict points and amount of delay for the left turn movements on or off of the freeway (1). The DDI is a popular choice for retrofit designs because it is possible to reuse the existing infrastructure and right-of-way, making it a cheaper alternative compared to most other designs.

DDIs have several unique signal timing features. One of the striking peculiarities is that the crossover of the DDI does not allow the two mainline movements to run concurrently, as shown in the time-space diagram of Figure 1, requiring a major street split-phase scheme or some other innovative timing strategy. This poses challenges with progressing both directions’ mainline movements through the interchange as well as the adjacent intersections upstream and downstream of the DDI. Therefore, directional distribution of traffic has been found to have a significant influence on progression strategies at existing DDIs. One of the primary challenges in the optimization of a DDI corridor is verifying correct operations of the coordinated signals.

Figure 1 Time-space diagrams of a standard and DDI corridor with four intersections.

Time-space diagrams in off-the-shelf tools like SYNCHRO or VISTRO are helpful in visualizing and testing the validity of signal coordination settings but are more difficult to use with actuated timing. Furthermore, their use is difficult for a DDI with major-street split-phasing, and the need to model the crossover as two separate, one way arterial streets raises questions about the software’s ability to optimize the system. In a corridor using a semi-actuated coordinated control system, these questions require engineers to physically visit the site, observe early return to green and green extension for the coordinated phases at the adjacent intersections, and conduct extensive manual fine tuning. In this paper, the authors propose a method for remotely fine tuning offsets to improve flow along a corridor that includes a DDI and adjacent intersection. The proposed method uses the Dynamic Bandwidth Analysis Tool (DBAT) (2) which was developed for the North Carolina DOT to allow for dynamic optimization of signalized arterial corridors based on remotely monitored, cycle-by-cycle coordinated phase durations. The proposed fine tuning method produces improved progression for coordinated movements with minimal impact on non-coordinated movements.
OBJECTIVE
The primary objective of this paper is to provide a robust methodology and flow for remotely
fine tuning offsets along a DDI corridor using DBAT to assess the performance of semi-actuated
coordinated arterial streets. This effort provides a robust method for remotely optimizing offsets
by taking advantage of signal data from Advanced Traffic Management System (ATMS)
installations in lieu of vising the site and allows offsets to be checked on a recurring basis.
Overall, this study aims to contribute to the important goal of enhancing mobility through
continually improving performance of signalized corridors with DDIs.

LITERATURE REVIEW
Recently, many studies have shown DDIs provide several benefits over other interchange forms.
Chlewicki (3) compared the operations of a DDI to a standard diamond interchange with fixed
time signals using Synchro 5 and SimTraffic 5. In this study, the DDI was more efficient at every
movement with the exception of the though movement at the outbound signal. Bared et al. (4)
conducted a more extensive analysis using VISSIM to compare the capacity of a conventional
diamond interchange to that of four and six lane DDIs using five and six traffic flow scenarios,
respectively. In their study, the capacity per lane for all movements was higher for both the four-
and six-lane DDIs as compared to the standard diamond. The six-lane DDI was able to double
the capacity per lane of left turns from the off-ramp over the standard diamond. Siromaskul and
Speth (5) used VISSIM to compare SPUIs, tight and wide DDIs, tight and wide conventional
diamonds, and two types of partial cloverleafs. Under most scenarios, the DDI outperformed the
other interchange forms including a 40% reduction in average total delay over the conventional
diamond. Additional analysis was conducted by Hughes et al. (6) in the Alternative Intersections/
Interchanges Informational Report (7). Using VISSIM, three different DDI geometries and two
different traditional diamond geometries were tested. However, these studies lacked model
calibration since most were conducted prior to the installation of the first DDI in the United
States.

The first DDI was constructed at MO-13 and I-44 in Springfield, Missouri in 2009 and
the Missouri Department of Transportation (8) provided a post construction evaluation of
operations, safety, and public perception. The evaluation reported slower travel times during low
volume periods, presumably due to the traffic calming effect of the DDI. MoDOT also found
large improvements in queues and delays for left turning movements to and from the interstate
during peak hours. The Utah Department of Transportation (9) conducted a similar observational
study after constructing four DDIs. This report concluded that coordination of DDI in a corridor
can be challenging as the two phase signals at DDIs prefer a lower cycle length compared to
others signals along the corridor.

There are many past studies that provided tools for optimizing bandwidth of coordinated
systems. For example, Morgan and Little (10) first introduced a computational method to
maximize arterial signal bandwidth in 1964. Later, Little, Martin, and Morgan (11) proposed a
two-way bandwidth maximization method using mixed-integer linear programming (MILP) in
1966. Based on these theoretical foundations, Little, Kelson, and Gartner (12) developed
MAXBAND in 1991. In 1988, Chang, Cohen, Liu, Chauhary, and Messer refined the model,
creating MAXBAND-86 (13) which added the capability to solve coordination problems for
closed grid networks. Based on MAXBAND’s mathematical formulation, MULTIBAND (14),
MULTIBAND-96 (15) was developed. To minimize the impact that early return to green has on
coordinated arterials, Skabardonis (16) and Chang (17) proposed methods that considered semi-
actuated arterial coordination; however, both methods used fixed green times. Skabardonis used an analytical estimate of average coordinated green as the fixed time split for offset optimization, and Chang used the average of field observed green times. Skabardonis and Geroliminis (18) introduced an analytical model to estimate arterial travel time based on spatial and temporal queuing at the signalized intersection. Yin et al. developed a methodology to fine-tune the offsets in arterial streets to improve the progression (19). Their approach, Offset Refiner, created a stochastic distribution of coordinated phases’ green start and end times at each intersection using archived signal data. Then, they estimated the maximum expected bandwidth and the corresponding offsets based on the stochastic distributions. More recently, Yang, Chang, and Rahwanji (20) introduced a signal optimization model for DDIs based on Webster’s formula and MAXBAND. However, all of these studies assumed pre-timed signal controllers, or in the case of Skabardonis and Chang, used average green times from a semi-actuated coordinated system.

Purdue University and the Indiana DOT (21) developed a new system which provides the “Purdue Coordination Diagram.” This innovate system uses hi-resolution vehicle event data to optimize cycle length and vehicle arrival percentage during green time. This tool uses the first vehicle estimated trajectory to adjust offsets in order to improve the percentage of vehicle arriving on green. The University of Minnesota (22) also developed a real-time arterial performance monitoring system called SMART-SIGNAL which also uses hi-resolution data to calculate vehicle arrival type and the proportion of vehicles arriving during the green phase. Both new signal systems may handle the offset fine-tuning problem for semi-actuate coordinated systems including the DDI, but it requires changing signal systems or installing extra monitoring systems.

METHODOLOGY
The method for remotely optimizing and fine tuning offsets proposed by the authors requires only that the signal system provides the split monitor log and detector log, including near real time signal operation status and detected volume counts (calls). The split monitor log reports the programmed as well as extra green time for the coordinated phases on a cycle-by-cycle basis. DBAT needs only the split monitor log to optimize the offsets, while the detector log can be used to verify the performance after offset adjustments are made. Fortunately, most actuated controllers and closed-loop systems have these functions, making the tool a viable solution for practitioners. When the required real word data does not exist, well-calibrated microsimulation data can be used to generate the necessary logs prior to implementing a signal plan in the field.

DYNAMIC BANDWIDTH OPTIMIZATION AND DBAT
Although many DDIs are using pre-timed signal plans at this time due to a lack of understanding on how actuation can be used effectively at this type of interchange, the entire arterial corridor generally uses semi-actuated signal systems. Also, due to the nature of semi-actuated signal systems, adjacent intersections’ coordinated green times are not fixed but are dynamically changing cycle-by-cycle.

Developed for the North Carolina DOT, the objective of DBAT was to allow for analysis of real arterial bandwidth from traffic controller data (ATMS data) to evaluate and improve arterial coordination. DBAT has several interesting and useful applications for practitioners in that it allows for: 1) customization of the coordination path (through vs. left turns, for example); 2) link-specific calibration of travel speed (due to slow-down through the DDI crossovers and...
turns); 3) consideration of actuated signal timing; and, 4) further customization to the needs of specific DDI corridors.

With DBAT, dynamic bandwidth based on field actuated green times becomes a new method for optimizing the arterial and evaluating coordination quality. The tool was verified against well-established coordination approaches (23) and field tested using various real-world applications in NC. DBAT was able to improve the coordination settings over optimized software results (23), (28). The DBAT optimized timings performed similarly to manual field-adjusted timings by trained professionals which further supports the merit of the tool.

The concept of dynamic bandwidth optimization is that the optimal offset value for a certain time-of-day plan can be defined by the coordinated movements’ directional volumes, as well as the total sum of bandwidth reported by the controllers’ split monitor data (i.e. dynamic green) to provide bandwidths proportional to the volumes along those movements. The objective function used to find the optimal offsets is defined below. Let \( b_j \) and \( \overline{b}_j \) represent the \( j^{th} \) cycle bandwidth in the outbound and inbound directions, respectively, where \( j \in J \). Then the objective function can be written as follows:

\[
\text{Objective Function} = \max \sum_{\forall j \in J} (b_j + k\overline{b}_j)
\]  

(1)

where:
- \( b_j = j^{th} \) cycle outbound bandwidth in sec,
- \( \overline{b}_j = j^{th} \) cycle inbound bandwidth in sec, and
- \( k = \) inbound demand over outbound demand.

For selecting offsets which satisfy equation (1), the authors used DBAT which provides the entire solution space from all feasible offset combinations.

DBAT creates a virtual vehicle trajectory for each second of the green durations at the first intersection of the system during the entire study period, \( T \) (which includes \( J \) cycles), and determines whether the trajectory reaches the next downstream intersection during the green or red signal indication of the coordinated phase. If the trajectory intersects the red signal of the coordinated phase, the process is stopped; otherwise, it is continued to the following downstream intersection. If the trajectory makes it through all intersections of the system, it is counted as a success. The same process is performed for all time steps. The total number of successes in a row is the duration of a directional band. The inputs to the DBAT tool are minimal and include the following:
- green time for each phase and intersection along the optimization path, including early return to green and green extension;
- phase sequence for each intersection;
- distance between intersections; and,
- travel speed between intersections.

An example of this dynamic bandwidth for a signalized corridor in NC is shown in Figure 2a. The figure shows the northbound bandwidth (yellow) and southbound bandwidths (black), and how they vary from cycle to cycle. The red line at 07:12:00 shows one second where no bandwidth is present. It happened due to controllers’ clock time drift. Normally, there are maximum ± 1 second clock drift in the controller system. For this specific corridor, the signal
engineer’s selected offsets allowed for only one way progression in the outbound (north) direction since the system included 7 signalized intersections; the inbound (south) direction had only non-programmed bands. The cycle-by-cycle green times (inbound on top of outbound), a portion of which is shown in Figure 2a, are used as inputs for DBAT. An example of the bandwidth optimization output from DBAT for the test corridor is shown in Figure 2b. There are more than 25,000 possible offset combinations with the resulting sum of bidirectional dynamic bandwidth plotted as individual points.

Figure 2  DBAT outputs
METHODS FOR FINE TUNING OFFSETS REMOTELY

There are two potential options for using DBAT: 1) during the development of a new signal plan and 2) after implementation of an existing plan where the user only fine tunes offsets using remotely captured data. The difference between the two processes is whether the controller’s split monitor data is available or not. If there is available controller ATMS data, DBAT directly reads each controller’s used green time and provides the entire solution space with an optimal bandwidth solution, statistics, and each intersection’s recommended offsets. However, in applying DBAT to a new construction project, two additional steps are necessary. The entire process is documented in six steps below, with the first two steps only necessary if a new signal plan is implemented (italicized for emphasis). The efficiency of using DBAT is evident in steps four and five, where the user can replace the manual offset fine-tuning process of physically visiting the study site to observe the quality of progression on the arterial.

1. Optimize corridor cycle lengths and intersection splits in an optimization tool such as Synchro or VISTRO,
2. Simulate the optimized offset timing scheme and create the controller log file,
3. Obtain base-line performance,
4. Optimize offsets in DBAT using remotely collected data from ATMS or from the simulated controller log if new signal plan is being implemented,
5. Apply updated offset values,
6. Evaluate new offsets through a before-and-after study.

Fine tuning of offsets for existing systems only requires steps three through six, with step six being a before-and-after field study conducted through Bluetooth or probe car travel time collection.

EVALUATION OF THE PROPOSED METHOD

Network Development
The proposed method was tested under congested and uncongested conditions; the congested conditions tested DBAT’s ability to account for queue accumulation when cycle failure was possible. This paper used a single generic DDI model based loosely on the National Avenue DDI in Springfield, MO to evaluate the proposed methodology and DBAT tool results. The model was developed and calibrated for an FHWA project evaluating some of the first DDIs built in America (24). Figure 3 shows the National Avenue DDI and its adjacent intersection.
The base model is a symmetric, north/south oriented corridor composed of a pair of DDI crossovers with two standard signalized intersections adjacent to the DDI to the north and the south. Left turns onto the freeway were accessible by use of a single shared through-and-left turn lane. Right turning movements onto the freeway had a single exclusive right turn lane. All movements from the freeway off-ramp used single exclusive turn lanes which developed 850 feet upstream of the stop bar. The total length from the stop bar for off-ramp movements to the freeway was 1,340 feet.

The two adjacent intersections were located 1,000 feet north of the north and south of the crossovers. The arterial had three travel lanes in both the north- and southbound directions. At the adjacent intersection, those lanes transitioned into two through lanes and a left turn lane for the outbound approach. The right turn lane and second left turn lane pockets developed upstream of the stop bar at the downstream adjacent intersection. All left turning movements at the adjacent intersections were coded with exclusive dual turn lanes, while right turning movements were exclusive single lanes. All turn pockets for adjacent intersection mainline (north/south) movements were developed a distance of 250 feet from the stop bar, while side street (east/west orientation) left turn lane pockets developed 400 feet upstream of the stop bar.

Traffic Demand Scenarios
In designing the congested and uncongested volume scenarios, consideration was given to conditions commonly seen at DDIs throughout the United States. At suburban interchanges where DDIs are often used, large retail stores, a combination of fuel and food outlets, or housing developments are often located within the quadrants of the interchange. Heavy turning
movements from the minor street are present as the majority of traffic coming from these land uses desires to access the corridor as opposed to cross the corridor.

The uncongested scenario was designed to function below capacity. The Capacity Analysis for Planning of Junctions (CAP-X) Tool (25) was used to provide a starting point for the volume combinations. The critical lane volume was assumed to be 1,600 vph, with a left turn adjustment factor of 0.95, a right turn adjustment factor of 0.85, and a truck to passenger car equivalence factor of 2. A volume combination was then developed which resulted in a DDI with volume to capacity (v/c) ratios between 0.35 and 0.44 for all six merging or crossing points. The adjacent intersections had a v/c of 0.69. From this base demand model, the corridor volumes were increased to create congested conditions. Because the two-critical phase DDI is more efficient than the adjacent four-critical phase conventional intersection, v/c at the DDI was still modest under the congested scenario. These volumes did, however, provide a congested scenario at the adjacent intersections. Figure 4 shows the uncongested and congested case demands.

**Figure 4** Uncongested (a, b, & c) and congested (d, e, & f) cases demand scenarios.

**Traffic Demand Scenarios**

Following model development and development of traffic demands, the six step methodology was employed to dynamically determine the optimum offsets at the four signalized intersections
(two DDI and adjacent intersection each) using the actual cycle-by-cycle green times produced during simulation. This process is described below.

3 **Step 1: Signal Timing**

The base network was built in VISTRO (26) according to the traffic demands provided in Figure 4. In addition, a network optimization was performed using VISTRO’s genetic algorithm. The optimization was exclusively a function of delay. Each optimization consisted of a maximum of 100 iterations, but the optimization process would terminate if any 50 consecutive generations were modeled with less than a 1% improvement. The offset and split were optimized to the nearest one second, and lead/lag optimization was allowed at the adjacent intersections.

4 **Step 2: Microsimulation and Controller Log Generation**

VISSIM 7 (27) was used as the microsimulation tool as it paired nicely with the macroscopic VISTRO tool. The base model was built in VISSIM according to the geometries and demand as defined in Figure 3 and Figure 4. The VISSIM model used in this paper was based on a calibrated and validated model of the National Avenue DDI corridor. VISSIM’s simulation controller was used to run 15 trials with each run using a unique random seed. Each trial lasted 4,500 seconds, with the first 900 seconds being a “warm-up” period allowing the network to populate the model. Data was collected over the remaining 3,600 seconds.

The authors selected controller log file of the first of the 15 simulation files. Since the first 900 seconds were a “warm-up” period, the authors used green times from the last hour of simulation for the DBAT input file. The same random seed was selected in both the congested and uncongested scenario. Because the actuation of every peak hour is unique, selecting a different simulation file— analogous to collecting field data on a different day—could result in a slightly different optimal offset.

5 **Step 3: Obtain Baseline Performance**

The DDI arterial’s baseline performance was measured using VISSIM simulation results for our test; however, the same measurements could be collected at an existing site using Bluetooth or probe vehicle data. Average delay, average maximum queue length, stop severity index (SSI), and high resolution vehicle trajectory plots were used as performance measures.

A direct comparison of stops does not account for the variation in the number of intersections encountered over the OD paths. Therefore, SSI was defined as a standardized value representing the number of stops squared, divided by the number of intersections traversed. One stop over one intersection is equal to two stops over four intersections.

\[ SSI = \frac{\text{average # of stops per vehicle}^2}{\text{# of intersections traversed}} \]  

To generate trajectories, VISSIM’s vehicle record file (.TRJ file) were used. These files contain the position of each vehicle along a link in each time step. High-resolution vehicle trajectories can be visualized through the vehicle record file help evaluate progression quality. The baseline performance analysis results are detailed in Step 6.

6 **Step 4: Optimize Offsets in DBAT Based on Controller Log Information**

Figure 5 shows DBAT results which provided an improved bandwidth solution compared to VISTRO. For the one hour simulation from which the controller log was created, DBAT’s offset
would, on average, provide an additional 35.6 and 11.5 seconds of bandwidth per cycle to the uncongested and congested scenarios, respectively. It is emphasized here that these results do not mean that VISTRO is unable to optimize corridor offsets, but rather that the DDI characteristics and the way DDIs have to be coded in macroscopic tools like VISTRO or SYNCRO are incompatible with the built-in optimization routines. Additionally, these macroscopic optimization tools may not consider the non-programmed bandwidth along the corridor when unused green time is given to the coordinated movement.

![Graph showing uncongested and congested bandwidth solution spaces with VISTRO and DBAT results.]

**Figure 5** Two Scenario DBAT Results plotting DBAT and VISTRO Objective Function Values (with VISTRO interlaid for comparison).

**Step 5: Apply Updated Offset Values**

The microsimulation was updated with the DBAT generated offsets. Since DBAT only adjusts offsets, each signal controller retained the initial cycle length, splits, and phase sequence. Therefore, there is no sacrifice to the capacity of non-coordinated phases. From this step, DBAT’s optimal offset performance was measured through VISSIM simulation. The congested
and uncongested scenarios were run again with the same 15 random seeds utilized in Step 2 to allow before and after comparisons using four performance measures.

**Step 6: Evaluate New Offsets through Before and After Study**

In this step, a before and after comparison of VISTRO and DBAT calculated offsets was conducted using VISSIM. Four different measures of effectiveness (average delay, stop severity index, average maximum queue length, and high resolution vehicle trajectory plots) were utilized to see how DBAT performed along the DDI corridor. Excepting U-turns, all feasible corridor paths were compared in a before and after study.

**Results**

In the field, measures of effectiveness could be collected via Bluetooth or probe vehicle data. Because the method in this paper simulated a “new build” scenario, the measures were collected through microsimulation.

**Delay**

Figure 6 shows the results of average delay per vehicle for both volume demand conditions. For most paths, DBAT optimized offsets decreased delay in the uncongested demand scenario. In the case of through movements, the delay was decreased by 53% and 47% in the northbound and southbound directions, respectively. The average reduction in delay for all paths measured in the uncongested and congested scenario was 14.3% and 3.5%, respectively. A few paths’ delays were increased using DBAT calculated offsets, but the effect was minor compared to the entire network performance.

![Figure 6](image-url)
To further illustrate the performance of DBAT over VISTRO, Figure 7 shows the cumulative distribution function plot for coordinated movements. It again shows the improvement of coordinated movement performances.

![Cumulative distribution of travel time performance](image)

**a) NB Travel Time (uncongested)**

**b) SB Travel Time (uncongested)**

**c) NB Travel Time (congested)**

**d) SB Travel Time (congested)**

*Figure 7 Cumulative distribution of travel time performance (in seconds) for coordinated movements in uncongested and congested conditions.*

**Stop Severity Index**

Stop severity index (SSI) shows a similar pattern to delay. Across the uncongested scenario, excepting one path, SSI values decreased. The coordinated paths’ SSI values remarkably improved with a 60% and 40% reduction in the SSI in the northbound and southbound paths, respectively. In the congested scenario, DBAT showed some improvement in the peak (northbound) direction; however, it succeeded in reducing the SSI in the southbound path by nearly 40%. The comparison results are shown in Figure 8. DBAT’s strength lies in improving peak progression not at the expense of non-peak progression, but in conjunction with it.
Queue and Trajectory

Average maximum queue length and trajectory plots also show the strength of the proposed offset fine-tuning method employed by DBAT. The trajectory analysis provides a useful visual confirmation of the validity of the updated coordination settings. As with SSI, the congested scenario shows the greatest improvement in the non-peak (southbound) progression without sacrificing the peak progression. Additionally, most of the coordinated approaches’ queue lengths were decreased and trajectory plots depict better progression compared to VISTRO’s offset results. Figures 9 a-f shows both the average maximum queue lengths and trajectory plot results using VISTRO and DBAT provided offsets for the north and southbound directions of travel. Figures 9 a and b are shown to scale on the y axis.
Figure 9 Average maximum queue length and trajectory plots.

Before and after study results provide strong evidence for the robustness and effectiveness of the proposed offset fine-tuning workflow and method. The example cases
proposing offset fine-tuning each took less than an hour. This time is considerably shorter than
the time needed to manually fine tune offsets in the field. In addition, before and after
comparison results showed much better performance in all performance measures studied.

CONCLUSION
Diverging diamond interchanges are relatively new in the United States and the signal timing is
challenging. This paper provides an innovative offset fine tuning method and flow for a DDI and
its adjacent intersections. The proposed method uses Dynamic Bandwidth Analysis Tool
(DBAT), which is intended for use with field-generated (or simulated) actuated phase time and
optimizes the dynamic bandwidth based on that entry data set. Since most arterials in the United
States use coordinated actuated control systems, the dynamic bandwidth nature of the tool allows
for consideration of early returns to mainline green, as well as green extension of the coordinated
phases. The results provide better offsets compared to other bandwidth optimization tools which
generally optimize for programmed bandwidth only. From the before and after study, it can be
concluded that the performance of the proposed method’s offsets is considerably better than the
commercial tool. Most notably, the peak progression is improved not at the expense of the off-
peak progression, but in conjunction with it. In addition, the proposed method and workflow can
significantly reduce the offset retiming work process which traditionally requires visiting the
study site to observe early return to green and green extension. Normally, this manual process
takes more than a day, but this proposed method can be completed in less than an hour without
visiting the study site. Furthermore, the proposed method can coordinate any set of movements
as well as multiple travel paths. The authors believe that the proposed method and workflow will
significantly help both retiming and new timing of arterial signal coordination along DDI
corridors and other signal systems.
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