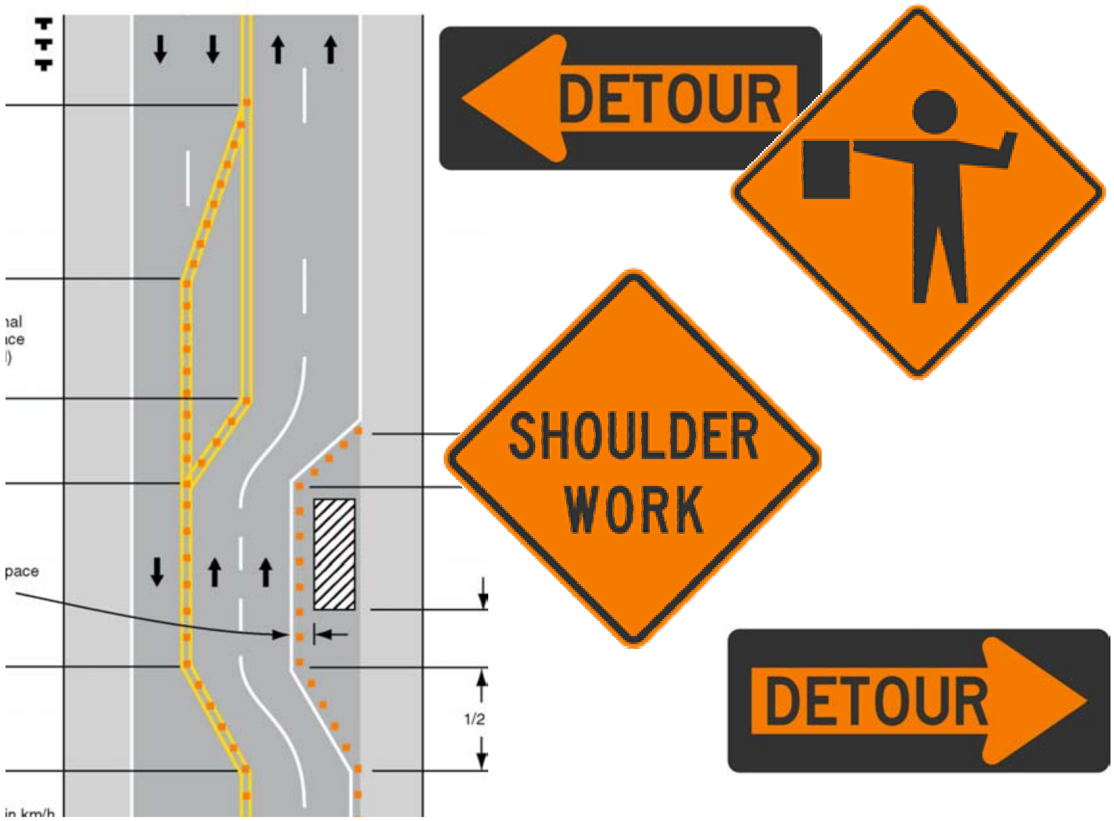
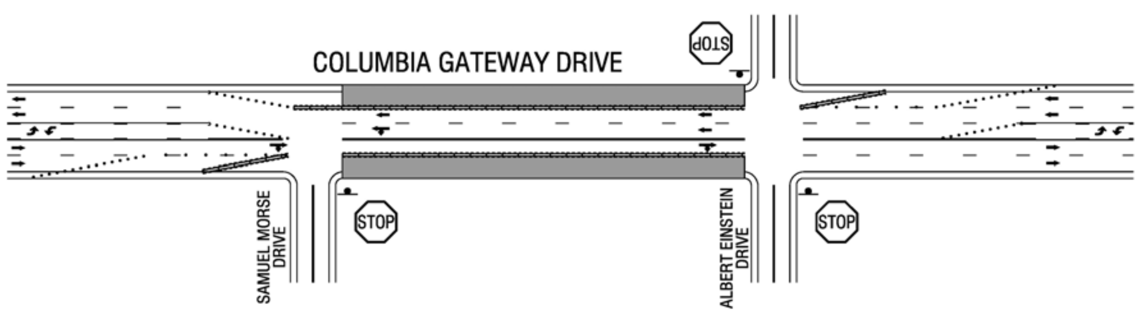
WORK ZONE ANALYSIS GUIDE





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SHA State Highway Administration
Maryland Department of Transportation

Sabra, Wang & Associates, Inc.
Engineers • Planners • Analysts

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I. INTRODUCTION

The Federal Highway Administration's (FHWA) Rule on Work Zone Safety and Mobility, 23 CFR 620 Subpart J, requires every state to identify methods of improving roadway safety and mobility in and around the work zone. In response to this Rule, the Maryland State Highway Administration (SHA) has prepared *Transportation Management Plans: Guidelines for Development, Implementation and Assessment*. One of the components of assessing work zone safety and mobility impacts for the Transportation Management Plan (TMP) is work zone traffic analysis, which is the subject of this guide. The SHA also prepared *Work Zone Lane Closure Analysis Guidelines*, which present allowable thresholds for decreasing mobility (measured in terms of queues and delays) in work zones. The purpose of this document is to provide guidance on evaluating the impacts of work zones on roadway capacity.

The presentation of traffic analysis methods in work zones is separated into arterial and freeways, because performance measures differ between these two roadway types. The performance measures for arterial work zone analysis are control delays and levels of service at intersections, and arterial travel time along segments. The primary performance measure for freeway work zone analysis is queues.

II. ANALYSIS OBJECTIVES AND ALTERNATIVES

When performing work zone analyses, the first step of the process is to determine the objective of the study. The analysis performed for any given project will be a balance between the desired precision of the results, data availability and quality, and the stage of project development. Study objectives will vary based on the aforementioned criteria; however, objectives often include determining construction sequencing, determining the optimal temporary traffic control alternative, determining allowable durations for temporary lane closures, evaluating the impacts of detouring traffic onto other roadways, and identifying the need for mitigation measures. The objectives of the study should be discussed with and agreed upon by the project manager and District Traffic.

Concurrent with selecting study objectives, the appropriate analysis tools should be selected. There are many tools available to address work zones, as discussed further in the next sections of this Guide. The available tools range from simple to complex. Simpler tools include Highway Capacity Manual techniques and sketch planning while more complex tools include macro, meso and microscopic simulation tools. Choosing a tool is generally a tradeoff between desired functionality, results, time, training and cost. **Figure 1**, as presented in FHWA's Draft *Work Zone Analysis Primer*, shows some of the available tools that can be used to assess the impacts of roadway construction projects and the level of complexity involved with each of them.

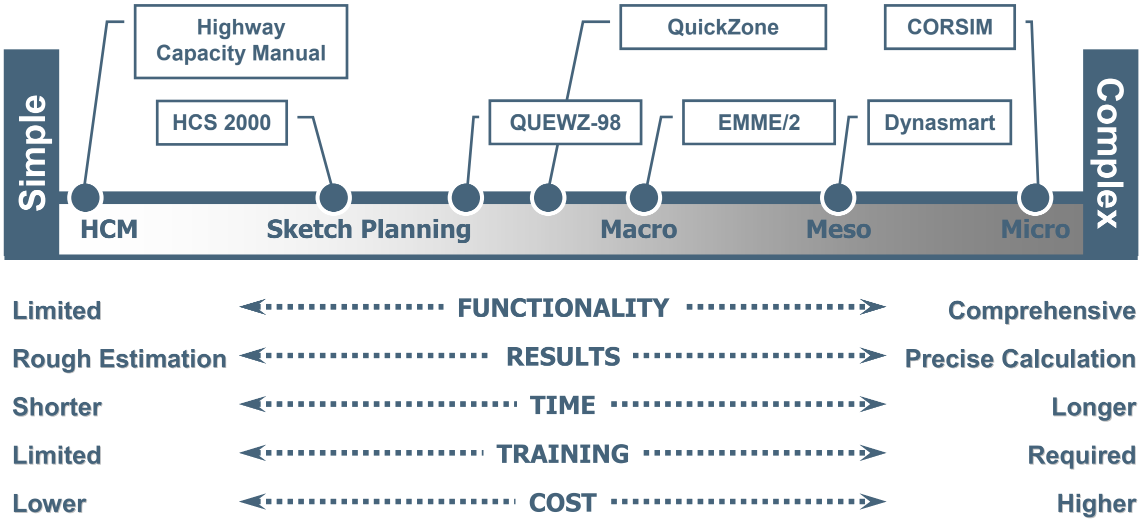


Figure 1. Work Zone Modeling Spectrum
(from FHWA's Draft *Work Zone Analysis Primer*, January 2008)

During the selection of analysis objectives, construction staging, temporary traffic control options, and potential impact mitigation strategies should be discussed. The following are descriptions of potential construction and mitigation alternatives. It should also be noted that, in accordance with Senate Bill 699 (SB 699), a full closure shall be considered for all projects on expressways or controlled-access highways with a speed limit of 45 mph or greater and an anticipated project duration of 2 weeks or longer. This bill also requires consideration of the availability and feasibility of detours and maintaining access to abutting businesses, residences, and other facilities.

A. The Traditional Alternative

The simplest work zone concept that can be used is a partial width reconstruction where road work is performed during daytime weekday off-peak hours only and lane closures remain in effect until the corresponding phase of construction has been completed. The definition of peak hours varies by project, but is generally limited to the AM and PM weekday hours when the roadway under construction experiences the greatest traffic volumes. This strategy will likely yield an easy Maintenance of Traffic (MOT) design and low MOT costs, however there are also disadvantages. Projects constructed using this strategy are likely to take longer than other projects, involve narrow lanes, with increased difficulty of constructability and decreased safety to both workers and motorists.

B. Other Construction Alternatives

If a project is complex, or if there are other factors such as traffic characteristics or public concerns, the traditional alternative may not be feasible. There are several other alternatives that may provide a suitable strategy for project construction, including the following:

- Use of Existing Shoulder(s) as Travel Lane(s)
- Nighttime Work
- Weekend Work
- Contraflow Lanes with Crossover Construction
- Temporary Pavement
- Temporary Structures
- Detours
  - "Soft" or "Hard" Detour Signing
  - Sign Only Detours
  - One-Direction Detours
  - Full Detours
- Ramp Closures
- Reversible Lanes
- Movable Barrier Systems

Table 1, which was adapted from the Ohio DOT's *Traffic Management in Work Zones: Interstate and Other Freeways,* shows some advantages and disadvantages of each of the aforementioned work zone alternatives. For further discussion on these construction strategies and presentation of other construction strategies, refer to SHA's *Transportation Management Plans: Guidelines for Development, Implementation and Evaluation*

C. Mitigation Measures

Many times, the preferred construction staging/phasing may result in unacceptable traffic impacts. In these situations, work zone impact management strategies may be employed to help lessen the traffic impacts. These strategies may include:

- Corridor/Network Management, such as temporary traffic signals, signal timing optimization, and reversible lanes;
- Demand Management, such as transit service improvements and carpool incentives; and
- Work Zone Intelligent Transportation Systems, such as dynamic late lane merge and dynamic speed limit signs.

In addition, other transportation operations (TO) and public information and outreach (PI&O) strategies can be employed to manage the safety and mobility impacts caused by the work zone. For further discussion on these work zone impact management strategies and presentation of other impact management strategies, refer to SHA's *Transportation Management Plans: Guidelines for Development, Implementation and Evaluation.*

Table 1. Advantages and Disadvantages of Selected Work Zone Strategies

Work Zone Strategy	Advantages	Disadvantages	When to Use
The Traditional Strategy	• Easy design • Low MOT costs	• Longer overall project duration • Increased difficulty of construction • May require narrow travel lanes • May result in narrow work zones	• Project involves minor work • When such a work zone is not excepted to create excessive delays
Use of Existing Shoulder(s) as Travel Lane(s)	• Low costs • Allows for the maintenance of the existing number of lanes	• Shoulder must be travel-worthy (traffic bearing) • May increase difficulty of construction access • No room for breakdowns to pull off	• When volumes dictate that the existing number of lanes should be maintained • When work is to be performed in the travel lanes
Nighttime Work	• Low costs (time & fuel) to motorists • Fewer impacts to peak hour traffic/congestion	• Increased labor costs • Decreased worker safety with limited visibility and impaired drivers • All work must be completed, and lane closures reopened at the end of each night	• When daytime volumes are high • When work requires a restriction of turning movements that would be unacceptable during the day
Weekend Work	• Same as Nighttime Work	• Increased labor costs • Impacts travelers less familiar with alternate routes	• Same as Nighttime Work • When work cannot be completed in one night
Contraflow Lanes with Crossover Construction	• Reduced conflicts between workers and vehicles • Easier construction • May reduce overall project duration	• Time and cost associated with constructing and removing crossover • Difficulties arise in proximity to ramps	• Long sections of pavement reconstruction/rehabilitation • If work zone is not in the vicinity of ramps
Temporary Pavement – Temporary Roadway	• Same as Contraflow Lanes	• Costs of constructing roadway • Time to construct and remove temporary roadway • Inefficient use of materials	• Long section of pavement • No adequate detours exist • Bridge work
Temporary Pavement – Widening	• Increases capacity through the work zone	• Time and cost of widening the roadway • Inefficient use of materials	• When volumes require that the number of lanes remain be maintained • Project duration is expected to be long
Temporary Structures	• No reduction in roadway capacity through work zone	• Time and costs of design and construction of structure • Inefficient use of materials	• When volumes prohibit a reduction in capacity • No adequate detours exist
“Soft” Detour Signing	• Reduces congestion on the mainline • Magnitude of increased congestion on alternate routes is less than for “hard” detour signing	• Unfamiliar drivers will not know the available detour routes • Increases congestion on alternate routes	• When an available nearby alternate route exists with sufficient additional capacity • When work zone is expected to causes backups on the mainline • Project duration expected to be long
“Hard” Detour Signing	• Reduces congestion on the mainline • Provides unfamiliar drivers with a specific detour route	• Increases congestion on signed alternate route	• Same as “Soft” Detour Signing • Limited number of alternate routes exist
Sign Only Detours	• Reduces demand through the work zone	• May have low driver compliance rates	• Work zone will reduce roadway capacity
One-Direction Detour	• Same as Contraflow Lanes • Only half of the traffic is required to detour onto alternate routes • Fewer delay/congestion increases on alternate routes than for a full detour	• Increased costs (time & fuel) to some motorists • Increased delays/congestion in one direction on alternate routes • May reduce access to some nearby businesses	• When an available nearby alternate route exists with sufficient additional capacity • If work is to be performed on one direction of a roadway
Full Detours	• Same as Contraflow Lanes • Reduced MOT costs	• Increased costs (time & fuel) to motorists • Increased delays/congestion on alternate routes • May reduce access to nearby businesses • May confuse drivers	• When an available nearby alternate route exists with sufficient additional capacity • If such a detour would reduce overall project duration
Ramp Closures	• Same as Contraflow Lanes • Reduced MOT costs	• Same as Full Detours	• Other ramps are nearby • Where alternate routes exist
Reversible Lanes	• Accommodates fluctuations in peak traffic flow direction	• May confuse drivers	• Where large variations exist between AM and PM directional volumes • Where the number of travel lanes is limited
Movable Barrier Systems	• Provides additional work space during off-peak hours • Provides for peak flow capacity	• Cost of the movable barrier system is higher than that for drums or fixed traffic barriers	• Need to provide for capacity during peak hours • The work requires frequent barrier shifts

D. The Recommended Alternative

This Guide focuses on selecting the recommended alternative from a traffic standpoint. Results from a work zone traffic analysis should never be used to *make* key decisions, but instead used as a trusted resource in identifying the potential mobility impacts that *inform* key decisions. Results of a work zone traffic analysis should be provided to decision makers in such a manner that connects the findings of the analysis to the broader decision-making process. Many times, the recommended alternative from a work zone traffic analysis perspective may not be the preferred alternative. Other work zone impacts and considerations should be included in the overall selection of the preferred alternative. In addition to considering whether the alternative satisfies the thresholds presented in the *Lane Closure Analysis Guidelines*, the following are suggested factors for consideration in the process of selecting the recommended alternative:

- Ability to maintain access to nearby businesses and communities;
- Ability to provide required ramp merge distances and ramp capacity;
- Right-of-way impacts;
- Environmental and cultural resource impacts;
- Impacts on earthwork, retaining walls, pier clearances, profile differences, etc.;
- Ability to maintain existing drainage, utility and lighting systems;
- Constructability and construction equipment access;
- Impacts on pedestrian and bicycle facilities;
- Impacts on emergency services;
- Safety (of workers and the traveling public);
- Construction duration; and,
- Construction and MOT costs.

For further discussion on work zone alternatives analysis, refer to the following SHA documents:

- *Guidance on Maintenance of Traffic Alternatives Analysis*
- *Transportation Management Plans: Guidelines for Development, Implementation and Evaluation*
- *Work Zone Design Checklist*

III. ARTERIAL WORK ZONE ANALYSIS

The process for performing analysis of a work zone on an arterial is similar to the process for performing a traffic analysis for a roadway improvement project. Level of Service (LOS) analyses should be performed and a simulation analysis may be performed of the recommended alternative. The first step in performing arterial work zone analysis is to determine the objective of the study, as described in the previous section. Once the study objective has been determined, the appropriate traffic analysis tool may be selected.

A. Mobility Thresholds

The SHA's *Work Zone Lane Closure Analysis Guidelines* contains allowable mobility thresholds for work zones on arterials. The thresholds are reprinted in **Table 2** for the reader's convenience. Note that the measures of effectiveness (MOEs) are LOS, intersection control delays, and arterial travel time. Additional MOEs should be selected using the analyst's judgment.

Table 2. Mobility Thresholds for Arterials

Signalized Intersections	
Existing Level of Service	**Mobility Threshold**
A, B or C	Maximum LOS D Control delay ≤ 45 seconds
D	Maximum increase in Control delay of 30%
E	Maximum increase in Control delay of 30%, or Control delay ≤ 80 seconds
F	No increase in Control delay
Unsignalized Intersections	
Existing Level of Service	**Mobility Threshold**
A, B or C	Maximum LOS D Control delay ≤ 30 seconds
D	Maximum increase in Control delay of 30%
E	Maximum increase in Control delay of 30%, or Control delay ≤ 50 seconds
F	No increase in Control delay
Arterials	
Existing Travel Time	**Mobility Threshold**
T	Travel time can not increase more than 15 minutes (Maximum of T+15)

Source: Maryland State Highway Administration Work Zone Lane Closure Analysis Guidelines, November 2006

B. Traffic Analysis Tools

As with any type of traffic analysis, there are several models that could be used to evaluate traffic conditions under work zone operations, such as Critical Lane Volume (CLV) analysis, simulation models such as CORSIM, VISSIM, PARAMICS or SimTraffic, and Highway Capacity Manual (HCM) based tools such as HCS or Synchro. **Table 3** lists the advantages and disadvantages of the most commonly used traffic analysis tools for performing work zone traffic analysis. The Synchro / SimTraffic software package is the recommended traffic analysis tool for work zone applications on arterials since many of Maryland's arterials have already been coded using Synchro and Synchro can calculate LOS, control delays and travel times directly, based on user inputs. Also, simulation analysis can be easily performed with SimTraffic. For a complete presentation of traffic analysis tools, see the Federal Highway Administration's *Traffic Analysis Toolbox*, available online at http://ops.fhwa.dot.gov/trafficanalysistools/toolbox.htm.

Table 3. Traffic Analysis Tools for SHA Work Zone Analysis

Traffic Analysis Tool	Strengths	Weaknesses
Critical Lane Volume Analysis	- Planning tool for quick calculation of LOS and V/C ratio	- Does not calculate travel time - Does not perform simulation analysis - Does not calculate control delay
CORSIM, VISSIM, PARAMICS	- Performs simulation - Performs travel time calculations	- Does not calculate LOS; must be manually calculated. - Delay calculations are not consistent with HCM control delay definition, but can be used as long as the existing conditions and alternatives analysis are compared using the same model. - Analysis and calibration of oversaturated conditions can be tedious.
Highway Capacity Software	- Performs travel time calculations - Performs LOS and control delay calculations	- Does not perform simulation analysis - The LOS and control delay calculations are not performed within the same model at the travel time calculations. Separate models are required.
Traffic Analysis Tool	**Advantage**	**Disadvantage**
Synchro / SimTraffic (RECOMMENDED)	- Performs travel time calculations - Performs LOS and control delay calculations - Performs simulation - OOTS maintains a database of Synchro files for arterials statewide	- Analysis and calibration of oversaturated conditions can be tedious.

In certain situations, the use of CLV analysis or HCS may be appropriate. Use engineering judgment when selecting the software package for use on each project.

C. Study Network

In preparation for the data collection required for arterial work zone analysis, it is necessary to determine the limits of the network to be studied. The following should be considered in determining the study network:

- Include, at a minimum, the adjacent intersections both upstream and downstream of the work zone.
- Include all intersections outside of the work zone that are impacted by queues from intersections within the work zone.
- Consider the limits of the coordinated signal system.

- Consider including any side streets that are expected to be impacted by work zone queues.
- Include all detour routes.

To obtain an initial estimation of the queue length caused by the work zone at signalized intersections, the following equation may be used:

$$L = \max\left\{\frac{V}{N} - \left(\frac{G}{C} * 1900\right) + \frac{V * C}{3600 * N}, \frac{V * C}{3600 * N}\right\}$$

,where L is the approach queue length (in number of vehicles), V is the through traffic volume for the approach, G is the duration of the green interval for the through movement, C is the cycle length, N is the number of open through lanes, and 1900 is the default saturation flow rate (in vehicles per lane per hour). If the work zone will directly impact more than one intersection, the queue length at the critical intersection, and at the first intersection that motorists will encounter while traveling through the work zone should be evaluated. The critical intersection is defined as the intersection where the approach(es) impacted by the work zone have the highest existing volume per through lane. **Figure 2** illustrates how to determine where the queue length should be evaluated.

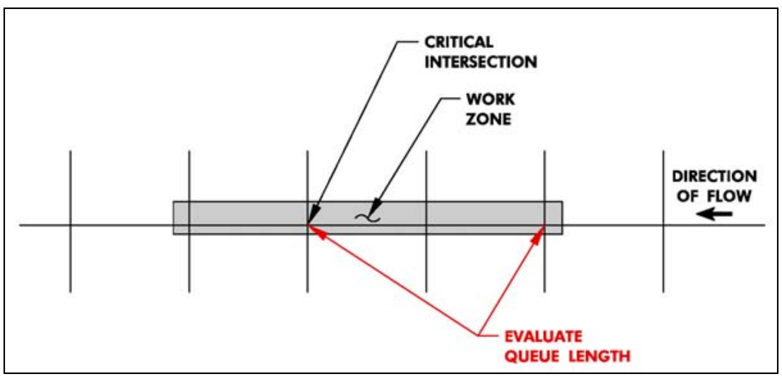


Figure 2. Locations of Queue Length Evaluation

D. Data Collection

Once the size of the study network has been determined, it is necessary to collect the data that will be needed to model work zone operations. Depending on the complexity of the study network and of the analysis needed, different types of data may be required.

1. Field Measurements

Field measurements include inventories of existing lane configurations and dimensions, locations of traffic control devices, turn bay lengths, and signal phasing. The data collection effort may be considerably reduced by obtaining the above information using aerial imagery, by downloading the traffic signal plans from SHA's website (http://marylandroads.com/SHAServices/SignalPlanLocator/Index.asp), and/or by obtaining the roadway design plans (if available). This data should be confirmed with a field visit. Note that the spacing between intersections may be verified using SHA's

Highway Location Reference, which can be downloaded at http://www.marylandroads.com/keepingcurrent/performtrafficstudies/dataandstats/hwylocationref/oppe/hlr_hist.asp.

2. *Existing Signal Timings*

Existing signal timings should be obtained by contacting the SHA Signal Shop at (410) 787-7650. Existing Signal Timings in Montgomery County may be obtained by contacting the Montgomery County Transportation Management Center (TMC) at (240) 777-2190.

3. *Existing Synchro Models*

The SHA maintains a database of Synchro files for many arterials. The file containing the project area may be obtained, if available, by contacting the Traffic Development and Support Division (TDSD) at the Office of Traffic and Safety (OOTS) at (410) 787-5800. A field visit must be performed to verify the accuracy of the model input data.

4. *Traffic Volumes*

The collection of existing traffic volumes is required for all work zone analyses. This information can either be obtained through existing traffic counts, such as the SHA-maintained database of traffic counts (available online at http://marylandroads.com/tmsreports/), from recent traffic studies that have been performed in the area, or through the collection of new traffic counts. If existing data is available and not older than three years, the collection of new traffic counts may not needed. For existing data two to three years old, it will be necessary to determine if any significant changes (e.g. lane development, improvements to other roadways, etc.) have occurred since the collection of those volumes. If such changes have occurred, it will either be necessary to apply adjustment factors to old volumes or collect new data. Depending on the project area, pedestrian volumes may also be necessary. Traffic volumes used for analysis should be adjusted to account for seasonal traffic surges, regional traffic patterns, and heavy vehicles. Growth factors should be applied to estimate construction year traffic volumes. Consult with SHA's Travel Forecasting Division when determining growth factors. Several of the aforementioned adjustment factors can be obtained in the SHA's *Traffic Trends Report* (available online at http://www.marylandroads.com/traffictrends2/). For projects where night or weekend work is being considered, traffic volumes that include these time periods should also be obtained.

5. *Origin-Destination Data*

For projects where a detour is being considered, it may be necessary to obtain origin-destination (O-D) information. This data can be used to determine the likely detour routes, and serve as a basis for trip redistribution. O-D data may be estimated based on field observations/studies or with a select link analysis using a regional model. The preferred method of obtaining origin-destination data is a field study, such as a post card survey or license plate study. For less complex projects, origin-destination data may not need to be collected. Instead, assumptions may be made based on engineering judgment as to reasonable traffic distribution and traffic trends. Additionally, SHA's Travel

Forecasting Division may be consulted for assistance with traffic distribution and diversion assumptions. More information on performing O-D studies can be found in the Institute of Transportation Engineers' (ITE's) *Manual of Transportation Engineering Studies.*

6. Field Observations

Field observations must be performed during the analysis period at all intersections within the study area. One time-saving technique is to observe the critical intersections for most of the analysis period, while only performing spot observations at the non-critical intersections. Typical field observations include observations of queue lengths, mid-block intersections, speeds, bottlenecks, and/or driver behavior.

7. Field Studies

Other information may be necessary depending on the characteristics of the project and the alternatives being considered. For instance, field measurements of travel times, queues, speeds, delays, saturation flow rates, lane utilization factors, etc. may be necessary for model calibration and validation. Note that travel time studies can be used to obtain speed, delay, and queue length data. More information on performing field studies can be found in the Institute of Transportation Engineers' (ITE's) *Manual of Transportation Engineering Studies.*

E. Traffic Modeling

Because Synchro/SimTraffic is the recommended analysis tool, the modeling techniques presented in this guide focus on the use of Synchro/SimTraffic. In order to fully understand the impacts of the proposed work zone, it is necessary to create Synchro models for both existing and work zone conditions. To create the existing conditions model, first use the data collected for the existing lane configurations throughout the study network. To this model, add existing signal timings and phasing and traffic volumes. Adjust the peak hour factor (PHF), saturation flow rates, turning speeds, link speeds, and OD data to calibrate the model.

1. Model Calibration and Validation

Validate the model to ensure that the model matches existing conditions. It should be noted that model calibration and validation might not be required for some projects. If the analyst is unsure as to whether validation will be required, consult with the Office of Traffic and Safety for a determination for the specific project. The objective of model calibration and validation is to obtain the best match possible between model estimates and the field measurements. However, there is a limit to the amount of time and effort that should be put into reducing model error. The following guidelines may be used to validate the Synchro model:

- Synchro queue lengths should match field-measured queues on the critical movements within a 85% error (for field-measured queues shorter than 10 vehicles, a 2-vehicle error may be acceptable).
- Synchro travel times should match field-measured travel times within 85%. Note that the travel times should be compared for the overall length of the arterial, and not on a link-by-link basis.

- The SimTraffic simulations should match field-observed bottlenecks to the analysts' satisfaction.

For a complete discussion on model calibration, see Chapter 5 of the FHWA's *Traffic Analysis Toolbox, Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*, available at http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol3/sect5.htm.

Once the model has been calibrated and validated, it may be used as a base model and Synchro reports can be used to determine the performance measures of the existing conditions. For the analysis of work zones at/near intersections, use the *HCM Signals* or *HCM Unsignalized* reports for each intersection that is directly impacted by the work zone.

2. Simulations

For the analysis of work zones on arterial segments, SimTraffic simulations may be the preferred method of determining the increase in travel times. In general, SimTraffic simulations of the study network are most beneficial when evaluating arterial segments (since the mobility threshold for segments relates to travel times rather than LOS) or for networks where intersection spacing would suggest that queues from a downstream intersection may impact traffic operations at upstream intersections. Prior to running SimTraffic simulations, adjust the seeding interval duration so that it exceeds the estimated time for one vehicle to traverse the entire coded network. A recording interval duration of one hour is preferred. However, if the simulated network is complex, the time required to run a one hour simulation may be prohibitive, and a duration of as little as 30 minutes may be acceptable. The random seed number should also be changed to zero (0). At least five (5) simulation runs should be completed, and the results from each run should be averaged to determine the existing delay in the network. SimTraffic has the capability to average the results from multiple runs if the "Multiple Runs" option is selected in the *Reports* window. The network delay for each run may be determined through the *Performance Report* by selecting "Total Delay" and "Delay / Vehicle."

3. Work Zone Model

The base model should then be modified to represent work zone conditions. Adjustments to the base model to create the work zone model may include:

- Lane Configurations
    - Lane reductions on arterial segments can be modeled by creating bend nodes on either end of the proposed work zone and overriding the number of lanes on one or both directions of the roadway. Take into consideration the required taper and buffer lengths approaching the work zone and adjust the model accordingly.
    - When lane reductions occur through an intersection, take into consideration any impacts that this may have on the turning lanes from the side street(s).
    - When lane and/or shoulder widths are reduced, the work zone capacity should be reduced accordingly.

- Traffic Volumes
    - When a detour route is being proposed, it will be necessary to redistribute the traffic volumes in the network based on O-D data and engineering judgment.
    - If work zone demand management strategies are being employed, it may be necessary to reduce the traffic volumes by the estimated reduction in vehicle demand through the work zone.
- Saturation Flow Rate
    - Where there are no lane reductions, but where work would occur adjacent to the roadway it may be necessary to adjust the saturation flow rate to represent the reduced capacity due to work zone operations. This can be accomplished either by reducing the lane widths through the work zone, or by changing the saturation flow rate directly.

When determining the length of the lane closure, consider the impacts of the required buffer and taper lengths. For details on these work zone components, see SHA's *Temporary Traffic Control Typical Applications (TTCTA)*, available in Category 1 of SHA's *Book of Standards*.

F. Analysis Procedure

Depending on the project, it may be necessary to evaluate several work zone alternatives before finding an alternative with acceptable impacts to the existing roadway. The complete procedure for performing arterial work zone analysis is shown in the flowchart presented as **Figure 3**. Prior to performing the steps as listed, the analyst should determine the study objectives, as described in the introduction to this Guide. Examples of work zone analysis for several different site conditions are located in **Appendix A**. **Appendix B** contains an analysis checklist to ensure that the analysis is complete and has considered all necessary factors.

1. Determine the Limits of the Study Network.

Follow the guidelines presented in Section C of this guide for determining the adjacent intersections to be included in the analysis; what, if any, detour routes should be included in the model; the level of detail to be used for side streets; and potential impacts to coordinated signal systems.

2. Data Collection.

Follow the guidelines presented in Section D of this guide for the collection of all necessary data, including obtaining existing signal plans, lane configurations, traffic volumes, field observations, signal timings/phasings, and any other necessary information.

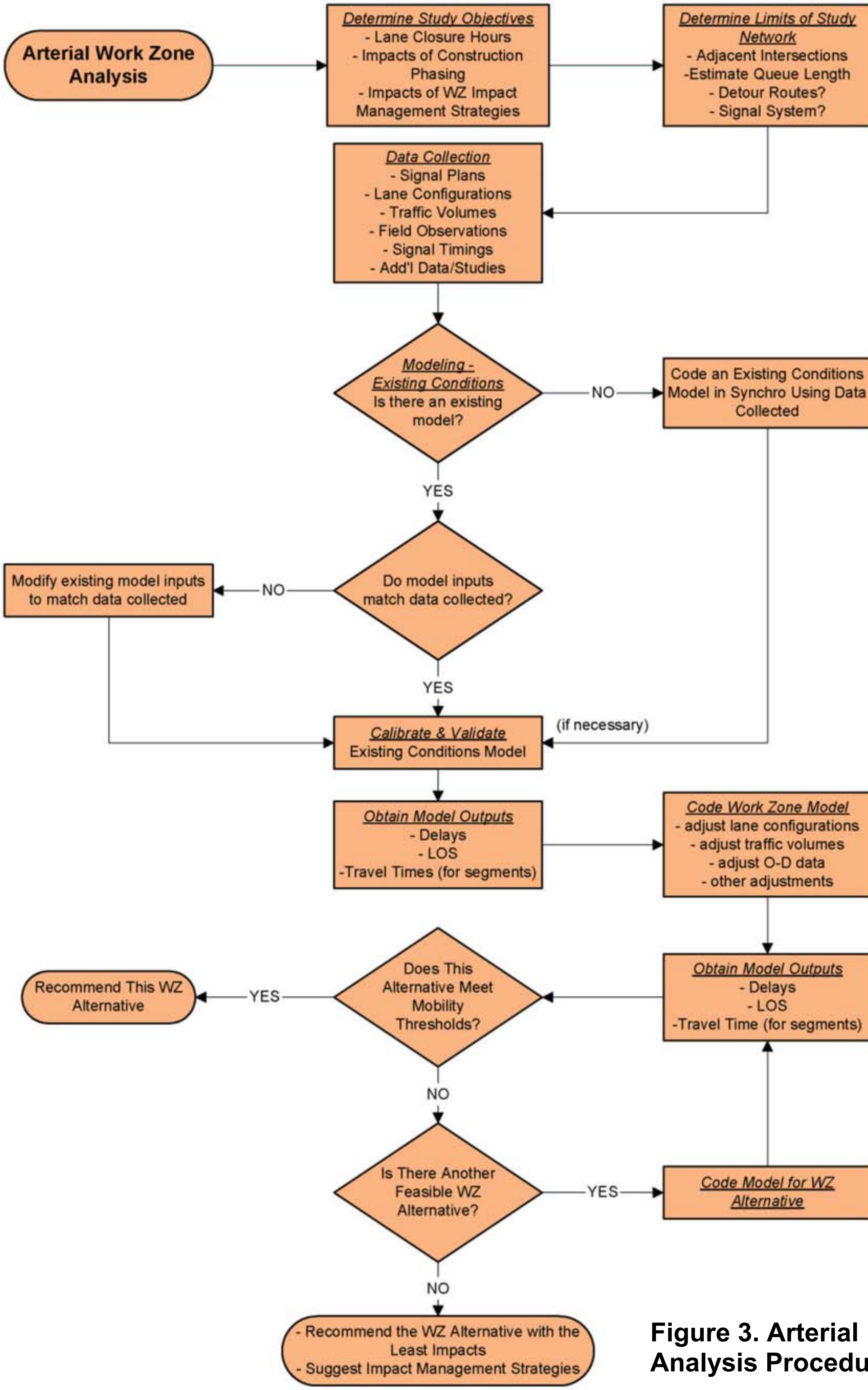


Figure 3. Arterial Analysis Procedure

3. *Modeling – Existing Conditions.*
The first step of the modeling process is to determine if there is an existing Synchro model for the study network. These models can be obtained from the SHA-maintained database or from recent traffic studies. If no existing model is available, it will be necessary to code a new model, as described in Section E of this guide. If there is an available model, this model must be checked to ensure that the input data matches the data collected during the data collection step. If this data does not match, the model should be updated to reflect the most recent data.

4. *Modeling – Calibration and Validation.*
After the existing model has been properly coded, it may be necessary to calibrate the model and validate that the model reflects existing conditions, as described in Section E of this guide. After the model has been calibrated and validated, it is ready to be used as the base model.

5. *Modeling – Obtain Model Outputs.*
Using the Synchro-prepared reports, obtain the existing delays and levels of service for each intersection in the study network. For the analysis of arterial segments, run SimTraffic simulations and average the delay over at least five (5) runs.

6. *Modeling – Code Work Zone Model.*
Modify the Synchro model created for the existing network conditions to reflect the first proposed work zone alternative, as described in Section III.E of this Guide. Modifications will often include changing lane configurations, traffic volumes, and/or origin-destination data. Verify, through viewing a SimTraffic simulation of the alternative, that the new model accurately represents work zone conditions.

7. *Modeling – Obtain Model Outputs.*
Using the Synchro reports, obtain the delays and levels of service for each intersection in the study network under work zone conditions. For the analysis of arterial segments, run SimTraffic simulations and average the delay over at least five (5) runs.

8. *Determine if the Alternative Meets the Mobility Thresholds.*
Compare the outputs obtained in steps 5 and 7 to determine if this alternative meets the mobility thresholds presented in Section III.A of this Guide. If the alternative satisfies the thresholds, proceed to step 9 and recommend this alternative, unless the model showed detrimental operational impacts that were not captured in the evaluation of the mobility thresholds. If there were other operational impacts, consider using work zone management strategies, such as alternative temporary traffic control, work zone ITS, demand management or corridor/network management strategies to minimize the impacts. Refer to SHA's *TMP Guidelines* for more information on work zone impact management strategies. Where other operational impacts are observed, they should be noted in the report. If the alternative does not satisfy the thresholds, determine whether or not there are any other feasible work zone alternatives that have not yet been considered. If there are no other feasible alternatives, recommend the alternative with the least traffic impacts, and the Chief Engineer will be responsible for determining if the

impacts are acceptable. If there is another feasible alternative, code a Synchro model of this alternative and repeat steps 7 and 8.

9. Recommend an Alternative.

If the alternative evaluated in step 8 meets all relevant mobility thresholds, this alternative can be recommended. If all possible work zone alternatives have been exhausted and no alternative meets the mobility thresholds, use engineering judgment to make a recommendation. Normally this recommendation will be the alternative with the least impact on the existing roadway; however, other factors should be considered, such as the required construction cost or time, and/or environmental impacts. In some cases, it might be useful conduct a benefit/cost analysis, comparing the added benefit of additional service life of a structure or pavement surface to the user cost of delay. In a similar manner, construction costs can be compared with the user costs of delay for different alternatives in order to select the preferred alternative. The recommendation should include a detailed explanation of the work zone alternative, including any lane closure schedules or mitigation measures. Lane closure schedules can be determined by looking at the collected traffic volumes and determining which hours of the day experience volumes lower than the volumes analyzed (if the analyzed alternative met the thresholds).

IV. FREEWAY WORK ZONE ANALYSIS

The process for performing analysis of a work zone on a freeway is similar to the process of performing an alternatives traffic analysis for a roadway improvement project. Queuing analyses should be performed and a simulation analysis may be performed for the recommended maintenance of traffic alternative. The first step in performing freeway work zone analysis is to determine the objective of the study. Example objectives include determining lane closure schedules, determining the impacts of detours on the network, and determining possible construction phasing. Once the study objective has been determined, the appropriate traffic analysis tool may be selected and the necessity for model calibration and validation can be determined.

A. Mobility Thresholds

The SHA's *Work Zone Lane Closure Analysis Guidelines* contains allowable mobility thresholds for work zones on freeways. The thresholds are reprinted in **Table 4** for the reader's convenience. Note that the MOEs are queue length and duration. Additional MOEs should be selected using the analyst's judgment. The analyst should check with the District Traffic Engineer to verify of the queue lengths and durations presented in this table are acceptable for the project area.

Table 4. Mobility Thresholds for Freeways

Estimated Queue Length	Queue Duration for Unacceptable Conditions
< 1.0 miles	Acceptable for all durations
1.0 – 1.5 miles	> 2 hours
> 1.5 miles	Any duration

B. Traffic Analysis Tools

As with any type of traffic analysis, there are several methods that can be used to evaluate freeway traffic conditions under work zone operations, including analytical tools such as Highway Capacity Software (HCS), lane closure software (such as QuickZone, the Lane Closure Analysis Program *LCAP* tool, or Queue and User Cost Evaluation of Work Zones *QUEWZ-98*), Excel calculations, and simulation models such as CORSIM, VISSIM, and PARAMICS. **Table 5** lists the strengths and weaknesses of the most commonly used traffic analysis tools for performing freeway work zone traffic analyses. CORSIM/VISSIM models are the recommended traffic analysis tools for complex work zone applications on freeways since these models can best represent vehicle interactions in these intricate work zones. For simple work zones, QuickZone, LCAP, and Excel analytical tools are recommended due to the ease of use. Determining the study objective (choose between work zone alternatives, select suitable lane closure hours, determine the number of lanes that may be closed at one time, etc.) may also aid in deciding the proper traffic analysis tool. It should be noted that more than one tool may be used in a freeway work zone analysis to address various study objectives. For a complete presentation of traffic analysis tools, see the Federal Highway Administration's *Traffic Analysis Toolbox* (link provided in Section VI).

Table 5. Traffic Analysis Tools for SHA Freeway Work Zone Analysis

Traffic Analysis Tool	Strengths	Weaknesses
Highway Capacity Software (HCS)	- Planning tool for quick calculation of LOS and density	- Does not consider vehicle interactions - Does not calculate queue length or duration - Only considers 1 hour of traffic data
QuickZone, LCAP, QUEWZ-98	- Performs queue length and duration calculations	- Does not consider vehicle interactions - Does not analyze the impacts of ramps in or near work zones - Does not generate potential network impacts
Excel Calculations	- Performs queue length and duration calculations - Quick to setup and use	- Does not consider vehicle interactions - Does not analyze the impacts of ramps in or near work zones - Does not generate potential network impacts
CORSIM, VISSIM, PARAMICS	- Performs simulations using several hours of traffic data - Performs maximum queue length calculations - Simulations allow visual observation of queue lengths and duration - Considers the impacts of ramps on work zones - Capable of modeling complex work zone projects and estimating network impacts	- Analysis and calibration of oversaturated conditions can be tedious - Requires intimate knowledge of simulation software - More time-intensive then other tools

C. Study Network

In preparation for the data collection required for freeway work zone analysis, it is necessary to determine the limits of the network to be studied. The following should be considered in determining the limits of the study network:

- When determining the length of the actual work zone, consider the required buffer and taper lengths on the approaches to the work zone. (For more information on these work zone components, see SHA's *Temporary Traffic Control Typical Applications (TTCTA)*, available in Category 1 of SHA's *Book of Standards*)

- Include all ramps and lane transitions outside of the work zone that are expected to be impacted by queues from the work zone. If the work zone queue is expected to be long, limit the study network to 1.5 miles in advance of the work zone, as the mobility thresholds dictate that queues in excess of 1.5 miles for any duration are unacceptable.
- Include all potential detour routes. If the proposed detour routes include arterials, refer to the arterial analysis section of this guide for more information on the analysis along the detour.
- Engineers in the District Traffic Office will have knowledge of traffic characteristics and operations in the study area and may have recommendations about possible study limits. Consider consulting a District Traffic Engineer for assistance in determining the study network limits.
- The objectives of the analysis (e.g. determining allowable durations of lane closures, determining the allowable construction phasing, etc.) may help when determining which adjacent ramps and roadways will be impacted by the proposed work zone.

Once the study network has been determined, an analysis tool may be selected. As shown in Table 4, if the study network does not include any ramps one of the analytical tools (HCS, QuickZone, LCAP, or Excel calculations) may be selected, or if the network includes ramps, it may be preferable to use a simulation tool.

D. Data Collection

Once the size of the study network has been determined, it is necessary to collect the data that will be needed to model work zone operations. Depending on the complexity of the study network, the study objectives, and the analysis tool used, different types of data may be required.

1. Field Measurements

Field measurements include inventories of existing lane and ramp configurations and dimensions, locations of ramps and lane transitions, and acceleration and deceleration lengths of ramps. The data collection effort may be considerably reduced by obtaining the above information using aerial photography or roadway plans (if available). This data should be confirmed with a field visit. Note that the spacing between ramps and the locations of lane reductions/additions may be verified using the SHA's *Highway Location Reference* (link provided in Section VI).

2. Traffic Volumes

The collection of existing traffic volumes is required for all work zone analyses. This information can either be obtained through existing traffic counts, such as the SHA-maintained database of traffic counts (link provided in Section VI), from recent traffic studies that have been performed in the area, or through the collection of new traffic counts. If existing data is available and not older than three years, the collection of new traffic counts may not be needed. For existing data two to three years old, it will be necessary to determine if any significant changes (e.g. land development, improvements to other roadways, etc.) have occurred since the collection of those volumes. If such changes have occurred, it will either be necessary to apply adjustment factors to old volumes or collect new data. Traffic volumes used for analysis should be adjusted to account for seasonal traffic surges, regional traffic patterns, heavy vehicles, and any proposed developments that will be completed by the estimated end of construction. Growth factors should be applied to estimate construction year traffic volumes. Consult with SHA's Travel Forecasting Division when determining growth factors. Several of the aforementioned adjustment factors can be obtained in the SHA's *Traffic Trends Report* (link provided in Section VI). For projects where night or weekend work is being considered, traffic volumes that include these time periods should also be obtained.

3. Origin-Destination Data

For projects where a detour is being considered, it may be necessary to obtain origin-destination (O-D) information. This data can be used to determine the likely detour routes, and serve as a basis for trip redistribution. Additionally, for analysis of work zones that impact multiple interchanges using simulation tools (CORSIM/VISSIM), it may be necessary to collect O-D data to create the traffic model. O-D data may be estimated based on field observations/studies or with a select link analysis using a regional model. The preferred method of obtaining O-D data is a field study, such as a post card survey or license plate study. For less complex projects, origin-destination data may not need to be collected. Instead, assumptions may be made based on engineering judgment as to reasonable traffic distribution and traffic trends. Additionally, SHA's Travel Forecasting may be consulted for assistance with traffic distribution and diversion assumptions. More information on performing O-D studies can be found in ITE's *Manual of Transportation Engineering Studies*.

4. Travel Time Studies

For analysis using CORSIM/VISSIM simulations, it may be necessary to perform field travel time studies for use in the calibration and validation of the model. Travel time studies can also be used to obtain speed and delay data. There are several different methods of performing field travel time studies, including test driver and license plate studies. More information on performing travel time studies can be found in ITE's *Manual of Transportation Engineering Studies*.

5. Field Observations

Field observations may be performed throughout the study network. Typical field observations include observations of queue lengths, speeds, bottlenecks, heavy vehicle percentages, and/or driver behavior.

6. Field Studies

Other information may be necessary depending on the characteristics of the project and the alternatives being considered. For instance, field measurements of speeds, saturation flow rates, lane utilization factors, etc. may be necessary for model calibration and validation. More information on performing field studies can be found in ITE's *Manual of Transportation Engineering Studies*.

E. Traffic Modeling

Because the mobility threshold for freeway work zones only relates to the work zone queues, it may not be necessary to model existing roadway conditions. If a simulation model (such as CORSIM or VISSIM) is selected as the analysis tool, an existing conditions model should be developed and calibration/validation of the model may be necessary to ensure that the model's approximation of work zone capacity is realistic.

1. Model Calibration and Validation

Model calibration is the process of modifying model inputs so that the outputs match field measurements. Model validation is the process of verifying that the model outputs match field measurements. Calibration and validation may be required to ensure that the existing conditions model matches the observed existing conditions. It should be noted that model calibration and validation might not be required for some projects. If the analyst is unsure as to whether validation will be required, consult with the Office of Traffic and Safety and/or the District Traffic Engineer for a determination for the specific project. The following guidelines may be used to validate the simulation model:

- Model queue lengths should match field-measured queues within a 85% error.
- Model travel times should match field-measured travel times within 85%. Note that the travel times should be compared for the overall length of the network, and not on a link-by-link basis.
- The simulations should match field-observed bottlenecks to the analysts' satisfaction.

For a complete discussion on model calibration, see Chapter 5 of the FHWA's *Traffic Analysis Toolbox, Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* (link provided in Section VI). Once the model has been calibrated and validated, it may be used as a base model.

2. Work Zone Model Adjustments

Existing conditions should be modified to represent work zone conditions. The most important adjustment that must be made is with regards to the roadway capacity through the work zone. There are several methods of determining work zone capacity, including a conservative estimation originally published in the *Highway Capacity Manual, 1997 Update*, an equation for short term work zone capacities presented in Chapter 22 of the *Highway Capacity Manual, 2000 Update*, and an equation created by the University of Maryland. The analyst should use engineering judgment when choosing appropriate equations and work zone capacity for use in the analysis. The following three models provide some guidance on selecting work zone capacitites.

Model 1: Highway Capacity Manual, 1997 Update

Table 6 presents a conservative estimation of work zone capacities due to lane reductions, which was originally published in the *Highway Capacity Manual, 1997 Update*.

Table 6. Estimation of Work Zone Capacities *(HCM, 1997 Update)*

Number of Lanes		Work Zone Capacity	
Normal (Existing)	**Open (to traffic)**	**VPH**	**VPHPL**
3	1	1170	1170
2	1	1340	1340
5	2	2740	1370
4	2	2960	1480
3	2	2980	1490
4	3	4560	1520

Model 2: University of Maryland Capacity Equation

The University of Maryland has developed the following work zone capacity equation:

$$C_a = 1857 - 168.1N - 37L - 9HV + 92.7LD - 34.3WL - 106.1WI - 2.3WG * HV$$

where,
- C_a = adjusted mainline capacity (vphpl)
- N = number of closed lanes
- L = location of closed lanes (right side = 1, otherwise = 0)
- HV = proportion of heavy vehicles (%)
- LD = lateral distance to open lanes (feet)
- WL = work zone length (miles)
- WG = work zone grade (%)
- WI = work zone intensity (heavy = 1, light or medium = 0)

Model 3: Highway Capacity Manual, 2000 Update

For an analytical expression for work zone capacities, an analyst can refer to Chapter 22 of the *Highway Capacity Manual* (HCM)*, 2000 Update*. This chapter of the HCM presents the following expression for work zone capacity in short-term work zones:

$$C_a = (1600 + I - R) * f_{HV} * N$$

where,
- C_a = adjusted mainline capacity (vphpl)
- f_{HV} = adjustment for heavy vehicles
- I = adjustment for type, intensity, and location of work activity (-160 to +160)
- R = adjustment for ramps
- N = number of lanes

Additionally, the capacity can be reduced by 9-14% for narrow lane widths. For more information about determining the values of these factors, see Chapter 22 of the HCM.

Other adjustments to existing conditions model may include:

- Lane Configurations
  - Lane reductions may be necessary throughout the work zone.
  - When lane reductions occur through ramps, take into consideration any impacts that this may have on ramp lanes.
  - When multiple lane reductions occur, take into consideration the required buffer length between each lane reduction.
  - When lane and/or shoulder widths are reduced, the work zone capacity should be reduced accordingly.
- Traffic Volumes
  - When a detour route is being proposed, redistribute the traffic volumes in the network based on O-D data and/or engineering judgment.
  - If work zone traffic management strategies are proposed, it may be necessary to adjust traffic volumes in the work zone and the surrounding roadway network.
- Work Zone Speeds
  - Motorists may reduce speeds when traveling through the work zone due to reduced capacity, reduced shoulder/lane widths, or rubbernecking.
- Simulation Factors
  - When a simulation model is selected as the analysis tool, model factors such as bottlenecking, rubbernecking, and headway should be increased to achieve a throughput similar to the work zone capacity.

3. Analysis Methods

After the necessary work zone adjustments have been determined, it is time to begin coding the analysis model. As noted in Section B of the freeway analysis section of this guide, the three recommended analysis tools are QuickZone, Excel calculations, and CORSIM/VISSIM simulations.

a. Spreadsheet & LCAP Analysis

Spreadsheets can be used to compare demand and capacity during each time interval to determine the residual queues. This tool can be implemented either using spreadsheet software (such as Microsoft Excel) or the Lane Closure Analysis Program (LCAP), a program recently developed by the University of Maryland for the SHA, that extracted the lane closure functions from the QuickZone software. These spreadsheet methods can take as inputs: hourly traffic volumes, truck percentages, work zone length, number of existing and work zone lanes, location of closed lanes, lateral clearance, work zone intensity, work zone grade, existing capacity, and type of terrain. These inputs are used to implement any of the aforementioned capacity approximations in order to determine the estimated work zone capacity. Once the work zone capacity has been determined, the roadway capacity is compared to the demand volume during each analysis interval and the difference between them will be the change in queue length of the analysis interval. These applications will report the estimated queue length at the end of each analysis interval. Queue duration is determined by counting the number of intervals where a particular queue length exists. Using trial and error, the user can select desired lane closure hours and view the anticipated resulting queue. Based on the allowable queue length, lane closure schedules can be determined for each day of the week. This type of analysis should be performed for work zones that involve lane closures and are not influenced by ramps. A sample Microsoft Excel analysis spreadsheet is presented in **Figure 4**. **Figure 5** shows a sample output from LCAP analysis.

b. QuickZone Analysis

In addition to providing lane closure analysis in the same manner as the LCAP application, QuickZone can be used to evaluate several other work zone strategies. These work zone strategies include full or partial detours (with or without improvements to the detour route to accommodate detour traffic), multiple work zones within the limits of the study area, and changes in travel behavior (mode changes or canceled trips) due to the work zone. QuickZone can provide the analyst with estimates of queue lengths, travel times, and user delay as a result of the proposed work zone. Model outputs may be obtained either by using the program's "Delay Graph" function from the Output Data menu, which can produce graphs of several user-selected measures of effectiveness, or by using the "Closure Analysis" option from the Input Data menu.

c. CORSIM/VISSIM Simulations

CORSIM/VISSIM simulations may be used to create simulations of existing and work zone traffic conditions for complex work zone scenarios. Simulations are most beneficial when evaluating work zone operations in the vicinity of ramps or interchanges, or for evaluating detours involving freeway and arterial roadways. When creating these simulations it may be necessary to calibrate and validate the existing conditions model in order to improve the accuracy of the analysis results of work zone conditions. In order to modify the existing conditions model to represent work zone operations, it may be necessary to adjust factors in the model (such as bottlenecking, rubbernecking, and work zone speeds), adjust lane configurations (to analyze lane closures or changes to existing lane configurations), and/or adjust traffic volumes. In order to obtain outputs from these models, observations of simulations may be made (recording queue lengths and durations) or the output files made be read to determine the maximum queue lengths.

F. Analysis Procedure

Depending on the project, it may be necessary to evaluate several work zone alternatives before finding an alternative with acceptable impacts. The complete procedure for performing freeway work zone analysis is shown in the flowchart presented in **Figure 6**. Prior to performing the steps as listed, the analyst should determine the study objectives, as described in the introduction to this Guide. Examples of work zone analysis for several different site conditions and analysis tools are located in **Appendix C**. **Appendix D** contains an analysis checklist to ensure that the analysis is complete and has considered all necessary factors.

USER INPUTS:

Mitigation Measures?	No	
Percent Traffic Reduction	0%	
Percent Heavy Vehicles	10%	
Percent Passenger Cars	90%	
Length of Work Zone	1.00	Miles
Number of Closed Lanes in Work Zone	1	
Location of Closed Lanes	1	(1=Right, 0= All others)
Number of Open Lanes in Work Zone	3	
Lateral Clearance	0.00	Feet
Work Zone Intensity	0	(1= Heavy, 0=Light and Medium)
Work Zone Grade	0	%
Actual Construction End Time	8:00 AM	
Lane Capacity Without Closure	2,300	pc/hr/ln (From Exhibit 23-2, HCM 2000)
Type of Terrain	2	(1=Level, 2=Rolling, 3=Mountainous)

PROCEDURE INPUTS:

Heavy Vehicle Factor (f_{hv})	0.87	
Lane Capacity without Closure	2,000	Veh / Hr / Ln
Lane Capacity with Closure	1,528	Veh / Hr / Ln

Traffic Volumes

Begin Time	Basic Hourly Volume	Reduced Hourly Volume
3:00 AM	704	704
4:00 AM	1,425	1,425
5:00 AM	3,000	3,000
6:00 AM	4,000	4,000
7:00 AM	5,500	5,500
8:00 AM	6,000	6,000
9:00 AM	6,865	6,865
10:00 AM	5,808	5,808
11:00 AM	5,836	5,836
12:00 PM	5,752	5,752
1:00 PM	5,354	5,354
2:00 PM	5,444	5,444

Begin Time	Demand (vehp15)	Lane Capacity (pcplp15)	Scenario-1 No of lanes kept open by contractor	Total Work Zone Capacity (pcp15)	Residual 15-min Demand (veh)	Cumulative Residual 15-min Demand	Queue Length (miles)
3:00 AM	176	382	3	1,146	0	0	0.00
3:15 AM	176	382	3	1,146	0	0	0.00
3:30 AM	176	382	3	1,146	0	0	0.00
3:45 AM	176	382	3	1,146	0	0	0.00
4:00 AM	356	382	3	1,146	0	0	0.00
4:15 AM	356	382	3	1,146	0	0	0.00
4:30 AM	356	382	3	1,146	0	0	0.00
4:45 AM	356	382	3	1,146	0	0	0.00
5:00 AM	750	382	3	1,146	0	0	0.00
5:15 AM	750	382	3	1,146	0	0	0.00
5:30 AM	750	382	3	1,146	0	0	0.00
5:45 AM	750	382	3	1,146	0	0	0.00
6:00 AM	1,000	382	3	1,146	0	0	0.00
6:15 AM	1,000	382	3	1,146	0	0	0.00
6:30 AM	1,000	382	3	1,146	0	0	0.00
6:45 AM	1,000	382	3	1,146	0	0	0.00
7:00 AM	1,375	382	3	1,146	229	229	0.36
7:15 AM	1,375	382	3	1,146	229	459	0.72
7:30 AM	1,375	382	3	1,146	229	688	1.09
7:45 AM	1,375	382	3	1,146	229	917	1.45
8:00 AM	1,500	500	4	2,000	0	417	0.66
8:15 AM	1,500	500	4	2,000	0	0	0.00
8:30 AM	1,500	500	4	2,000	0	0	0.00
8:45 AM	1,500	500	4	2,000	0	0	0.00
9:00 AM	1,716	500	4	2,000	0	0	0.00
9:15 AM	1,716	500	4	2,000	0	0	0.00
9:30 AM	1,716	500	4	2,000	0	0	0.00
9:45 AM	1,716	500	4	2,000	0	0	0.00
10:00 AM	1,452	500	4	2,000	0	0	0.00
10:15 AM	1,452	500	4	2,000	0	0	0.00
10:30 AM	1,452	500	4	2,000	0	0	0.00
10:45 AM	1,452	500	4	2,000	0	0	0.00
11:00 AM	1,459	500	4	2,000	0	0	0.00
11:15 AM	1,459	500	4	2,000	0	0	0.00
11:30 AM	1,459	500	4	2,000	0	0	0.00
11:45 AM	1,459	500	4	2,000	0	0	0.00
12:00 PM	1,438	500	4	2,000	0	0	0.00
12:15 PM	1,438	500	4	2,000	0	0	0.00
12:30 PM	1,438	500	4	2,000	0	0	0.00
12:45 PM	1,438	500	4	2,000	0	0	0.00
1:00 PM	1,339	500	4	2,000	0	0	0.00
1:15 PM	1,339	500	4	2,000	0	0	0.00
1:30 PM	1,339	500	4	2,000	0	0	0.00
1:45 PM	1,339	500	4	2,000	0	0	0.00
2:00 PM	1,361	500	4	2,000	0	0	0.00
2:15 PM	1,361	500	4	2,000	0	0	0.00
2:30 PM	1,361	500	4	2,000	0	0	0.00
2:45 PM	1,361	500	4	2,000	0	0	0.00

Figure 4. Sample Excel Calculation

Project: I-95 Resurfacing - Howard County (Columbia Area)
Analyst:
Date: 04/01/2007

Start Time	End Time	Base Demand	Approach Volume	Roadway Volume	Vehicles In Queue	Queue Length (Miles)	Workzone Up
Sat-14:00	Sat-15:00	5383	5383	5383	0	0.00	
Sat-15:00	Sat-16:00	6408	6408	6408	0	0.00	
Sat-16:00	Sat-17:00	6256	6256	6256	0	0.00	
Sat-17:00	Sat-18:00	5955	5955	5955	0	0.00	
Sat-18:00	Sat-19:00	5510	5510	5510	0	0.00	
Sat-19:00	Sat-20:00	4747	4747	4747	0	0.00	
Sat-20:00	Sat-21:00	4643	4643	4643	0	0.00	
Sat-21:00	Sat-22:00	4287	4287	4287	0	0.00	
Sat-22:00	Sat-23:00	3127	3127	3127	0	0.00	
Sat-23:00	Sun-0:00	2751	2751	2751	0	0.00	
Sun-0:00	Sun-1:00	1673	1260	1673	413	0.54	X
Sun-1:00	Sun-2:00	1141	1260	1554	294	0.39	X
Sun-2:00	Sun-3:00	757	1051	1051	0	0.00	X
Sun-3:00	Sun-4:00	658	658	658	0	0.00	X
Sun-4:00	Sun-5:00	563	563	563	0	0.00	X
Sun-5:00	Sun-6:00	799	799	799	0	0.00	X
Sun-6:00	Sun-7:00	1361	1260	1361	101	0.13	X
Sun-7:00	Sun-8:00	2032	2133	2133	0	0.00	
Sun-8:00	Sun-9:00	2755	2755	2755	0	0.00	
Sun-9:00	Sun-10:00	3590	3590	3590	0	0.00	
Sun-10:00	Sun-11:00	4949	4949	4949	0	0.00	
Sun-11:00	Sun-12:00	5848	5848	5848	0	0.00	
Sun-12:00	Sun-13:00	6702	6702	6702	0	0.00	
Sun-13:00	Sun-14:00	6593	6593	6593	0	0.00	
Sun-14:00	Sun-15:00	6344	6344	6344	0	0.00	
Sun-15:00	Sun-16:00	6017	6017	6017	0	0.00	
Sun-16:00	Sun-17:00	5845	5845	5845	0	0.00	

Figure 5. Sample LCAP Output

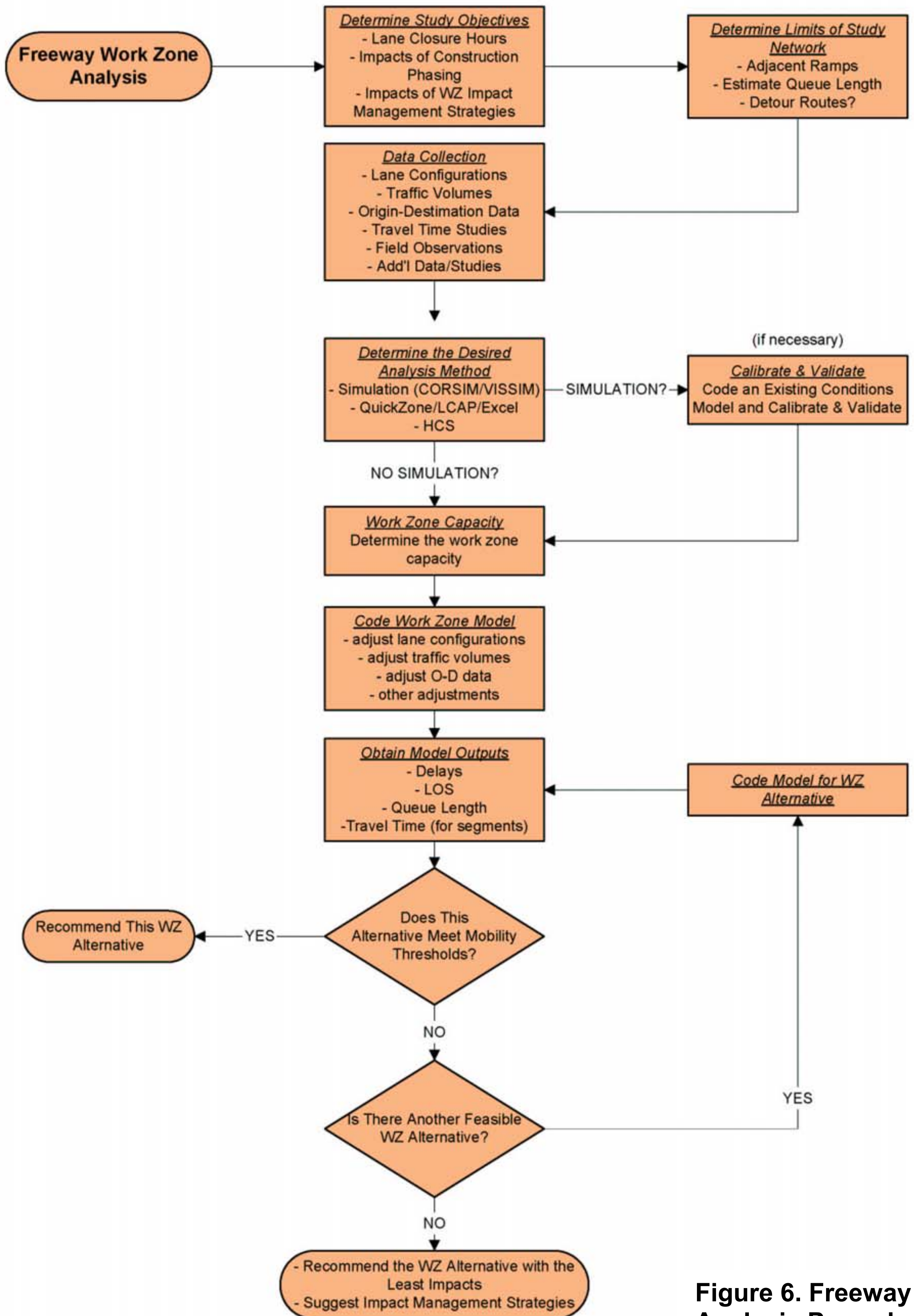


Figure 6. Freeway Analysis Procedure

1. Determine the Limits of the Study Network.
Follow the guidelines presented in Section C of the freeway analysis section of this guide for determining the adjacent ramps to be included in the analysis and what, if any, detour routes should be included in the model. This step should also include determining the objective of the analysis.

2. Data Collection.
Follow the guidelines presented in Section D of the freeway analysis section of this guide for the collection of all necessary data including obtaining existing lane configurations, traffic volumes, field observations, and any other necessary information.

3. Determine the Analysis Method.
Follow the guidelines presented in Section E of the freeway analysis section of this guide for determining the analysis method, based on the characteristics of the study network and the objective(s) of the analysis. It may be necessary to perform traffic analysis of existing conditions for all analysis methods in order to have a baseline that the work zone conditions can be compared to. If a simulation method is selected, code an existing conditions model. After the existing model has been coded, it may be necessary to calibrate the model and validate that the model reflects existing conditions, as described in Section E of this guide. After the model has been calibrated and validated, proceed to the next step.

4. Modeling – Code Work Zone Model.
If an existing conditions model was created, modify the existing conditions to reflect work zone conditions. Modifications will often include changing lane configurations, roadway capacity, traffic volumes (if volume redistribution is required), and/or origin-destination data. If an existing conditions model has not been created, perform analysis, as described in Section E of the freeway analysis section of this guide.

5. Modeling – Obtain Model Outputs.
Depending on the analysis tool used, the method of extracting model outputs will differ. For the work zone model, determine the length and duration of queues. Impacts on the surrounding network should also be identified.

6. Determine if the Alternative Meets the Mobility Thresholds.
Compare the outputs obtained in step 5 with the mobility thresholds presented in Section A of the freeway analysis section of this guide. If the alternative satisfies the thresholds, proceed to step 7 and recommend this alternative, unless the model showed detrimental operational impacts (such as queuing through interchanges or onto arterials, unsafe weaves or merges, and insufficient ramp capacities) that were not captured in the evaluation of the mobility thresholds. If there were other operational impacts, consider using work zone management strategies, such as alternative temporary traffic control strategies, work zone ITS, or demand management to minimize the impacts. Refer to SHA's *TMP Guidelines* for more information on work zone impact management strategies. Where other operational impacts are observed, determine whether or not there are any other work zone alternatives that have not yet been considered. If there are no

other feasible alternatives, proceed to step 7. If there is another alternative, repeat steps 4 and 5 for the next alternative.

7. Recommend an Alternative.

If the alternative evaluated in Step 6 meets all relevant mobility thresholds, this alternative can be recommended. If all possible work zone alternatives have been exhausted and no alternative meets the mobility thresholds, use engineering judgment to make a recommendation, and the Chief Engineer will be responsible for determining if the impacts are acceptable. Ideally, the recommendation will be the alternative with the least mobility impacts; however, other factors should be considered before selecting an alternative, such as construction cost and duration, worker safety, constructability, environmental impacts, etc. The recommendation should include a detailed explanation of the selected work zone alternative, including lane closure schedules and any proposed work zone management strategies.

V. Network Work Zone Analysis

For the analysis of work zones that will impact both arterial and freeway systems, mobility thresholds for both roadway types should be evaluated. For work zone analysis in these networks, analysis can either be performed by creating a simulation model that includes all network facilities or by performing separate analyses for the arterial and freeway facilities. The strengths and weaknesses of using both of these two analysis alternatives are presented in **Table 7**.

Table 7. Traffic Analysis Tools for SHA Network Work Zone Analysis

Traffic Analysis Tool	Strengths	Weaknesses
Single Simulation Model for Entire Network	- Considers the cumulative impacts for work zone operations throughout the network	- Simulation model does not provide the necessary outputs for arterial work zone analysis - Calibration of the model may be difficult and time-consuming
Separate Freeway and Arterial Analysis Models	- Ease of use - Able to obtain the appropriate model outputs for both freeway and arterial work zone analysis	- Does not consider the cumulative impacts of work zone operations throughout the network

In situations where SHA's allowable mobility thresholds cannot be applied, mobility impacts should be examined in detail and engineering judgment should be used to determine whether the levels of anticipated work zone delay/congestion will be acceptable. In these situations, model results should always be discussed with a District Traffic Engineer before a work zone alternative is selected.

VI. ANALYSIS REPORT STRUCTURE

After evaluating all feasible alternatives for work zone configurations and potential mitigation measures, the results of the study should be summarized in a report and submitted to the SHA. The report shall present the justification for the selection of the optimal work zone solution. The following is the recommended information for inclusion in the report.

A. Introduction

The introduction of the analysis report should include background information regarding the project and study area.

1. Project Area

This section of the report should include information about the location of the project and the limits of work. Information about the existing lane widths and configurations, traffic control at intersections, speed limits, grade, roadway classification, pedestrian and bicycle facilities, sight distance limitations, and nearby roadways and businesses should also be included. Include an area map showing the study limits and any other nearby roadways that may be affected by the project. Also include any other background information (such as stakeholder concerns) that could be relevant to the study, and the study objective that was identified prior to performing the analysis.

2. Project Description

This section of the report should include information about the project. It should include a description of the project type, the proposed changes (geometric, traffic control, etc.), and any potential work zone impacts (right-of-way, utilities, etc.). Consider including concept plans showing the proposed improvements.

3. Project Constraints

This section of the report should include constraints, such as project timing, stakeholder concerns, other related projects, or traffic volumes in or around the work area. If there is more than one construction phase, include which constraint is impacted by each construction phase.

B. Data Collection

This section of the report should include information about data used in the analysis. Include whether existing data was used or new data was collected. Also include when and how the data was collected, the type of data collected, and a summary of the data. If adjustment factors, such as growth factors, seasonal adjustments, or day of week factors, were applied to traffic volumes, include this information.

C. Existing Conditions

In this section of the report, include a description of existing conditions, including existing traffic operations (intersection controls, signal timings/phasing), accident history, a summary of the data collected (can be presented in a table, figure, or graph). Printouts of traffic volumes, etc. can be included in an appendix.

D. Future Conditions

This section may or may not be necessary for inclusion in the report. Include discussion of any proposed businesses, developments, or construction projects in this area. This section should discuss the nature of the expected future changes and how these changes will affect the study area. For instance, if construction of a grocery store is proposed to be completed either before or during construction of the study project, this should be mentioned and the potential impacts on that store should also be considered. Additionally, if traffic volumes are expected to increase prior to the completion of the construction project, this should be presented and these volumes should be included in the analysis of work zone alternatives. Include growth factors used to determine construction year volumes.

E. Alternatives Considered

In this section of the report, present the proposed sequence of construction and the work zone alternatives that were considered for each construction phase. This should be a detailed description that includes any assumptions that were made and the existing lanes or directions of traffic that will be affected by the work zone. If a detour is considered, include information about the proposed alternate route and the type of signing that will be used. This section should also include a justification for why other alternatives were not considered. Also include the criteria that were used to determine suitable alternatives (existing traffic volumes, safety concerns, stakeholder concerns, existing geometrics, etc.). For clarity, concept plans for each proposed alternative, including lane use arrows, the locations of traffic signals, and typical sections may be included.

F. Alternatives Analysis

This section of the report should include the results of the analysis of each alternative considered. The analysis method(s) should be described and a summary of the analysis results, advantages and disadvantages of each alternative should be included. The description of the analysis method(s) should include information on how the expected work zone traffic volumes and conditions were determined, the measures of effectiveness that were used to analyze each alternative, and how the analysis tools were selected. The results from a comparison analysis should be presented along with a recommendation as to the preferred work zone alternative. This section may also include any work zone impact management strategies considered. Refer to SHA's *TMP Guidelines* for more details on work zone impact management. Work zone impact management strategies may include:

- Temporary traffic control strategies
- Demand management
- Work zone ITS
- Corridor/Network management
- Safety strategies

At the conclusion of this section, include a table summarizing the results of the analysis for each alternative, advantages and disadvantages of each alternative, and any other factors that impacted the determination of the preferred alternative. Other factors may include:

- Cost (construction and/or user)
- Duration of construction
- Service life
- Impacts on access
- Impacts on emergency services
- Impacts on pedestrians/bicyclists
- Impacts to buses/transit

G. Recommendations

This section of the report should include a summary of the analyses performed should conclude with a description of the recommended combination of work zone strategies, and impact management measures. This section could also include any information about holiday, weekend, or special event restrictions. This section may also include a recommended lane closure schedule.

VII. REFERENCE MATERIALS

- *Work Zone Safety and Mobility Policy* by MD SHA
- *Maryland Manual on Uniform Traffic Control Devices* (MD MUTCD) by MD SHA
- *Developing and Implementing Transportation Management Plans for Work Zones* by the FHWA
- *Traffic Management in Work Zones: Interstate and Other Freeways* by Ohio D.O.T.
- *Guidance on Conducting a Maintenance of Traffic Alternative Analysis (MOTAA)* by MD SHA
- *Temporary Traffic Control Typical Applications (TTCTA)* by MD SHA
- *Manual of Transportation Engineering Studies* by the Institute of Transportation Engineers (ITE)
- *Transportation Management Plans: Guidelines for Development, Implementation and Evaluation* by MD SHA

VIII. RELEVANT LINKS

- SHA's Signal Plan Locator
  - http://marylandroads.com/SHAServices/SignalPlanLocator/Index.asp
- SHA's Traffic Count Database
  - http://marylandroads.com/tmsreports/
- SHA's Traffic Trends Report
  - http://www.marylandroads.com/traffictrends2/
- SHA's Highway Location Reference
  - http://www.marylandroads.com/keepingcurrent/performTrafficStudies/dataAndStats/hwyLocationRef/oppe/hlr.asp
- SHA's Book of Standards for Highway & Incidental Structures
  - http://www.marylandroads.com/BusinessWithSHA/bizStdsSpecs/desManualStdPub/publicationsonline/ohd/bookstd/index.asp
- FHWA's Traffic Analysis Toolbox
  - http://ops.fhwa.dot.gov/trafficanalysistools/toolbox.htm
- Maryland Manual on Uniform Traffic Control Devices (MdMUTCD)
  - http://marylandroads.com/businesswithsha/bizStdsSpecs/desManualStdPub/publicationsonline/oots/mmutcd/mmutcd.asp
- SHA's Work Zone Traffic Control Website
  - http://marylandroads.com/safety/workzone.asp
- FHWA's Work Zone Safety and Mobility Program Website
  - http://ops.fhwa.dot.gov/wz/index.asp

APPENDIX A – ARTERIAL WORK ZONE ANALYSIS EXAMPLES

APPENDIX A: ARTERIAL WORK ZONE ANALYSIS EXAMPLES

To illustrate the application of the analysis steps presented in this Guide, several examples have been developed. Each example represents the analysis procedures for different site conditions and includes explanations of the analysis process and, where necessary, the process of developing additional alternatives. The site conditions evaluated are as follows:

Example	Objective
A. Unsignalized Isolated Intersection with Single Lane Approaches	Determine Phasing and Allowable Flagging Hours
B. Unsignalized Isolated Intersection with Multiple Lane Approaches	Determine Allowable Lane Closure Type and Duration
C. Unsignalized Arterial	Determine Number of Construction Phases
D. Single Lane Roundabout[1]	Detour/Network Impacts
E. Multiple Lane Roundabout[1]	Detour/Network Impacts
F. Signalized Isolated Intersection with Single Lane Approaches	Determine Phasing and Allowable Flagging Hours
G. Signalized Isolated Intersection with Multiple Lane Approaches	Determine Allowable Lane Closure Type and Duration
H. Signalized Arterial	Determine Allowable Lane Closure Type and Duration
I. Arterial Segment (Two-Lane, Two-Way Roadway) – Flagging Operations	Determine Phasing and Allowable Flagging Hours
J. Arterial Segment (Two-Lane, Two-Way Roadway) – Full Detour	Network Impacts from Full Closure and Possible Mitigation Measures
K. Arterial Segment (Multiple Lane Approaches)[1]	See Freeway Analysis Section

1. No detailed example is provided for this scenario

A. Unsignalized Isolated Intersection with Single Lane Approaches

Work zones that impact unsignalized isolated intersections with single lane approaches generally require the use of flaggers on all affected approaches to facilitate the movement of traffic through and around the work zone. To illustrate the type of analysis required for such a work zone, an example work zone was developed at the intersection of MD 144 (Frederick Road) at Dutton Avenue in Catonsville, Baltimore County. For this example, full-depth reconstruction of the intersection and approaches was proposed. The complete example is included.

B. Unsignalized Isolated Intersection with Multiple Lane Approaches

Work zone that impact unsignalized isolated intersections with multiple lane approaches may require lane reductions on one of more approaches and/or flagging operations when work is being performed in the middle of the intersection or when the work impacts a single lane approach. To illustrate the type of analysis required for lane reductions approaching the intersection, an example work zone was developed at the intersection of US 1 (Washington Boulevard) at Old Washington Road in Elkridge, Howard County. For this example, the extension of Old Washington Road through the intersection (changing the intersection from three legs to four legs) was proposed. This work required the closure of one mainline lane to perform the tie-in and construction of a right turn storage lane. The complete example is included.

C. Unsignalized Arterial

Work zones along unsignalized arterials generally required lane reductions on the arterial that may be accompanied by lane closures on side streets. It should be noted that work zone analysis along arterial sections should take into consideration the impacts of the work zone on upstream intersections. To illustrate the type of analysis required for lane closures along the arterial, an example work zone was developed along Columbia Gateway Drive in Columbia, Howard County. For this example, the removal of the existing median and full-depth reconstruction of all lanes between two intersections was proposed. This example focuses on determining a sequence of construction that meets mobility thresholds. The complete example is included.

D. Single Lane Roundabout

When evaluating work zones that impact single lane roundabouts, the two main work zone alternatives are to (1) institute a full or partial detour or (2) use flaggers at the roundabout and permit vehicles to travel the "wrong" way around the roundabout. If the desired alternative is to institute a full or partial detour, redistribute volumes to other roadways and perform analysis. For more on volume redistribution, see the example for Arterial Segment (Two-Lane, Two-Way Roadway) – Full Detour. If the desired alternative is to use flagging at the intersection while permitting vehicles to travel the "wrong" way around the roundabout to avoid to the work area, perform the analysis in Synchro using a traffic signal to represent flagging operations. For more on analyzing an unsignalized intersection under flagging operations modeled as a traffic signal, refer to the example for Unsignalized Isolated Intersection with Single Lane Approaches.

E. Multiple Lane Roundabout

When evaluating work zones that impact multiple lane roundabouts, the main work zone alternatives include (1) reducing the number of lane in the roundabout, institute a full or partial detour and (2) using flaggers at the roundabout and permitting vehicles to travel the "wrong" way around the roundabout. If the desired work zone alternative is to reduce the number of lanes in the roundabout, perform Sidra analysis of the roundabout with the modified lane configurations. Note that the Office of Traffic and Safety has guidelines for the setup of Sidra models. Contact the Traffic Safety Analysis Division for further details. If either of the other two alternatives is desired, refer to the Single Lane Roundabout section of this appendix for more details.

F. Signalized Isolated Intersection with Single Lane Approaches

Work zones that impact signalized isolated intersections with single lane approaches generally require the use of flaggers on all approaches to facilitate the movement of traffic through and around the work zone. To illustrate the type of analysis required for such a work zone, an example work zone was developed at the intersection of MD 26 (Liberty Road) at Wards Chapel Road in Randallstown, Baltimore County. For this example, a Fund 87 improvement involving the widening of MD 26 through the intersection was proposed, and the analysis focused on the use of flaggers to perform the intersection reconstruction. The complete example is included.

G. Signalized Isolated Intersection with Multiple Lane Approaches

Work zones that impact signalized isolated intersections with multiple lane approaches may require lane reductions on one or more approaches and/or flagging operations when work is being performed in the middle of the intersection or when the work impacts a single lane approach. To illustrate the type of analysis required for lane reductions approaching the intersection, an example work zone was developed at the intersection of MD 940 (Owings Mills Boulevard) at Red Run Boulevard in Owings Mills, Baltimore County. For this example, the reconstruction of an existing median to provide an additional left turn storage lane was proposed. The analysis for this example focuses on determining the lane closure schedule. The complete example is included.

H. Signalized Arterial

Work zones along signalized arterials generally required lane reductions on the arterial that may be accompanied by lane closures on side streets. It should be noted that work zone analysis along arterial sections should take into consideration the impacts of the work zone on upstream intersections. To illustrate the type of analysis required for lane closures along the arterial, an example work zone was developed along Shady Grove Road in Rockville, Montgomery County. For this example, a sidewalk reconstruction between two intersections was proposed, requiring the closure of one adjacent lane during work hours. This example focused on determining the lane closure schedule considering the impact of the work zone queue on upstream intersections. The complete example is included.

I. Arterial Segment (Two-Lane, Two-Way Roadway) – Flagging Operations

For work zones on two-lane, two-way arterials where detours are unfeasible, there are two types of available work zone configurations. The first type of work zone configuration involves redirecting traffic by shifting the travel lanes onto the existing shoulder or onto temporary pavement. This work zone alternative is beneficial if the existing shoulder is traffic bearing or if there is enough clear space adjacent to the existing roadway to permit the installation of temporary pavement. If a lane shift is the desired alternative, work zone traffic analysis can be performed by adjusting lane widths and/or saturation flow rates for work zone conditions. Due to the simple nature of this analysis, no example was developed for this configuration.

The second work zone alternative for this configuration is to use flaggers (or temporary traffic signals) on either end of the work zone. To illustrate the type of analysis required for the use of flaggers approaching the work zone, an example work zone was developed on the MD 23 (East West Highway) bridge over Morse Road in Forest Hill, Harford County. The proposed work for this example was a bridge reconstruction, requiring the reduction of the bridge to a one-lane, two-way bridge. For this example, no detour routes were available, so the use of flaggers or traffic signals at either end of the bridge was considered. The complete example is included.

J. Arterial Segment (Two-Lane, Two-Way Roadway) – Full Detour

Work zones along two-lane, two-way arterial segments may also involve full or partial detours of existing traffic. To illustrate to type of analysis required for a full detour, an example work zone was developed on the Grosvenor Lane bridge over I-270 in North Bethesda, Montgomery County. For this example, a bridge reconstruction project required the complete closure of the existing bridge for the duration of the project. A detour route was identified and traffic volumes were redistributed throughout the study network. The complete example is included.

K. Arterial Segment (Multiple Lane Approaches)

Analysis of this type of site can generally be performed using freeway work zone analysis techniques. Generally, for such a project, lanes will be reduced in one or both directions of the roadway while maintaining at least one lane in each direction. Analysis of these conditions can be performed using freeway analysis techniques and by using the freeway work zone mobility thresholds. Refer to the Freeway Work Zone Analysis Guide for more information.

EXAMPLE A: UNSIGNALIZED INTERSECTION WITH SINGLE LANE APPROACHES
MD 144 (FREDERICK ROAD) AT DUTTON AVENUE

SITE DESCRIPTION:

MD 144 (Frederick Road) and Dutton Avenue are two-lane, two way undivided roadways. MD 144 runs in an east-west direction, and Dutton Avenue runs in a north-south direction. The nearest intersection is the unsignalized intersection of MD 144 and Overhill Road, approximately 450 feet to the east of the study intersection. **Figure 1** shows an area map of the study location.

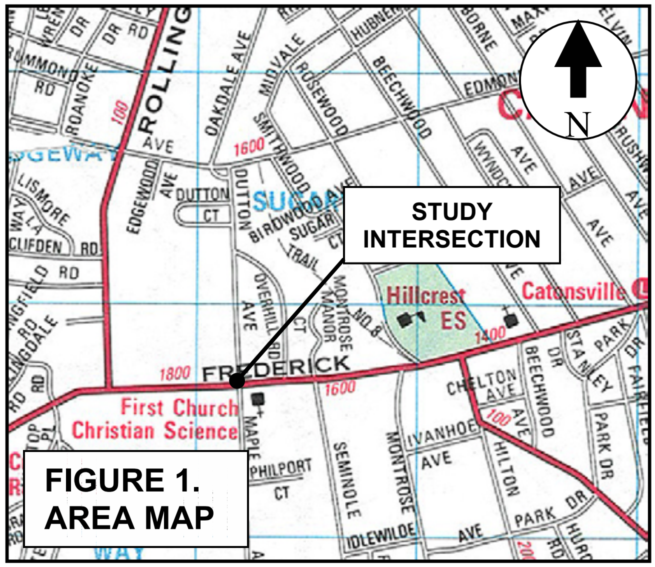


FIGURE 1.
AREA MAP

OBJECTIVE:

Full-depth reconstruction of the intersection is proposed, including the reconstruction of the northbound and southbound approaches. It is anticipated that this work will be accomplished by reconstructing one approach at a time. The objectives of this analysis are to (1) determine if the reconstruction of the intersection can be performed under flagging operations, or if a detour must be used, and (2) if flagging operations are suitable, during what periods of the day flagging may be used.

ANALYSIS:

1. **Determine the Limits of the Study Network.** The first step in determining the limits of the study network is to estimate the work zone queue length. Given the nature of the work to be completed, it is anticipated that the greatest impacts to traffic flow through and around the intersection will occur during the reconstruction of the intersection itself. During this stage of construction, it is expected that the intersection would operate under flagging, which would be comparable to a four-way stop control intersection. For the purposes of estimating the work zone queue length, it will be assumed that the intersection will operate under four-way split phasing and the equation presented in Section II.C of this Guide was used to approximate the resulting queue. It was assumed that the "cycle length" would be 180 seconds with 5-second clearance intervals (yellow plus all-red time) for each approach, and that green time would be allocated to each approach based on the proportion of the total intersection volume attributable to each approach. Additionally, with knowledge of current intersection operations during AM and PM peaks, it was assumed that work would be restricted to off-peak hours (either midday or overnight). **Table 1** summarizes the signal timing assumptions, approach traffic volumes, and estimated queue lengths for the Midday peak hour.

Table 1. Summary of Queue Length Approximations – Midday Peak

Approach	Approach Volume (vph)	Thru Green (sec.)	Cycle Length (sec.)	Est. Queue Length	
				# veh	feet*
Eastbound	764	90	180	19	475
Westbound	542	60	180	9	225
Northbound	14	5	180	1	25
Southbound	41	5	180	1	25

* Average vehicle length of 25 feet assumed.

Based on the results presented in the table, the work zone queue is expected to extend, at most, 475' west of the intersection and 225' east of the intersection. Therefore, it will not be necessary to include other intersections in the study network. Because there are no nearby parallel routes, a detour is not feasible. Therefore, no detour routes need to be included in the study network.

2. **Data Collection.** In order to determine the limits of the study network, it was necessary to begin collecting data for the study intersection. No recent turning movement counts were available, so a new count was performed at the intersection from 6 AM to 7 PM (13-hour count). A field study was performed to verify lane configurations.

3. **Modeling – Existing Conditions.** There were no existing Synchro models, so a new model was coded using the data that was collected. Because this alternative involves off-peak work, midday peak hour (highest one-hour volume between 9AM and 3PM) traffic volumes were used for the existing conditions model.

4. **Modeling – Calibration and Validation.** Due to the low volumes at the intersection, especially on the minor street approaches, it was assumed that model calibration was unnecessary.

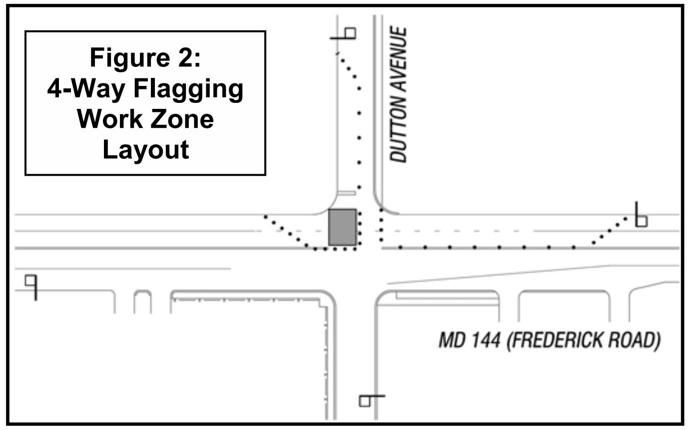
5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignalized* report was printed for the study intersection. **Table 2** summarizes the control delay and level of service. It should be noted that Synchro does not give HCM-based levels of service for two-way stop control intersections, and therefore it is necessary to refer to the HCM to determine the intersection level of service based on the control delay obtained from Synchro. SimTraffic simulations were not performed because this example involves an isolated intersection and Synchro will be sufficient to evaluate the mobility thresholds. The Synchro report for the existing conditions model is provided at the conclusion of this example.

Table 2. Synchro Model Outputs – Existing Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
MD 144 at Dutton Avenue	3.2	A

6. **Modeling – Code Work Zone Model.** The existing conditions model was modified to have all-way stop control. Because flagging operations will be used at this unsignalized intersection, it will not be necessary or possible to consider the buffer and/or taper lengths in

the Synchro model. **Figure 2** shows the assumed work zone lane configurations at the intersection. It was assumed that there would be no changes in O-D data or in the traffic volumes.



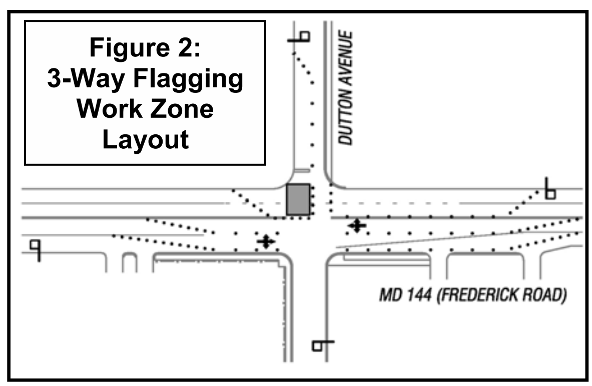
7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignalized* report was printed for the study intersection. **Table 3** summarizes the control delay and level of service for work zone conditions. The Synchro report for this model is presented at the conclusion of this example.

Table 3. Synchro Model Outputs – Work Zone Conditions – Midday

Intersection	Control Delay (sec.)	Level of Service
MD 144 at Dutton Avenue	*144.9*	*F*

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 2 and 3, the proposed alternative will not meet the mobility thresholds for unsignalized intersections (maximum LOS D with control delay of 30 seconds). Looking at the control delays by approach, it appears that this alternative operates at LOS F primarily due to the fact that the major street approaches are not permitted to operate concurrently. Therefore, the next alternative to be evaluated was to modify the lane configurations to permit eastbound and westbound approaches to operate concurrently.

6. **Modeling – Code Alternate Work Zone Model.** For this alternative, it was assumed that eastbound and westbound approaches would be changed to each have one shared left-through-right lane and that these lanes would be shifted throughout construction to permit these approaches to operate concurrently. **Figure 3** shows the assumed work zone lane configurations for this alternative. Due to the intended flagging operations at the study intersection, this alternative was modeled by changing the control of the intersection to actuated-uncoordinated signal control with split phasing for the minor street approaches to represent the intended flagging operations. To represent the additional time necessary to traverse the work zone and buffer and taper lengths, the all red timing for the model was adjusted. It was assumed that motorists would be traveling through the work zone at reduced speeds (approximately 25 mph) due to flagging operations, and therefore a buffer length of approximately 150' would be necessary. This assumption was used, in conjunction with SHA's *Policy for Determining Yellow Timings at Intersections* and the Institute of



Transportation Engineers (ITE's) *Traffic Signal Design Handbook*, to approximate a necessary all-red time of 12 seconds for each approach. For details on how clearance intervals are calculated, refer to Example I: Arterial Segment (Two-Lane, Two-Way Roadway)-Flagging.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* report was printed for this alternative. **Table 4** summarizes the control delay and level of service. The Synchro report for this model is presented at the conclusion of this example.

Table 4. Synchro Model Outputs – Modified Work Zone Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
MD 144 at Dutton Avenue	22.2	C

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 2 and 4, the control delay is less than the mobility threshold of a maximum LOS D and control delay of 30 seconds, thus satisfying the requirements.

9. **Recommend an Alternative.** Based on the results of this study, flagging operations will work at this intersection during the midday hours, but only if lanes on MD 144 are shifted so as to permit the eastbound and westbound approaches to be flagged concurrently. A review of the traffic volumes at the intersection indicates that traffic volumes at the intersection between the hours of 9 AM and 3 PM are at or below the volumes used for this analysis. Therefore, flagging operations are suitable at this intersection between 9 AM and 3 PM. **Table 5** summarizes the recommended work zone alternative.

Table 5. Recommended Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Perform reconstruction in the intersection using flagging operations on all approaches, permitting concurrent EB/WB movements	Monday-Friday: 9 AM to 3 PM

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Free			Free			Stop			Stop	
Grade		0%			2%			0%			0%	
Volume (veh/h)	26	738	0	3	510	28	8	2	4	12	0	29
Peak Hour Factor	0.65	0.82	0.33	0.75	0.85	0.64	0.50	0.50	0.50	0.50	1.00	0.66
Hourly flow rate (vph)	40	900	0	4	600	44	16	4	8	24	0	44
Pedestrians												
Lane Width (ft)												
Walking Speed (ft/s)												
Percent Blockage												
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	644			900			1632	1632	900	1598	1588	600
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	644			900			1632	1632	900	1598	1588	600
tC, single (s)	4.1			4.1			7.1	6.5	6.2	7.1	6.5	6.2
tC, 2 stage (s)												
tF (s)	2.2			2.2			3.5	4.0	3.3	3.5	4.0	3.3
p0 queue free %	96			99			78	96	98	70	100	91
cM capacity (veh/h)	941			763			72	98	340	79	104	505

Direction, Lane #	EB 1	EB 2	WB 1	WB 2	NB 1	SB 1
Volume Total	940	0	604	44	28	68
Volume Left	40	0	4	0	16	24
Volume Right	0	0	0	44	8	44
cSH	941	1700	763	1700	98	174
Volume to Capacity	0.04	0.00	0.01	0.03	0.29	0.39
Queue Length 95th (ft)	3	0	0	0	27	43
Control Delay (s)	1.2	0.0	0.1	0.0	55.9	38.4
Lane LOS	A		A		F	E
Approach Delay (s)	1.2		0.1		55.9	38.4
Approach LOS					F	E

Intersection Summary			
Average Delay	3.2		
Intersection Capacity Utilization	69.9%	ICU Level of Service	C
Analysis Period (min)	15		

Control Delay

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Stop			Stop			Stop			Stop	
Volume (vph)	26	738	0	3	510	28	8	2	4	12	0	29
Peak Hour Factor	0.65	0.82	0.33	0.75	0.85	0.64	0.50	0.50	0.50	0.50	1.00	0.66
Hourly flow rate (vph)	40	900	0	4	600	44	16	4	8	24	0	44

Direction, Lane #	EB 1	EB 2	WB 1	WB 2	NB 1	SB 1
Volume Total (vph)	940	0	604	44	28	68
Volume Left (vph)	40	0	4	0	16	24
Volume Right (vph)	0	0	0	44	8	44
Hadj (s)	0.10	0.00	0.09	-0.67	-0.06	-0.32
Departure Headway (s)	5.6	5.5	5.5	4.8	7.1	6.7
Degree Utilization, x	1.46	0.00	0.93	0.06	0.06	0.13
Capacity (veh/h)	638	656	644	740	484	513
Control Delay (s)	231.2	7.3	42.1	6.9	10.5	10.6
Approach Delay (s)	231.2		39.7		10.5	10.6
Approach LOS	F		E		B	B

Intersection Summary			
Delay	144.9		
HCM Level of Service	F		
Intersection Capacity Utilization	69.9%	ICU Level of Service	C
Analysis Period (min)	15		

Control Delay

Level of Service

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Grade (%)		0%			2%			0%			0%	
Total Lost time (s)		4.0			4.0			4.0			4.0	
Lane Util. Factor		1.00			1.00			1.00			1.00	
Frt		1.00			0.99			0.96			0.91	
Flt Protected		1.00			1.00			0.97			0.98	
Satd. Flow (prot)		1808			1778			1776			1704	
Flt Permitted		0.95			0.99			0.97			0.98	
Satd. Flow (perm)		1722			1768			1776			1704	
Volume (vph)	26	738	0	3	510	28	8	2	4	12	0	29
Peak-hour factor, PHF	0.65	0.82	0.33	0.75	0.85	0.64	0.50	0.50	0.50	0.50	1.00	0.66
Adj. Flow (vph)	40	900	0	4	600	44	16	4	8	24	0	44
RTOR Reduction (vph)	0	0	0	0	1	0	0	7	0	0	38	0
Lane Group Flow (vph)	0	940	0	0	647	0	0	21	0	0	30	0
Heavy Vehicles (%)	2%	5%	0%	0%	5%	2%	0%	0%	0%	0%	0%	0%
Turn Type	Perm			Perm			Split			Split		
Protected Phases		4			8		2	2		6	6	
Permitted Phases	4			8								
Actuated Green, G (s)		66.5			66.5			4.2			6.0	
Effective Green, g (s)		78.0			78.0			15.7			17.5	
Actuated g/C Ratio		0.63			0.63			0.13			0.14	
Clearance Time (s)		15.5			15.5			15.5			15.5	
Vehicle Extension (s)		3.0			3.0			3.0			3.0	
Lane Grp Cap (vph)		1090			1119			226			242	
v/s Ratio Prot								c0.01			c0.02	
v/s Ratio Perm		c0.55			0.37							
v/c Ratio		0.86			0.58			0.09			0.12	
Uniform Delay, d1		18.3			13.1			47.5			46.2	
Progression Factor		1.00			1.00			1.00			1.00	
Incremental Delay, d2		7.2			0.7			0.2			0.2	
Delay (s)		25.5			13.8			47.6			46.4	
Level of Service		C			B			D			D	
Approach Delay (s)		25.5			13.8			47.6			46.4	
Approach LOS		C			B			D			D	

Intersection Summary			
HCM Average Control Delay	22.2	HCM Level of Service	C
HCM Volume to Capacity ratio	0.64		
Actuated Cycle Length (s)	123.2	Sum of lost time (s)	12.0
Intersection Capacity Utilization	67.0%	ICU Level of Service	C
Analysis Period (min)	15		
c Critical Lane Group			

Control Delay **Level of Service**

EXAMPLE B: UNSIGNALIZED INTERSECTION WITH MULTIPLE LANE APPROACHES US 1 (WASHINGTON BOULEVARD) AT OLD WASHINGTON ROAD

SITE DESCRIPTION:

US 1 (Washington Boulevard) is a four-lane, two-way, undivided roadway with a center two-way left turn lane that runs in a north-south direction and Old Washington Road is a two-lane, two-way undivided roadway that runs east from the intersection. The nearest intersection is at US 1 and Brumbaugh Avenue, approximately 800' feet north of the study intersection. **Figure 1** shows an area map and sketch of the study location.

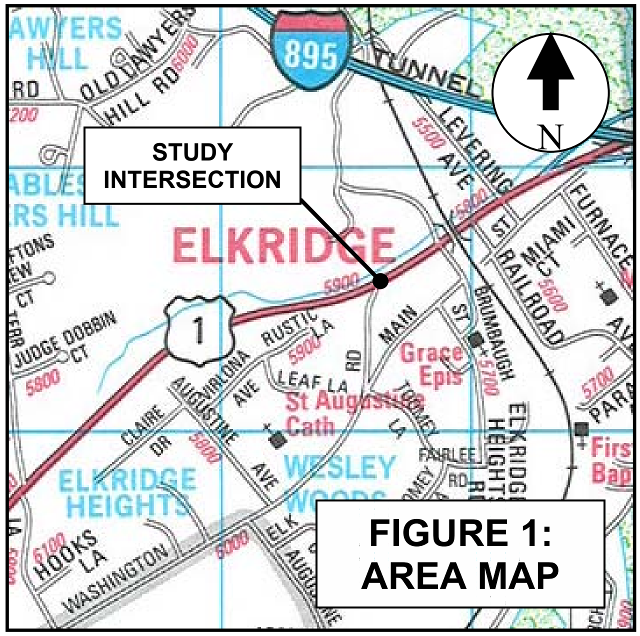


FIGURE 1: AREA MAP

OBJECTIVE:

The proposed work for this example is to construct an extension of Old Washington Road that will form a west leg to the intersection. Additionally, a 100' right turn storage lane will be installed on southbound US 1 approaching the intersection, which will require base widening and reconstruction of the existing right shoulder for this approach. The objective of this analysis is to (1) determine if one through lane on southbound US 1 can be closed or if temporary concrete barrier must be installed to avoid a lane closure, and (2) if the lane may be closed, during what hours can the lane be closed.

ANALYSIS:

1. **Determine the Limits of the Study Network.** The first step in determining the limits of the study network is to estimate the work zone queue length. Given the nature of the work to be completed, it is estimated that the southbound US 1 approach will be reduced to one through lane at the intersection. Because the proposed work zone will impact the major approach to an unsignalized intersection, which operates as a free movement, US 1 was treated as a freeway segment for the purposes of estimating the resulting queue length. Referring to SHA's *Work Zone Lane Closure Analysis Guidelines* (November 2006), a mainline reduction in lanes from two to one lane is expected to result in a work zone capacity of 1,340 vehicles per hour. The peak hour through volume for the southbound approach to the intersection is 1,278 (AM Peak), which falls below the expected capacity. Therefore, no queue will result. Because the work zone will not impact the northbound approach, there will be no queue on this approach as well. There are no nearby intersections along Old Washington Road within 1,000' of the study intersection, and the peak hour volume for this approach is only 71 vehicles (PM Peak), which is not expected to result in a queue longer than 1,000'. Therefore, it will not be necessary to include other intersections in the study network.

Due to the fact that the work to be completed will have a minimal impact on the existing roadway, and that there are no nearby parallel roadways, no detour routes need to be included in the study network.

2. **Data Collection.** A turning movement count performed in 2006 at the study intersection was obtained from the SHA-maintained database. This data was used for determining the limits of the study network. Aerial photographs were used to determine lane configurations and storage lengths.

3. **Modeling – Existing Conditions.** There were no existing Synchro models, so a new model was coded using the data that was collected.

4. **Modeling – Calibration and Validation.** This model was calibrated using peak hour factors. Because the intersection is isolated, with relatively low volumes, it was determined that model validation was not necessary.

5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignalized* reports were printed for the study intersection during each of the peak periods. **Table 1** summarizes the control delays and levels of service for the intersection during both peak periods. It should be noted that Synchro does not give HCM-based levels of service for two-way stop control intersections, and therefore it is necessary to refer to the HCM to determine the intersection level of service based on the control delay obtained from Synchro. SimTraffic simulations were not performed because this example involves an isolated intersection and Synchro will be sufficient to evaluate the mobility thresholds.

Table 1. Synchro Model Outputs – Existing Conditions – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
US 1 at Old Washington Rd	2.2 (5.6)	A (A)

6. **Modeling – Code Work Zone Model.** It was assumed that the greatest impact to existing traffic conditions would occur during the base widening for the proposed southbound right turn storage lane and the tie-in for the proposed roadway to the existing intersection, therefore this was the stage of construction evaluated. The prevailing speed on US 1 was assumed to be 45 mph, 5 mph above the posted speed limit. Based on this prevailing speed, a buffer length of 360' and a merging taper of 495' are required prior to the beginning of the work zone. However, given the proximity of the study intersection to the intersection of US 1 at Brumbaugh Avenue, it will be necessary to reduce the buffer length to 300' and the taper length to 350'. **Figure 2** shows the assumed work zone lane configurations at the intersection.

   The existing conditions model was modified to reflect the proposed length of the work zone, buffer zone, and tapers through the use of bend nodes. It was assumed that there would be no changes in O-D data or in the traffic volumes. Given the nature of the work to be completed, it was assumed that no turning restrictions are necessary at the study intersection.

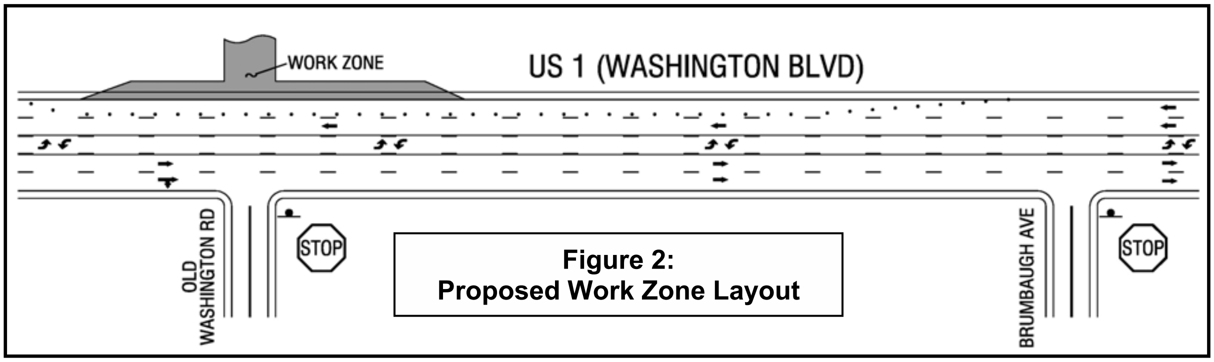


Figure 2: Proposed Work Zone Layout

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignalized* reports were printed for the study intersection during each peak period. **Table 2** summarizes the control delays and levels of service for the intersection during both peak periods. As with the existing conditions model outputs, intersection levels of service were obtained by referencing the HCM.

Table 2. Synchro Model Outputs – Work Zone Conditions – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
US 1 at Old Washington Rd	23.0 (20.4)	C (C)

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 1 and 2, the study intersection will meet mobility thresholds for unsignalized intersections (maximum LOS D and control delay of 30 seconds) under this work zone alternative.

9. **Recommend an Alternative.** Based on the results of this study, the recommended work zone alternative is to perform base widening for the southbound right turn storage lane and the tie-in for the proposed roadway by using drums for channelization devices while closing the existing right through lane on southbound US 1. Because analysis of this alternative during the AM and PM peaks meets the mobility thresholds, there is no need for any time restriction for this lane closure. **Table 3** summarizes the recommended work zone alternative.

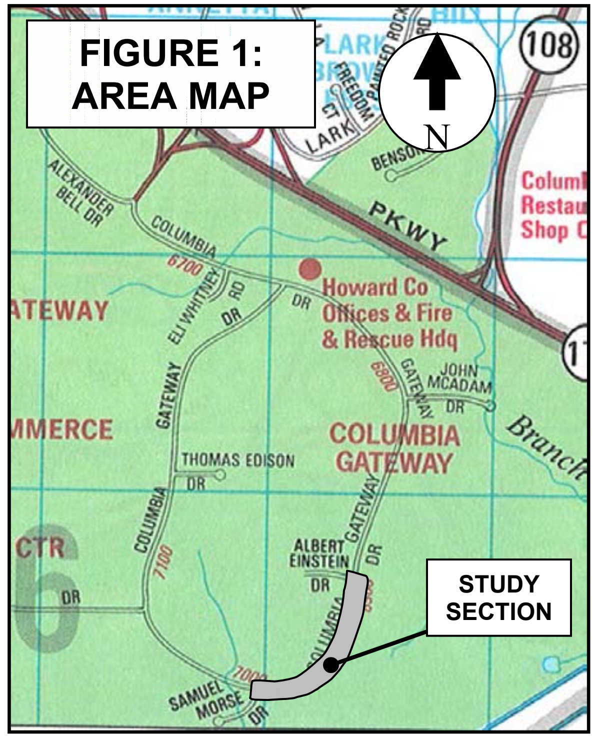
Table 3. Recommended Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Close the right through lane on SB US 1 using drums	No work hour restrictions

EXAMPLE C: UNSIGNALIZED ARTERIAL
COLUMBIA GATEWAY DRIVE

SITE DESCRIPTION:

Columbia Gateway Drive is a four-lane, two-way, divided roadway that runs in an east-west direction. The nearest intersection outside of the work zone is an unsignalized intersection approximately 1,375' west of the proposed work zone. **Figure 1** shows an area map of the study location.



OBJECTIVE:

The proposed project for this example is to remove the existing median between the intersections with Samuel Morse Drive and Albert Einstein Drive and replace it with a two-way center left turn lane. In addition to this work, full-depth reconstruction for the full width of the roadway between these intersections was proposed. The objective of this work zone analysis is to determine the number of phases of construction needed to complete the project. It was assumed that work zones would be set up using temporary concrete traffic barrier and that lanes would remain closed for the duration of each construction phase (i.e. staging must meet mobility thresholds during peak periods).

ANALYSIS:

1. **Determine the Limits of the Study Network.** The highest peak hour volume through the proposed work zone is almost 700 vph on eastbound Columbia Gateway Drive. Based on this peak hour volume, the capacity of the arterial section will not be exceeded if there were a one lane reduction on the mainline. Therefore, it is not anticipated that a queue will result on the mainline.

   The posted speed limit on Columbia Gateway Drive is 35 mph, and based on that speed, a buffer length of approximately 250 feet and a taper length of approximately 250 feet will be required on either end of the work zone. To account for any queuing or merging conflicts, the study network should include 1,000 feet along Robert Fulton Drive in either direction from the work zone. There are no other intersections along Columbia Gateway Drive within 1,000 feet of the work zone, or any nearby intersections along the side street approaches, so no other intersections will be included in the study network.

2. **Data Collection.** In order to determine the limits of the study network, it was necessary to begin collecting data for the two intersections impacted by the work zone. New 12-hour

turning movement counts were performed on January 24 and 30, 2007 at the intersections with Albert Einstein Drive and Samuel Morse Drive, respectively, because no recent traffic volume data was available. Field measurements of lane widths, lane configurations, and storage lengths were performed.

3. **Modeling – Existing Conditions.** There were no existing Synchro models, so new models for AM and PM peak periods were coded using the data that was collected. Because turning movement counts were performed on different days, the volumes were balanced between the two study intersections.

4. **Modeling – Calibration and Validation.** Because intersection volumes were relatively low, it was determined that model calibration was unnecessary.

5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignalized* reports were printed for the study intersections during each of the peak periods. **Table 1** summarizes the control delays and levels of service for the intersections during both peak periods. Because the work zone extends through more than one intersection, it is necessary to evaluate the mobility thresholds for arterial segments. Five (5) SimTraffic simulations with seeding times of 10 minutes and recording times of 60 minutes were performed for the existing conditions model. The average travel times along Columbia Gateway Drive through the work zone, as obtained using SimTraffic's *Arterial Report*, are summarized at the conclusion of Table 1.

Table 1. Synchro Model Outputs – Existing Conditions – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
Samuel Morse Drive	3.4 (24.6)	A (C)
Albert Einstein Drive	2.5 (3.0)	A (A)
Eastbound Travel Time		**1.0 (1.1) minutes**
Westbound Travel Time		**1.0 (1.3) minutes**

6. **Modeling – Code Work Zone Model.** Based on the estimated prevailing speed of the roadway, a buffer length of 250' and a merging taper of 250' are required prior to the beginning of the work zone. For this alternative, it was assumed that construction will be performed in three stages; the first stage will result in the removal of the existing median and construction of the proposed center two-way left turn lane while maintaining the existing lane, and the final two stages will result in the closure of one through lane in each direction while maintaining the center two-way left turn lane created in the first stage. Under this scenario, traffic would be impacted most during the last two stages where one through lane is closed in each direction. It should be noted that because the center lane will be reconstructed during the first construction stage, the final stages will permit one direction to maintain the existing two through lanes by have one lane drive on the newly reconstructed center lane. **Figure 2** shows the assumed work zone lane configurations during one of the final two construction stages.

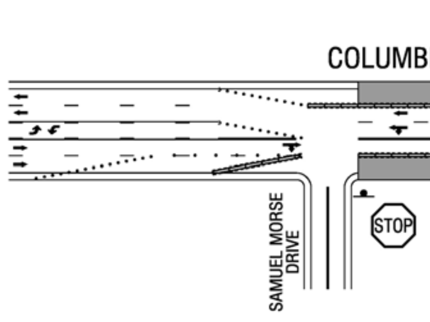


Figure 2: 3-Stage Phasing Work Zone Layout

The existing conditions model was modified to reflect the proposed length of the work zone, buffer zone, and tapers for one of the final two stages of construction through the use of bend nodes. It was assumed that there would be no changes in O-D data or in the traffic volumes. Based on the proposed work zone setup, no restrictions on the turning movements from the side streets were required.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignlized* reports were printed for the study intersections during each of the peak periods. **Table 2** summarizes the control delays and levels of service for the intersections during both peak periods, and the average travel times obtained from SimTraffic simulations of the work zone model, as obtained using SimTraffic's *Arterial Report*.

Table 2. Synchro Model Outputs – 3-Stage Construction Alternative – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
Samuel Morse Drive	3.4 (***33.4***)	A (***D***)
Albert Einstein Drive	2.5 (4.6)	A (A)
Eastbound Travel Time		**1.1 (1.1) minutes**
Westbound Travel Time		**1.1 (1.3) minutes**

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 1 and 2, this work zone alternative will violate mobility thresholds (maximum LOS D and control delay of 30 seconds) at the intersection of Columbia Gateway Drive with Samuel Morse Drive during the PM peak. Therefore, another method of construction phasing must be considered. For the next alternative, a 5-stage construction process will be considered, where only one lane will be closed during each stage so that two through lanes may be maintained in each direction during each stage.

6. **Modeling – Code Alternate Work Zone Model.** Because this work zone alternative will essentially involve lane shifts on either end of the work zone with no change in the number of through lanes, this scenario was modeled by modifying the existing conditions model to reflect lower saturation flow rates on the approaches to the work zone. This was accomplished by reducing the lane widths on the approaches. **Figure 3** shows the assumed work zone lane configurations during one of the analyzed construction stage.

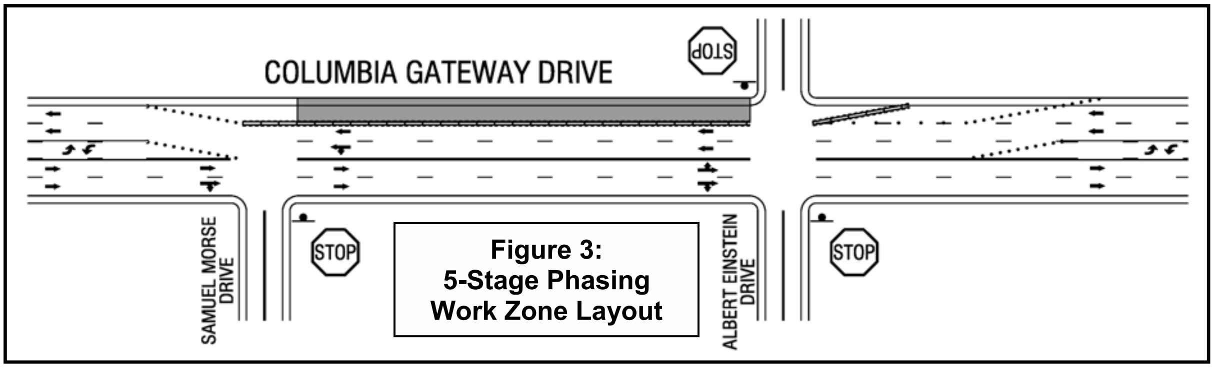


Figure 3: 5-Stage Phasing Work Zone Layout

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Unsignalized* reports were printed for the study intersections during each peak period. **Table 3** summarizes the control delays and levels of service for the intersections during both peak periods. SimTraffic simulations were not performed for this alternative, as the arterial segment mobility threshold (maximum increase in travel time of 15 minutes) was met for the previous alternative and this alternative is less disruptive than the previous alternative.

Table 3. Synchro Model Outputs – 5-Stage Construction Alternative – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
Samuel Morse Drive	3.4 (24.6)	A (C)
Albert Einstein Drive	2.5 (3.0)	A (A)

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 1 and 3, the 5-stage construction alternative will meet the mobility thresholds for individual intersections (maximum LOS D and control delay of 30 seconds) and the arterial segment.

9. **Recommend an Alternative.** Based on the results of the analysis presented in this study, it is recommended that this project be constructed using 5-stage phasing, where the existing median will be reconstructed during the first stage, and during each of the subsequent stages one existing lane will be reconstructed while shifting lanes through the work zone and maintaining two through lanes on both approaches during all stages. Because this alternative will satisfy the mobility thresholds during AM and PM peaks, the proposed lane closures will have no time-of-day restrictions. **Table 4** summarizes the recommended work zone alternative. It should be noted that consideration of traffic operations, construction costs and duration, and potential mitigation measures may lead decision-makers to prefer the 3-stage alternative over the 5-stage alternative.

Table 4. Recommended Work Zone Alternative

Work Zone Alternative Staging	Work Hour Restrictions
Stage 1: Remove existing median using temporary concrete barrier and maintaining existing lanes	No work hour restrictions
Stage 2-5: Reconstruction one lane during each stage, shifting travel lanes to maintaining two through lanes in either direction	No work hour restrictions

EXAMPLE F: SIGNALIZED INTERSECTION WITH SINGLE LANE APPROACHES
MD 26 (LIBERTY ROAD) AT WARDS CHAPEL ROAD

SITE DESCRIPTION:

MD 26 (Liberty Road) and Wards Chapel Road are two-lane, two-way undivided roadways. MD 26 runs in an east-west direction, and Wards Chapel Road runs in a north-south direction. The nearest intersection is the unsignalized intersection of MD 26 and Church View Avenue, approximately 500 feet to the east of the study intersection. **Figure 1** shows an area map and sketch of the study location.

OBJECTIVE:

The proposed work for this example is to widen MD 26 to provide an additional through lane on each approach, extending 750 feet from the study intersection. The objectives of this analysis are to (1) determine if the reconstruction of the intersection can be performed under flagging operations, or if a detour must be used, and (2) if flagging operations are suitable, during what periods of the day flagging may be used.

ANALYSIS:

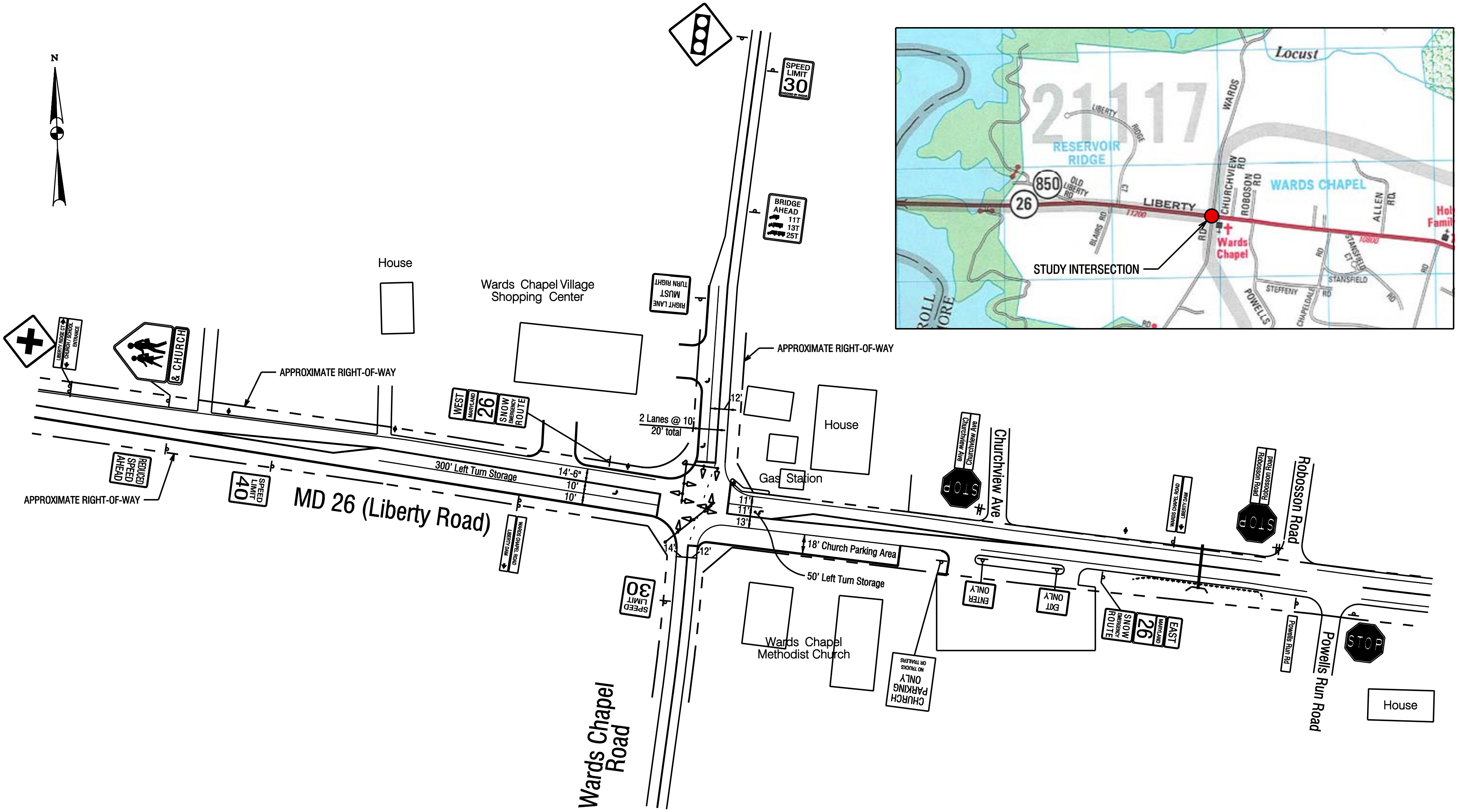
1. **Determine the Limits of the Study Network.** The first step in determining the limits of the study network is to estimate the work zone queue length. Given the nature of the work to be completed, it is anticipated that the greatest impacts to traffic flow through and around the intersection will occur during the reconstruction of the intersection itself. During this stage of construction, it is expected that the intersection would operate under flagging, which would be comparable to a signal operating under four-way split phasing. Additionally, due to high peak hour volumes, the work will be restricted to off-peak hours (either midday or overnight). It was assumed that the cycle length would be 150 seconds with 5-second clearance intervals (yellow plus all red time) for each approach, and that green time would be allocated to each approach based on the proportion of the total intersection volume attributable to each approach. **Table 1** summarizes the signal timing assumptions, approach traffic volumes, and estimated queue lengths (based on the equation presented in Section III.C of this Guide) for the midday peak hour.

Table 1. Summary of Queue Length Approximations – Midday Peak

Approach	Approach Volume (vph)	Thru Green (sec.)	Cycle Length (sec.)	Est. Queue Length	
				# veh	feet*
Eastbound	594	50	150	8	200
Westbound	703	59	150	12	300
Northbound	101	8	150	1	25
Southbound	154	13	150	1	25

* Average vehicle length of 25 feet assumed.

Based on the results presented in the table, the work zone queue is expected to extend, at most, 300' from the beginning of the work zone along either direction of MD 26. Considering the buffer and taper lengths that will be required approaching the work zone, it is likely that the westbound queue will extend through the two nearest unsignalized



Work Zone Analysis Guide
MD 26 and Wards Chapel Road Example

Intersection Reconstruction Analysis

Figure 1

Condition Diagram

intersections. However, those intersecting roadways are residential streets that are not expected to have high volumes during the midday period. Therefore, it will not be necessary to model these intersections in the study network.

Due to the fact that there are no nearby parallel roadways, a detour is not feasible; therefore, detour routes will be included in the study network. Lastly, by obtaining the signal timings from the SHA Signal Shop, it is evident that the signal is not a part of a coordinated system.

2. **Data Collection.** In order to determine the limits of the study network, it was necessary to begin collecting data for the study intersection. Signal timings and phasing for the study intersection were obtained from the SHA Signal Shop, and verified through field observations. A turning movement count performed in 2005 was obtained from the SHA-maintained database. The traffic signal plan for the study intersection was obtained from SHA's website, and verified through a field visit. Field measurements of lane widths and storage lengths were performed.

3. **Modeling – Existing Conditions.** A Fund 87 traffic study was performed at the study intersection in January 2006. The Synchro model used for this study was obtained from the consultant that performed the study. Traffic volumes in the model were modified to reflect Midday peak volumes and peak hour factors.

4. **Modeling – Calibration and Validation.** This model used for the Fund 87 study was calibrated during that study based on travel time measurements during the peak periods. It was assumed that the calibration performed for that study, with the exception of the peak hour factors, would result in a reasonable model for this study.

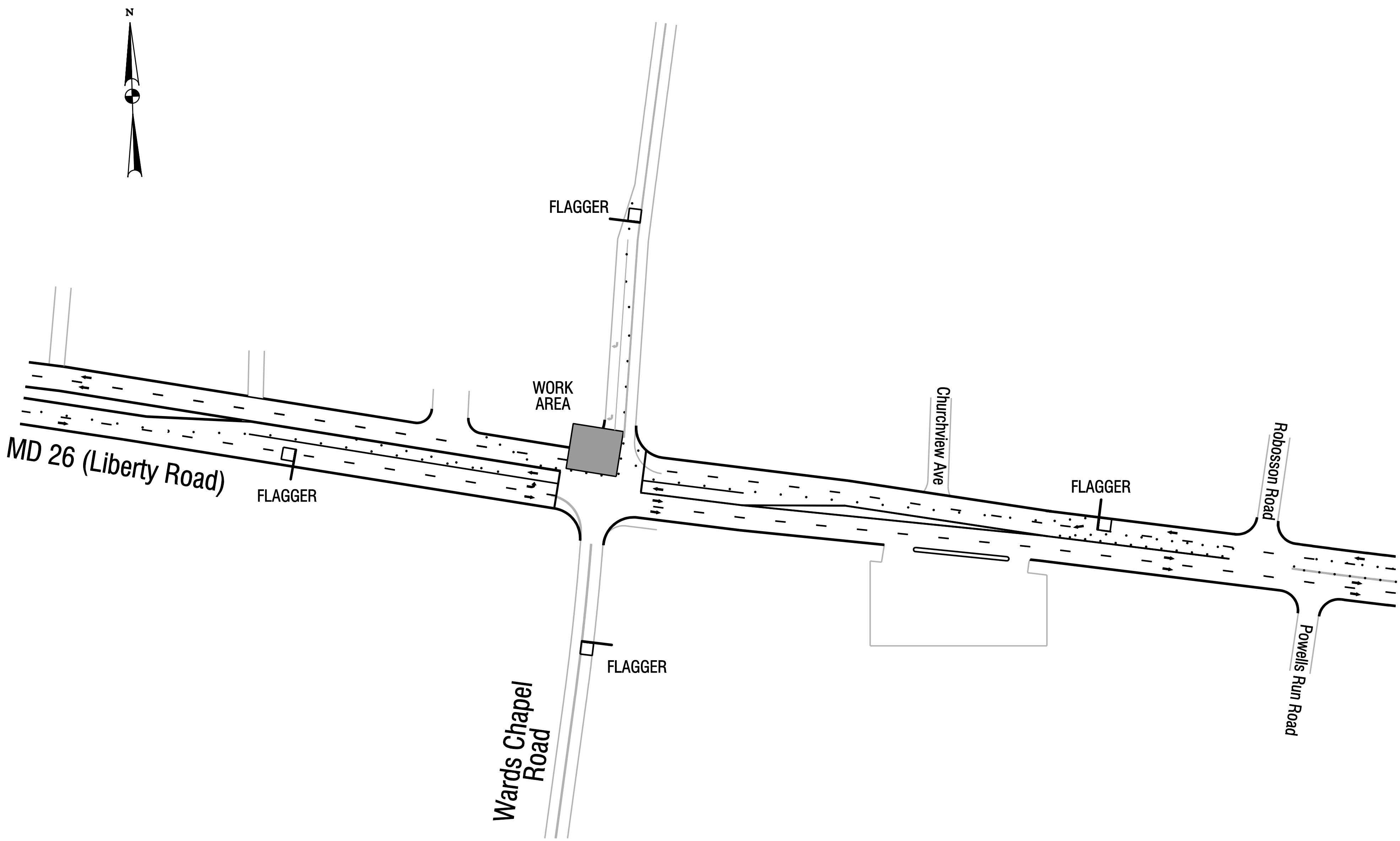
5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* report was printed for the study intersection. **Table 2** summarizes the control delay and level of service under existing conditions. SimTraffic simulations were not performed because this example involves an isolated intersection and Synchro will be sufficient to evaluate the mobility thresholds. The Syncrho report for this model is presented at the conclusion of this example.

Table 2. Synchro Model Outputs – Existing Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
MD 26 at Wards Chapel Rd	15.6	B

6. **Modeling – Code Work Zone Model.** Based on the work to be completed, it is assumed that the base widening of the approaches can be accomplished through the use of temporary concrete traffic barriers along the existing edge of pavement, which would not require any lane reductions. However, widening of the intersection itself will require the use of flaggers. **Figure 2** shows the assumed work zone lane configurations at the intersection.

Because it is proposed that the intersection will be reconstructed after the approaches have been widened, it was assumed that lanes on the MD 26 approaches to the intersection could be shifted approaching the work zone such that through movements for these approaches



Work Zone Analysis Guide
MD 26 at Wards Chapel Road Example

Intersection Reconstruction Analysis

Figure 2

Work Zone Lane Configurations

could operate concurrently. Given this assumption, signal phasing at the study intersection was modified such that the minor street approaches operate under split phasing, a phase was provided for eastbound left turns, and westbound lane configurations were assumed to be one shared left-through-right lane without separate left turn phasing. As in Example A, all-red clearance intervals at the study intersection were modified to account for the work zone, and buffer and taper lengths. The all-red time was calculated to be 13 seconds for each approach, based on an assumed prevailing speed of 30 mph though the work zone and a buffer length of 200’. The existing conditions model was modified to account for these changes. It was assumed that there would be no changes in O-D data or in the traffic volumes.

7. **Modeling – Obtain Model Outputs.** Synchro’s *HCM Signals* report was printed for the study intersection. **Table 3** summarizes the control delay and level of service under work zone conditions. The Synchro report for the work zone conditions model is presented at the conclusion of this example.

Table 3. Synchro Model Outputs – Work Zone Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
MD 26 at Wards Chapel Rd	40.5	D

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 2 and 3, this proposed work zone alternative will meet the mobility thresholds for signalized intersections (maximum LOS D and control delay of 45 seconds).

9. **Recommend an Alternative.** Based on the results of the analysis presented in this study, the recommended work zone alternative is to first perform base widening behind a temporary concrete traffic barrier, maintaining existing lane configurations, and then reconstruct the intersection through the use of flaggers, allowing the MD 26 through movements to operate concurrently. A review of the traffic volumes at the intersection indicates that traffic volumes at the intersection between the hours of 9 AM and 3 PM are at or below the midday peak volumes used for this analysis. Therefore, flagging operations are suitable at this intersection between 9 AM and 3 PM. **Table 4** summarizes the recommended work zone alternative.

Table 4. Recommended Work Zone Alternative

Work Zone Alternative Staging	Work Hour Restrictions
Stage 1: Perform base widening behind temporary concrete traffic barrier	No work hour restrictions
Stage 2: Reconstruction the intersection using flaggers, such that MD 26 through movements are flagged concurrently	Monday-Friday: 9 AM to 3 PM

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	12	12	12	12	12	12	10	10	12
Grade (%)		3%			2%			0%			0%	
Total Lost time (s)	4.0	4.0		4.0	4.0			4.0			4.0	4.0
Lane Util. Factor	1.00	1.00		1.00	1.00			1.00			1.00	1.00
Frt	1.00	0.99		1.00	1.00			0.97			1.00	0.85
Flt Protected	0.95	1.00		0.95	1.00			0.99			0.97	1.00
Satd. Flow (prot)	1643	1669		1769	1803			1813			1714	1599
Flt Permitted	0.21	1.00		0.39	1.00			0.91			0.72	1.00
Satd. Flow (perm)	359	1669		721	1803			1661			1271	1599
Volume (vph)	101	469	24	21	668	14	26	47	28	20	14	120
Peak-hour factor, PHF	0.79	0.81	0.75	0.88	0.89	0.70	0.72	0.65	0.78	0.63	0.58	0.83
Adj. Flow (vph)	128	579	32	24	751	20	36	72	36	32	24	145
RTOR Reduction (vph)	0	2	0	0	1	0	0	14	0	0	0	123
Lane Group Flow (vph)	128	609	0	24	770	0	0	130	0	0	56	22
Heavy Vehicles (%)	1%	4%	1%	1%	4%	1%	0%	0%	0%	1%	0%	1%
Turn Type	pm+pt			pm+pt			Perm			Perm		Perm
Protected Phases	1	6		5	2			4			8	
Permitted Phases	6			2			4			8		8
Actuated Green, G (s)	60.6	53.7		51.3	48.9			10.8			10.8	10.8
Effective Green, g (s)	62.6	55.7		53.8	50.9			12.8			12.8	12.8
Actuated g/C Ratio	0.75	0.67		0.65	0.61			0.15			0.15	0.15
Clearance Time (s)	4.5	6.0		4.5	6.0			6.0			6.0	6.0
Vehicle Extension (s)	3.0	8.0		3.0	8.0			4.0			4.0	4.0
Lane Grp Cap (vph)	388	1115		502	1100			255			195	245
v/s Ratio Prot	c0.03	c0.37		0.00	c0.43							
v/s Ratio Perm	0.22			0.03				c0.08			0.04	0.01
v/c Ratio	0.33	0.55		0.05	0.70			0.51			0.29	0.09
Uniform Delay, d1	7.2	7.2		5.5	11.1			32.4			31.3	30.3
Progression Factor	1.00	1.00		1.00	1.00			1.00			1.00	1.00
Incremental Delay, d2	0.5	1.8		0.0	3.7			2.3			1.1	0.2
Delay (s)	7.7	9.0		5.5	14.8			34.7			32.4	30.5
Level of Service	A	A		A	B			C			C	C
Approach Delay (s)		8.8			14.5			34.7			31.0	
Approach LOS		A			B			C			C	

Intersection Summary			
HCM Average Control Delay	15.6	HCM Level of Service	B
HCM Volume to Capacity ratio	0.67		
Actuated Cycle Length (s)	83.4	Sum of lost time (s)	16.0
Intersection Capacity Utilization	63.9%	ICU Level of Service	B
Analysis Period (min)	15		
c Critical Lane Group			

Control Delay **Level of Service**

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	12	12	12	12	12	12	10	10	12
Grade (%)		3%			2%			0%			0%	
Total Lost time (s)	4.0	4.0			4.0			4.0			4.0	4.0
Lane Util. Factor	1.00	1.00			1.00			1.00			1.00	1.00
Frt	1.00	0.99			1.00			0.97			1.00	0.85
Flt Protected	0.95	1.00			1.00			0.99			0.97	1.00
Satd. Flow (prot)	1643	1669			1803			1813			1714	1599
Flt Permitted	0.95	1.00			0.97			0.99			0.97	1.00
Satd. Flow (perm)	1643	1669			1749			1813			1714	1599
Volume (vph)	101	469	24	21	668	14	26	47	28	20	14	120
Peak-hour factor, PHF	0.79	0.81	0.75	0.88	0.89	0.70	0.72	0.65	0.78	0.63	0.58	0.83
Adj. Flow (vph)	128	579	32	24	751	20	36	72	36	32	24	145
RTOR Reduction (vph)	0	1	0	0	1	0	0	10	0	0	0	125
Lane Group Flow (vph)	128	610	0	0	794	0	0	135	0	0	56	20
Heavy Vehicles (%)	1%	4%	1%	1%	4%	1%	0%	0%	0%	1%	0%	1%
Turn Type	Prot			pm+pt			Split			Split		Perm
Protected Phases	1	6		5	2		4	4		8	8	
Permitted Phases				2								8
Actuated Green, G (s)	9.5	70.0			56.0			5.0			5.0	5.0
Effective Green, g (s)	10.0	84.0			70.0			18.0			18.0	18.0
Actuated g/C Ratio	0.08	0.64			0.53			0.14			0.14	0.14
Clearance Time (s)	4.5	18.0			18.0			17.0			17.0	17.0
Vehicle Extension (s)	3.0	8.0			8.0			4.0			4.0	4.0
Lane Grp Cap (vph)	124	1062			928			247			234	218
v/s Ratio Prot	c0.08	0.37						c0.07			c0.03	
v/s Ratio Perm					c0.45							0.01
v/c Ratio	1.03	0.57			0.86			0.54			0.24	0.09
Uniform Delay, d1	61.0	13.8			26.7			53.2			50.9	49.8
Progression Factor	1.00	1.00			1.00			1.00			1.00	1.00
Incremental Delay, d2	89.7	2.1			9.6			3.1			0.7	0.2
Delay (s)	150.7	15.8			36.3			56.2			51.6	50.1
Level of Service	F	B			D			E			D	D
Approach Delay (s)		39.2			36.3			56.2			50.5	
Approach LOS		D			D			E			D	

Intersection Summary			
HCM Average Control Delay	40.5	HCM Level of Service	D
HCM Volume to Capacity ratio	0.73		
Actuated Cycle Length (s)	132.0	Sum of lost time (s)	16.0
Intersection Capacity Utilization	76.9%	ICU Level of Service	D
Analysis Period (min)	15		

c Critical Lane Group

Control Delay

Level of Service

EXAMPLE G: SIGNALIZED INTERSECTION WITH MULTIPLE LANE APPROACHES MD 940 (OWINGS MILLS BOULEVARD) AT RED RUN BOULEVARD

SITE DESCRIPTION:

MD 940 is a four-lane, two-way, divided roadway that runs in a north-south direction and Red Run Boulevard is a four-lane, two-way divided roadway that runs in an east-west direction. The posted speed limit on both roadways is 40 mph. The nearest intersection is along Red Run Boulevard approximately 1,500 feet east of the study intersection. **Figure 1** shows an area map and sketch of the study location.

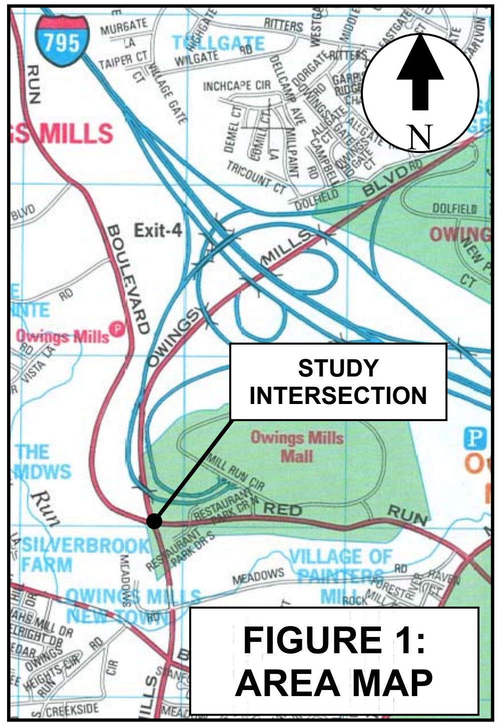


FIGURE 1: AREA MAP

OBJECTIVE:

The proposed work for this example is to make the single left-turning movement from westbound Red Run Boulevard a double left. This is to be accomplished by removing the median adjacent to the existing single left turn lane and constructing a new median that can accommodate two left turn lanes while maintaining the existing storage length. The objective of this work zone analysis is to determine (1) if this work can be accomplished through the use of temporary concrete traffic barriers with a permanent one lane reduction in both directions on Red Run Boulevard or if temporary lane closures are required using drums, and (2) what work hour restrictions are necessary to meet the mobility thresholds.

ANALYSIS:

1. **Determine the Limits of the Study Network.** The first step in determining the limits of the study network is to estimate the work zone queue length. Given the nature of the work to be completed, it is estimated that both Red Run Boulevard approaches will be reduced to one through lane at the intersection. **Table 1** summarizes the signal timing information, through traffic volumes, and estimated queue lengths (based on the equation presented in Section III.C of *The Guide*) for each approach by peak hour.

Table 1. Summary of Queue Length Approximations – AM (PM)

Approach	Thru Volume (vph)	Thru Green (sec.)	Cycle Length (sec.)	Est. Queue Length	
				# veh	feet*
Eastbound	173 (350)	30 (60)	223 (253)	11 (25)	275 (625)
Westbound	123 (229)	30 (30)	223 (253)	8 (20)	200 (500)

* Average vehicle length of 25 feet assumed.

Based on the results presented in the table, the work zone queue is expected to extend, at most, 625' west of the intersection and 500' east of the intersection. Because the nearest intersections along Red Run Boulevard and MD 940 are more than 1,000' from the study intersection, it will not be necessary to include other intersections in the study network.

Due to the fact that the work to be completed will have a minimal impact on the existing roadway, and that there are no nearby parallel roadways, it is not anticipated that a detour will be necessary or feasible. Therefore, the study network will not include detour routes. Lastly, by obtaining the signal timings from the SHA Signal Shop, it is evident that the work zone will not impact a coordinated signal system.

2. **Data Collection.** In order to determine the limits of the study network, it was necessary to begin collecting data for the two intersections impacted by the work zone. Signal timings and phasing for the study intersection were obtained from the SHA Signal Shop, and verified through field observations. A turning movement count performed in 2006 was obtained from the SHA-maintained database. The traffic signal plan for the study intersection was obtained from SHA's website. However, upon performing a field visit it was determined that the signal plans were inaccurate. Therefore, field measurements of lane widths, storage lengths, channelizing islands, and passage detector locations were performed. Field observations included queue lengths and lane utilization issues.

3. **Modeling – Existing Conditions.** There were no existing Synchro models, so a new model was coded using the data that was collected.

4. **Modeling – Calibration and Validation.** This model was calibrated using peak hour factors and the lane utilization factors that match field observations. Once calibrated, the model was validated to verify that queues resembled those observed in the field.

5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for the study intersection during each of the peak periods. **Table 2** summarizes the existing control delays and levels of service for the intersection during both peak periods. SimTraffic simulations were not performed because this example involves an isolated intersection and Synchro will be sufficient to evaluate the mobility thresholds.

Table 2. Synchro Model Outputs – Existing Conditions – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
MD 940 at Red Run Blvd	30.8 (57.9)	C (E)

6. **Modeling – Code Work Zone Model.** Based on the prevailing speed of the roadway (45 mph), a buffer length of 360' and a merging taper of 495' are required prior to the beginning of the work zone. Considering the width of the intersection to be a part of the buffer zone along eastbound Red Run Boulevard, it was estimated that the buffer would extend another 200' west of the stop line. **Figure 2** shows the assumed work zone lane configurations at the intersection.

   The existing conditions model was modified to reflect the proposed length of the work zone, buffer zone, and tapers through the use of bend nodes. It was assumed that there would be no

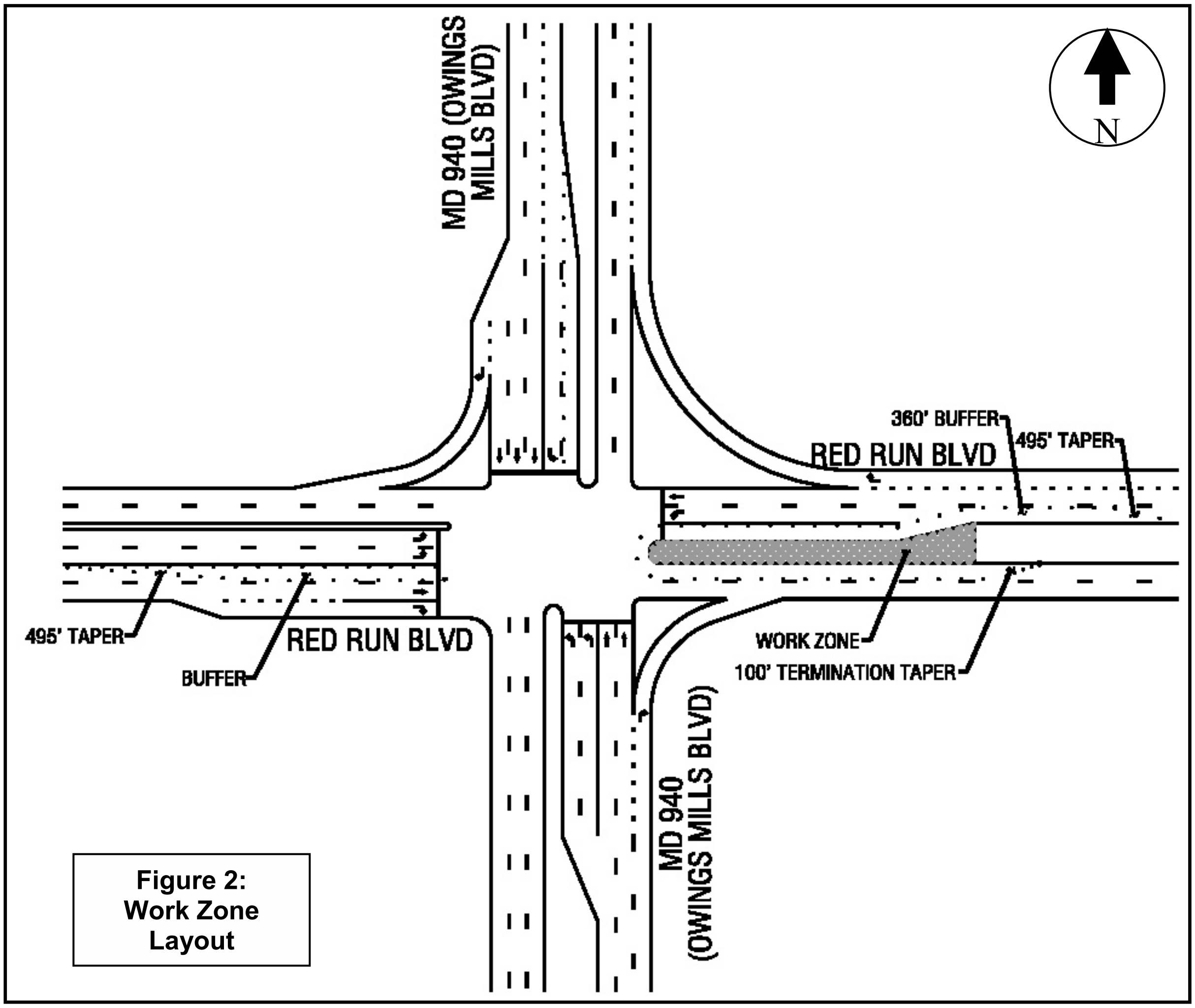


Figure 2: Work Zone Layout

changes in O-D data or in the traffic volumes. Based on the work zone setup, it was assumed that one of the existing double left turn lanes from southbound MD 940 would be closed because there will only be one receiving lane east of the intersection.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for the study intersection during each peak period. **Table 3** summarizes the control delays and levels of service for the intersection during both peak periods.

Table 3. Synchro Model Outputs – Work Zone Conditions – AM (PM)

Intersection	Control Delay (sec.)	Level of Service
MD 940 at Red Run Blvd	***48.3 (76.2)***	***D (E)***

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 2 and 3, control delays at the intersection are expected to worsen beyond the limits of the mobility thresholds (maximum control delay of 45 seconds for the AM peak, and a control delay increase of more than 30% for the PM peak).

Given the simplicity of the work to be performed, it does not seem feasible to consider contraflow lanes, temporary pavement, reversible lanes, or a full closure. Therefore, it seems that the only feasible work zone alternatives would involve imposing work hour restrictions. For this reason, the next alternative to be evaluated was off-peak hour (either midday or overnight) construction.

6. **Modeling – Code Midday Work Zone Model.** Because midday peak traffic volumes are expected to exceed overnight peak traffic volumes, this alternative was evaluated for the midday peak. The turning movement count used for this example was a 12-hour count, so midday peak hour volumes were obtained from this existing count. The existing conditions and work zone models created in previous steps were modified to reflect midday peak hour volumes and signal timings, while maintaining the same lane configurations.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for the study intersection during each peak period. **Table 4** summarizes the control delays and levels of service for the intersection under existing and work zone conditions.

Table 4. Synchro Model Outputs – Existing (Work Zone) Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
MD 940 at Red Run Blvd	27.9 (39.3)	C (D)

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Table 4, control delays at the study intersection are expected to increase under work zone conditions, but that increase is not enough to violate any of the mobility thresholds. Therefore, limiting road work to off-peak (midday or overnight) hours is the recommended alternative. Based on the turning movement count utilized for this study, if work is to be completed during the middle of the day, it should be limited to between the hours of 9 AM and 3 PM.

9. **Recommend an Alternative.** Based on the results of the analysis presented in this study, the recommended work zone alternative is to perform all work during midday hours using drums for channelization devices and closing the adjacent lanes in both directions along Red Run Boulevard. A review of the traffic volumes at the intersection indicates that traffic volumes at the intersection between the hours of 9 AM and 3 PM are at or below the volumes used for this analysis. Therefore, this work is suitable at this intersection between 9 AM and 3 PM. Because of the high costs of overnight construction work and the assumption that midday closures will be adequate to perform the necessary work within a reasonable time period, the recommendation for this project will not include work during night hours (8 PM to 5 AM). **Table 5** summarizes the recommended work zone alternative.

Table 5. Recommended Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Reconstruct the median while closing adjacent lanes in both directions on Red Run Boulevard with drums	Monday-Friday: 9 AM to 3 PM

EXAMPLE H: SIGNALIZED ARTERIAL
SHADY GROVE ROAD

SITE DESCRIPTION:

Shady Grove Road is a six-lane, two-way, divided roadway that runs in a north-south direction. In the vicinity of the proposed work zone, the land use adjacent to Shady Grove Road is commercial/retail. **Figure 1** shows an area map of the study location, accompanied by an illustration of link lengths, work zone location, and buffer and taper lengths.

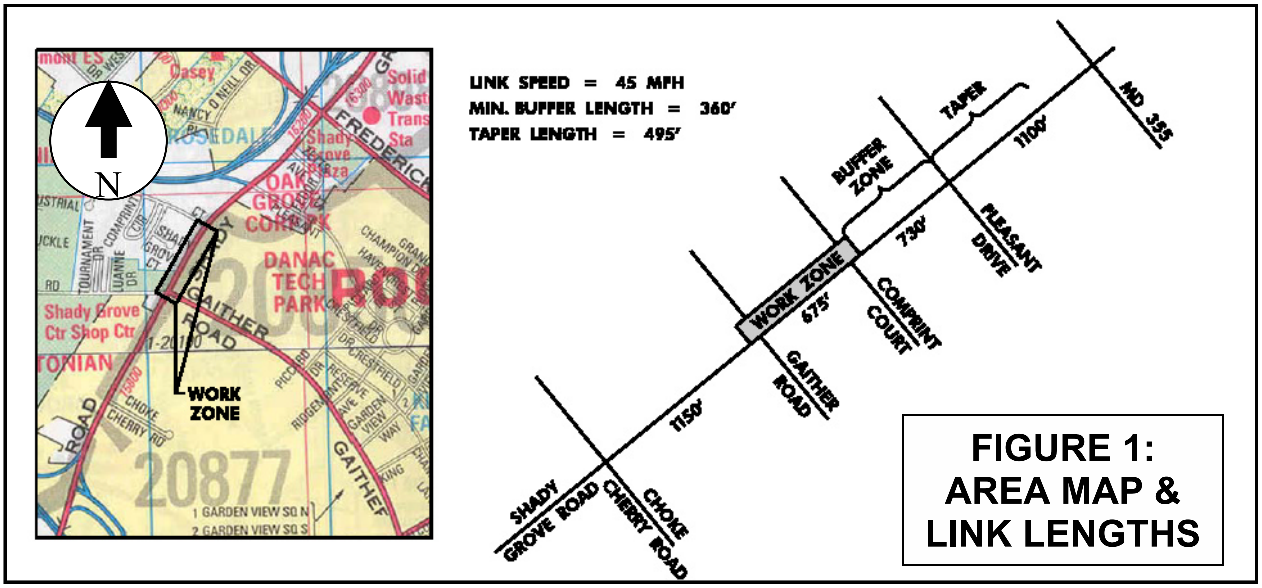


FIGURE 1: AREA MAP & LINK LENGTHS

OBJECTIVE:

The proposed work for this example is to reconstruct the sidewalk and curb and gutter along southbound Shady Grove Road between Comprint Court and Gaither Road, closing the right through lane using drums. The objectives of this work zone analysis are to determine (1) if a lane closure can be permitted along Shady Grove Road, and (2) what work hour restrictions are required to meet the mobility thresholds.

ANALYSIS:

1. **Determine the Limits of the Study Network.** The first step in determining the limits of the study network is to estimate the work zone queue length. Given the nature of the work to be completed, southbound Shady Grove Road will need to be reduced from three lanes to two lanes throughout the work zone. Because the work zone will go across two intersections, the queue length will be estimated at each of these intersections, and the longest queue length will be used for analysis. **Table 1** summarizes the signal timing information, through traffic volumes, and estimated queue lengths (based on the equation presented in Section III.C of this Guide) at these two intersections. It should be noted that the traffic volumes used were from the AM peak hour, which is the critical peak period for southbound Shady Grove Road.

Table 1. Summary of Queue Length Approximations

Intersection	SB Thru Volume (vph)	SB Thru Green (sec.)	Cycle Length (sec.)	Est. Queue Length	
				# veh	feet*
Gaither Road	1,950	66.5	150	350	7,000
Comprint Court	2,350	87.5	150	250	5,000

* Average vehicle length of 25 feet assumed.

Based on the results presented in the table, the analysis for this work zone should extend at least 7,000' north of Gaither Road. It will be necessary to collect data for and model Shady Grove Road from Choke Cherry Road (the intersection downstream of the work zone) to the EB I-370 On-Ramp (Metro Entrance), located approximately 7,000' upstream of Gaither Road.

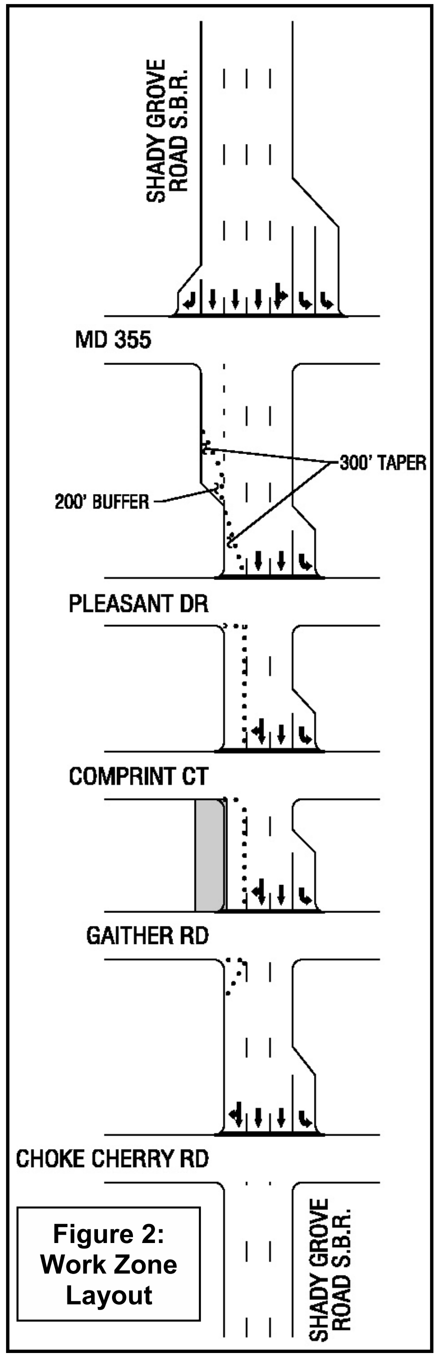


Figure 2: Work Zone Layout

Because there are no nearby parallel roadways, detour routes will not be included in this analysis, and because the work will have little, if any, impact on the intersecting roadways (Gaither Road or Comprint Court), it will not be necessary to include more detail on these roadways. Lastly, by obtaining the signal timings from the Montgomery County Transportation Management Center, it is evident that the work zone will impact a coordinated signal system. Since the signal system extends at least 3 miles in each direction from the work zone, it is not feasible to include the entire system in the analysis model. Therefore, the study network will be limited to Shady Grove Road from Choke Cherry Road to the EB I-370 On-Ramp.

2. **Data Collection.** Signal timings for all intersections in the study network were obtained from the Montgomery County Transportation Management Center. A turning movement count for the intersection with MD 355 (Frederick Road) was obtained from the SHA-maintained database. A turning movement count for the intersection with Choke Cherry Road was obtained through the Montgomery County TMC from a traffic study performed by another consultant. New turning movement counts were performed at the remainder of the intersections in the study network. Aerial photographs were used to develop preliminary lane configurations, which were verified during field visits. Field observations included queue lengths, lane utilization issues, and estimated truck percentages.

3. **Modeling – Existing Conditions.** There were no existing Synchro models, so a new model was coded using the data that was collected. Based on field observations, the existing congestion level on Shady Grove Road during AM and PM peaks would make a lane reduction during these peaks unfeasible. Therefore, the midday peak hour volumes and signal timings were utilized for this model.

4. **Modeling – Calibration and Validation.** This model was calibrated using peak hour factors, truck percentages, and lane utilization factors. Once calibrated, the model was validated to verify that queues and travel times resembled those observed in the field.

5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for each of the signalized intersections within the study network. There were no unsignalized intersections in the network, so unsignalized intersection reports were unnecessary. **Table 2** summarizes the control delays and levels of service for each intersection in the study network. Because the work zone queue is expected to extend through intersections other than those that are directly impacted by lane closures, it is necessary to evaluate the mobility thresholds for arterial segments. Five (5) SimTraffic simulations with seeding times of 15 minutes and running times of 30 minutes were performed for this model and an average travel time along southbound Shady Grove Road was obtained from SimTraffic's *Arterial Report*, which is summarized in Table 2.

Table 2. Synchro Model Outputs – Existing Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
Choke Cherry Road	10.1	B
Gaither Road	34.4	C
Comprint Court	9.4	A
Pleasant Drive	27.6	C
MD 355 (Frederick Road)	72.2	E
Solid Waste Entrance	3.7	A
The Great Indoors Entrance	4.0	A
Oakmont Avenue	36.0	D
Crabbs Branch Way	35.9	D
EB I-370 On-Ramp	1.7	A
SB Travel Time: EB I-370 On-Ramp to Choke Cherry Road		**6.8 minutes**

6. **Modeling – Code Work Zone Model.** For this alternative, it was assumed that in order to perform the work in as quickly as possible, the contractor would be permitted to close one southbound lane during the midday peak. Based on the speed of the roadway (45 mph), a buffer length of 360' and a merging taper of 495' are required prior to the beginning of the work zone. Due to link distances and existing lane reductions, it was assumed that the buffer zone would extend from the intersection with Pleasant Drive to the work zone, and that the taper would begin approximately 300' north of the intersection with Pleasant Drive. **Figure 2** shows the assumed work zone lane configurations on southbound Shady Grove Road.

The existing conditions model was modified to reflect the proposed length of the two-lane section through the use of bend nodes. It was assumed that there would be no changes in O-D data or in the traffic volumes. Based on the work zone setup, no restrictions on turning movements from the side streets were required.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for each of the signalized intersections within the study network. **Table 3** summarizes the control delays and levels of service for each intersection in the study network. Five (5) SimTraffic simulations were run for the work zone model with 15 minutes for the seeding time and 30 for the running time, and the average travel time along southbound Shady Grove Road is reported in Table 3.

Table 3. Synchro Model Outputs – Work Zone Conditions – Midday Peak

Intersection	Control Delay (sec.)	Level of Service
Choke Cherry Road	9.9	A
Gaither Road	***96.4***	***F***
Comprint Court	13.6	B
Pleasant Drive	***52.5***	***D***
MD 355 (Frederick Road)	72.2	E
Solid Waste Entrance	3.7	A
The Great Indoors Entrance	4.0	A
Oakmont Avenue	36.0	D
Crabbs Branch Way	35.9	D
EB I-370 On-Ramp	1.7	A
SB Travel Time: **EB I-370 On-Ramp to Choke Cherry Road**		**15.0 minutes**

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 2 and 3, the signalized intersection mobility thresholds at the intersections with Gaither Road and Pleasant Drive will be violated under this work zone alternative. Performance measures shown in ***bold red*** in the table are those where the mobility thresholds are violated. Evaluating the roadway segment mobility threshold shows that the work zone will result in an 8.2 minute average travel time increase, which meets the mobility threshold for roadway segments (maximum travel time increase of 15 minutes). Based on these results, another work zone alternative must be considered.

   Given the simplicity of the work to be performed, and the nature of the study network, it does not seem feasible to consider contraflow lanes, temporary pavement, reversible lanes, or a full closure. Therefore, it seems that the only feasible work zone alternatives would involve permitting lane closures during off-peak hours only. Because it was assumed that this work could be accomplished during one or two weekends, the next alternative to be evaluated was weekend construction.

6. **Modeling – Code Weekend Work Zone Model.** Weekend peak hour counts were performed during the data collection phase. It was assumed that the weekend peak hour occurs on Saturdays in the middle of the day. The existing conditions and work zone models created in previous steps were modified to reflect weekend peak hour volumes and signal timings, while maintaining the same lane configurations.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for each of the signalized intersections within the study network, and SimTraffic's *Arterial Report* was printed for the average of five simulations under each condition. **Table 4** summarizes the control delays and levels of service for each intersection in the study network and the travel time along southbound Shady Grove Road under existing and work zone weekend conditions.

Table 4. Synchro Model Outputs – Existing (Work Zone) Weekend Conditions

Intersection	Control Delay (sec.)	Level of Service
Choke Cherry Road	39.9 (39.3)	D (D)
Gaither Road	31.6 (33.7)	C (C)
Comprint Court	8.7 (10.7)	A (B)
Pleasant Drive	30.6 (31.9)	C (C)
MD 355 (Frederick Road)	87.8 (87.8)	F (F)
Solid Waste Entrance	4.3 (4.3)	A (A)
The Great Indoors Entrance	6.7 (6.7)	A (A)
Oakmont Avenue	20.5 (20.5)	C (C)
Crabbs Branch Way	24.4 (24.4)	C (C)
EB I-370 On-Ramp	0.6 (0.6)	A (A)
SB Travel Time: EB I-370 On-Ramp to Choke Cherry Road	**5.6 minutes (6.5 minutes)**	

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Table 4, control delays at the intersections with Gaither Road, Comprint Court, and Pleasant Drive are expected to increase under work zone conditions, but those increases would not violate any of the mobility thresholds. An evaluation of the increase in travel times attributable to the work zone shows that travel times would increase by 0.9 minutes, which meets the roadway segment mobility threshold.

9. **Recommend an Alternative.** Based on the results of the analysis presented in this study, the recommended work zone alternative is to perform all work during weekend hours using drums for channelization devices and closing the adjacent lane along southbound Shady Grove Road. **Table 5** summarizes the recommended work zone alternative.

Table 5. Recommended Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Reconstruct the sidewalk while closing the adjacent lane on SB Shady Grove Road with drums	Saturday & Sunday: Sat. Midnight-Mon. Midnight

EXAMPLE I: ARTERIAL SEGMENT (TWO-LANE, TWO-WAY ROADWAY) - FLAGGING MD 23 (EAST WEST HIGHWAY) BRIDGE OVER MORSE ROAD

SITE DESCRIPTION:

MD 23 (East West Highway) is a two-lane, two-way roadway that runs in an east-west direction over Morse Road. The nearest intersection to this bridge is where MD 23 terminates at MD 165, approximately one mile west of the bridge. There are no access points on MD 23 between MD 165 and several miles east of Morse Road. The posted speed limit along MD 23 in the vicinity of the bridge is 45 mph. **Figure 1** shows an area map of the study location.

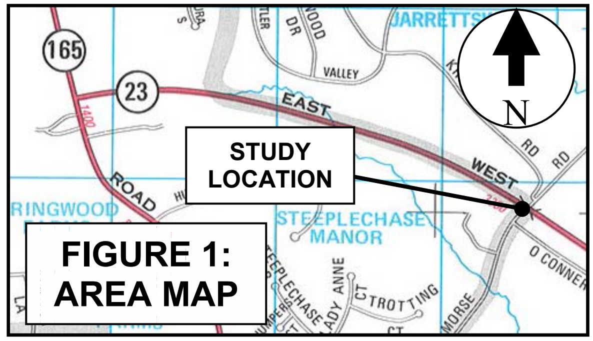


FIGURE 1: AREA MAP

OBJECTIVE:

The proposed work for this example is to reconstruct the full length (100') of the existing bridge. Because there are no nearby detour routes available, it was assumed that the work would be accomplished through a two-stage process, by which one lane at a time would be closed on the bridge permitting traffic flow in the other lane. The objective of this work zone analysis is to determine if maintaining one-lane, two-way bridge operations using traffic signals at either end of the bridge will meet the mobility thresholds. It should be noted that the analysis presented for this example is the same as would be performed for flagging operations. However, due to expected duration of construction activities and a desire for worker safety, traffic signals (rather than flaggers) were assumed for this example.

ANALYSIS:

1. **Determine the Limits of the Study Network.** Given the characteristics of the study area, it is not anticipated that adjacent intersections will need to be included in the analysis. However, to verify this, the work zone queue length was approximated. For this calculation, it was assumed that the cycle length for the two signals would be 250 seconds, with green allocated proportional to approach volumes. **Table 1** summarizes the signal timing information, through traffic volumes, and estimated queue lengths (based on the equation presented in Section II.C of *The Guide*) for each approach by peak hour.

Table 1. Summary of Queue Length Approximations – AM (PM)

Approach	Thru Volume (vph)	Thru Green (sec.)	Cycle Length (sec.)	Est. Queue Length	
				# veh	feet
Eastbound	632 (513)	120 (100)	250 (250)	44 (36)	1,100 (900)
Westbound	677 (754)	130 (150)	250 (250)	47 (52)	1,175 (1,300)

Based on the results presented in the table, the work zone queue is expected to extend, at most, 1,100' west of the intersection and 1,300' east of the intersection. Therefore, it will not be necessary to include other intersections in the study network.

2. **Data Collection.** In order to determine the limits of the study network, it was necessary to begin collecting data for the traffic volumes along MD 23 at the bridge. A traffic count performed in February 2004 was obtained from the SHA-maintained database. Traffic volumes were adjusted to April (the heaviest month of the year) and a growth factor (estimated at 2.6%) was applied to update traffic volumes to the year 2007. Because there is no existing intersection at the study location, intersection observations were not required.

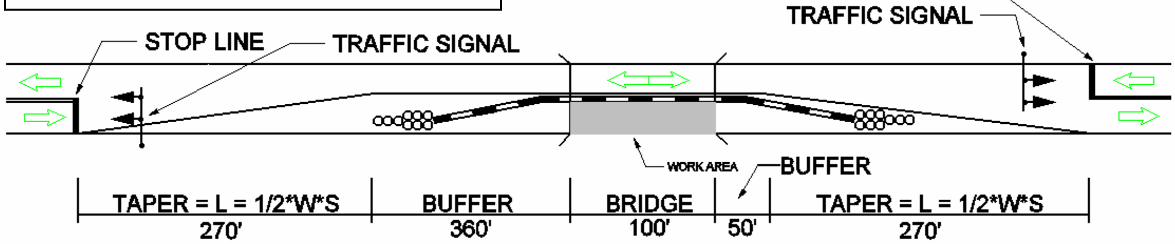
3. **Modeling – Existing Conditions.** Because there are no existing intersections at, or in the vicinity of, the study location, it was not possible to create a model for the existing conditions.

4. **Modeling – Calibration and Validation.** Because no model of existing conditions was created, there was no need to do any calibration or validation.

5. **Modeling – Obtain Model Outputs.** Because no model of existing conditions was created, there was no need to obtain existing model outputs.

6. **Modeling – Code Work Zone Model.** Based on the speed of the roadway (45 mph), a buffer length of 360' and a taper of 270' are required prior to the beginning of the work zone. Based on these assumptions, the work zone is expected to be 1,050' long. **Figure 2** shows the assumed work zone lane configurations at the bridge.

Figure 2:
1-Lane Bridge Work Zone Layout



To create the Synchro model for this alternative, two intersections, placed 1,050' apart, were created along the link representing MD 23. Based on the calculations of the estimated queue lengths, MD 23 was modeled for 2,200' on either end of the bridge. The two intersections were signalized and coded as fully actuated intersection controlled by one controller through the use of the "Cluster Editor" option in Synchro.

Clearance intervals for the signal timings at the two intersections were developed using SHA's *Policy for Determining Yellow Timings at Intersections* and the Institute of Transportation Engineers (ITE's) *Traffic Signal Design Handbook.* Based on these guidelines, **Table 2** presents the yellow and all-red times used for this example, where t is the perception-reaction time (assumed to be 1 sec), V_{posted} is the posted speed limit (45 mph), $V_{operating}$ is the operating speed (assumed to be 35 mph), a is the acceleration (10 ft/s^2), W is the total work zone length (1,050 ft), and L is average vehicle length (assumed to be 25 ft).

Table 2. Clearance Interval Calculations

Interval	Equation	Duration (sec)
Yellow (Y)	$t + 1.47 * V_{posted}/(2a)$	4.5
All-Red (AR)	$(W + L) / 1.47 * V_{operating}$	21
Total Clearance (CL)	$Y + AR$	25.5

The cycle length for the two signals was determined based on the requirement that the queues in each direction should clear during each cycle. This is comparable to the method used for flagging operations, where a flagger will only stop a particular direction once the queue has cleared. It was assumed that queues would disperse at an average flow rate of 2.2 seconds per vehicle, and that the total green time required during each cycle to dissipate queues would be equal to the volume per cycle multiplied by the dissipation rate. An expression was developed for the minimum necessary cycle length based on these assumptions, and is presented below, where G is the cumulative green time per cycle for both directions, V is the total hourly volume for both directions, CL is the total clearance interval for each direction, and C is the total cycle length.

$$C = 2.2 \frac{V * C}{3600} + 2CL$$

Based on this expression, cycle lengths of 250 and 220 seconds would be required for AM and PM peaks, respectively. Cycle lengths and clearance intervals, as indicated above, were entered into Synchro models for both AM and PM peaks.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for the two intersections during each peak period. **Table 3** summarizes the control delays for both approaches to the bridge during both peak periods. It should be noted that SimTraffic simulations of this model showed lower delays at the intersections than did the Synchro model. The Synchro reports for the work zone conditions during the PM peak are presented at the conclusion of this example.

Table 3. Synchro Model Outputs – Work Zone Conditions

Approach	Control Delay (sec.)	
	AM Peak	PM Peak
Eastbound	195.2	221.4
Westbound	188.3	196.2

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Table 3, control delays are expected to be less than 3.7 minutes per vehicle for both approaches during either peak period. In this case, the control delay is equal to the expected increase in travel time through the work zone. Therefore, this work zone alternative will satisfy the 15-minute travel time increase limit, and no other alternatives need be explored. If it were desired to evaluate the mobility threshold using SimTraffic simulations rather than Synchro outputs, the travel times in each direction for each peak (obtained from

SimTraffic's *Arterial Report*) could have been compared with the estimated running time through the network, which is equal to the total distance divided by the travel speed. The difference between the two values is equal to the increase in travel time. In this case, SimTraffic simulations show queues and delays 20% – 30% shorter than those shown in the Synchro reports.

9. **Recommend an Alternative.** Based on the results of the analysis presented in this study, the recommended work zone alternative is reconstruct one lane existing bridge at a time, controlling the two-way traffic over the bridge either by flagging or installing temporary traffic signals at either end of the work zone. Because the bridge meets the mobility thresholds during the AM and PM peaks, the one-lane, two-way traffic option is feasible for all times of day. **Table 4** summarizes the recommended work zone alternative.

Table 4. Recommended Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Reconstruct one lane of the existing bridge at a time, using temporary traffic signals to control the two-way traffic	24/7 signal operations are acceptable/required

Movement	EBL	EBT	WBT	WBR	SBL	SBR
Lane Configurations		↑	↑			
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Total Lost time (s)		44.0	44.0			
Lane Util. Factor		1.00	1.00			
Frt		1.00	1.00			
Flt Protected		1.00	1.00			
Satd. Flow (prot)		1863	1863			
Flt Permitted		1.00	1.00			
Satd. Flow (perm)		1863	1863			
Volume (vph)	0	513	754	0	0	0
Peak-hour factor, PHF	0.90	0.90	0.90	0.90	0.90	0.90
Adj. Flow (vph)	0	570	838	0	0	0
RTOR Reduction (vph)	0	0	0	0	0	0
Lane Group Flow (vph)	0	570	838	0	0	0
Turn Type						
Protected Phases		1	Free			
Permitted Phases						
Actuated Green, G (s)		71.5	220.0			
Effective Green, g (s)		53.0	220.0			
Actuated g/C Ratio		0.24	1.00			
Clearance Time (s)		25.5				
Vehicle Extension (s)		3.0				
Lane Grp Cap (vph)		449	1863			
v/s Ratio Prot		c0.31	0.45			
v/s Ratio Perm						
v/c Ratio		1.27	0.45			
Uniform Delay, d1		83.5	0.0			
Progression Factor		1.00	1.00			
Incremental Delay, d2		137.9	0.1			
Delay (s)		221.4	0.1			
Level of Service		F	A			
Approach Delay (s)		221.4	0.1		0.0	
Approach LOS		F	A		A	

Intersection Summary			
HCM Average Control Delay	89.7	HCM Level of Service	F
HCM Volume to Capacity ratio	0.70		
Actuated Cycle Length (s)	220.0	Sum of lost time (s)	44.0
Intersection Capacity Utilization	76.4%	ICU Level of Service	D
Analysis Period (min)	15		
c Critical Lane Group			

EB MD 23 Control Delay

Movement	EBL	EBT	WBT	WBR	SBL	SBR
Lane Configurations						
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900
Total Lost time (s)		44.0	44.0			
Lane Util. Factor		1.00	1.00			
Frt		1.00	1.00			
Flt Protected		1.00	1.00			
Satd. Flow (prot)		1863	1863			
Flt Permitted		1.00	1.00			
Satd. Flow (perm)		1863	1863			
Volume (vph)	0	513	754	0	0	0
Peak-hour factor, PHF	0.90	0.90	0.90	0.90	0.90	0.90
Adj. Flow (vph)	0	570	838	0	0	0
RTOR Reduction (vph)	0	0	0	0	0	0
Lane Group Flow (vph)	0	570	838	0	0	0
Turn Type						
Protected Phases		Free	2			
Permitted Phases						
Actuated Green, G (s)		220.0	97.5			
Effective Green, g (s)		220.0	79.0			
Actuated g/C Ratio		1.00	0.36			
Clearance Time (s)			25.5			
Vehicle Extension (s)			3.0			
Lane Grp Cap (vph)		1863	669			
v/s Ratio Prot		0.31	c0.45			
v/s Ratio Perm						
v/c Ratio		0.31	1.25			
Uniform Delay, d1		0.0	70.5			
Progression Factor		1.00	1.00			
Incremental Delay, d2		0.0	125.7			
Delay (s)		0.0	196.2			
Level of Service		A	F			
Approach Delay (s)		0.0	196.2		0.0	
Approach LOS		A	F		A	

Intersection Summary			
HCM Average Control Delay	116.8	HCM Level of Service	F
HCM Volume to Capacity ratio	0.73		
Actuated Cycle Length (s)	220.0	Sum of lost time (s)	44.0
Intersection Capacity Utilization	76.4%	ICU Level of Service	D
Analysis Period (min)	15		
c Critical Lane Group			

WB MD 23 Control Delay

EXAMPLE J: ARTERIAL SEGMENT (TWO-LANE, TWO-WAY) – FULL DETOUR GROSVENOR LANE BRIDGE OVER I-270

SITE DESCRIPTION:

Grosvenor Lane is a two-lane, two-way roadway that runs between MD 355 (Rockville Pike) and MD 187 (Old Georgetown Road). Tuckerman Lane is a parallel route ¾ mile north of Grosvenor Lane, and I-495 is a parallel route ¼ mile south of Grosvenor Lane. **Figure 1** shows the study area and the proposed detour signing.

OBJECTIVE:

The proposed work for this example is the reconstruction of the Grosvenor Lane bridge over I-270. Based on the nature of the work to be performed, this bridge must be closed to all traffic during construction. The proposed detour routes will be via Tuckerman Lane for traffic from the north, or via I-495 for traffic from the south. The objective of this work zone analysis is to determine (1) if the proposed detour routes will meet mobility thresholds, and (2) if not, determine if there are any mitigation measures that can be used.

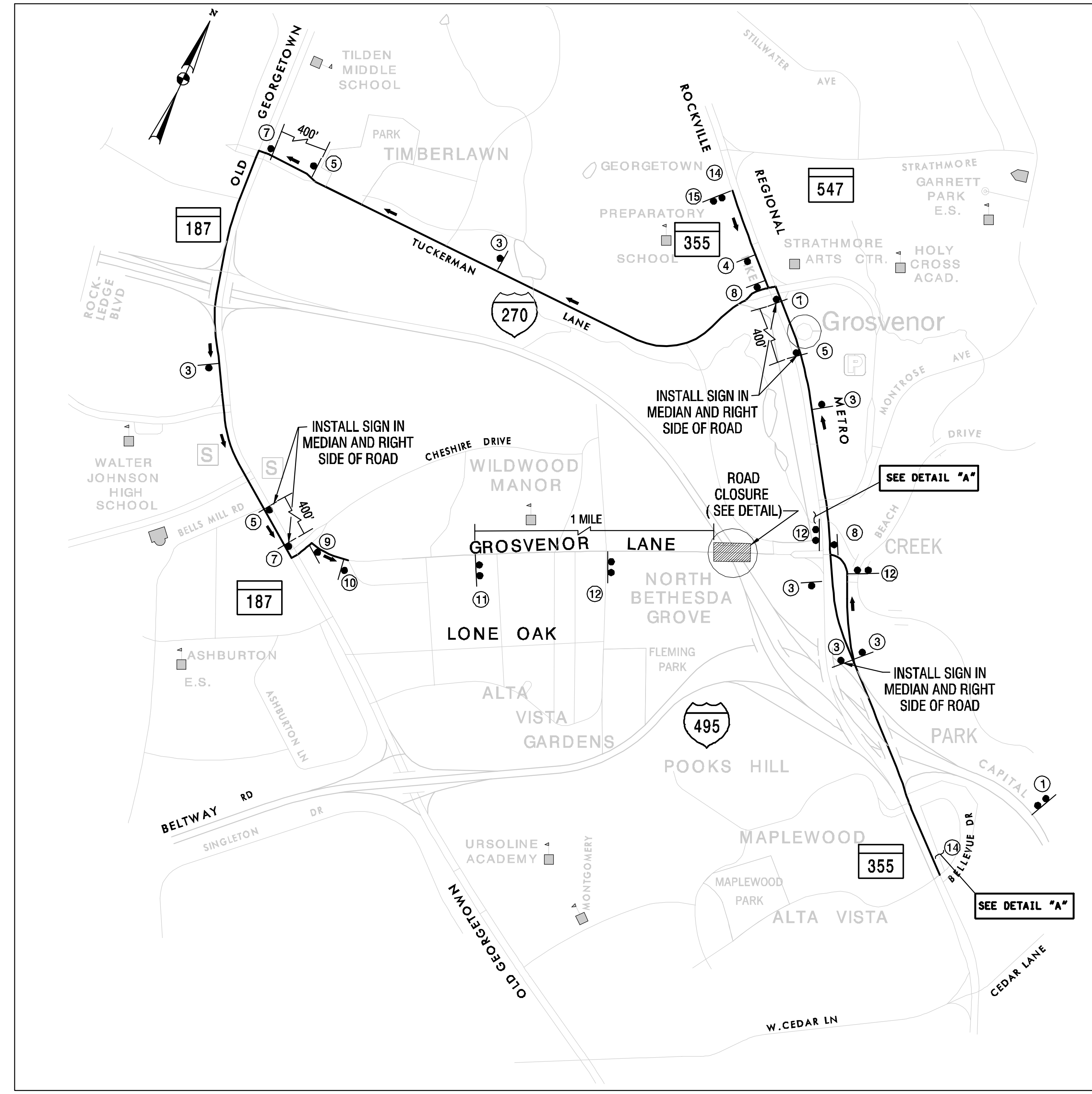
ANALYSIS:

1. **Determine the Limits of the Study Network.** Because this example involves the use of a detour, it will not be necessary to determine any queue lengths. Instead, the limits of the study network will be determined based on the intersections included in the detour and existing intersections along Grosvenor Lane. It was assumed that the detour routes would include MD 355 (from I-495 to Tuckerman Lane), Tuckerman Lane (from MD 355 to MD 187), and MD 187 (from Tuckerman Lane to I-495).

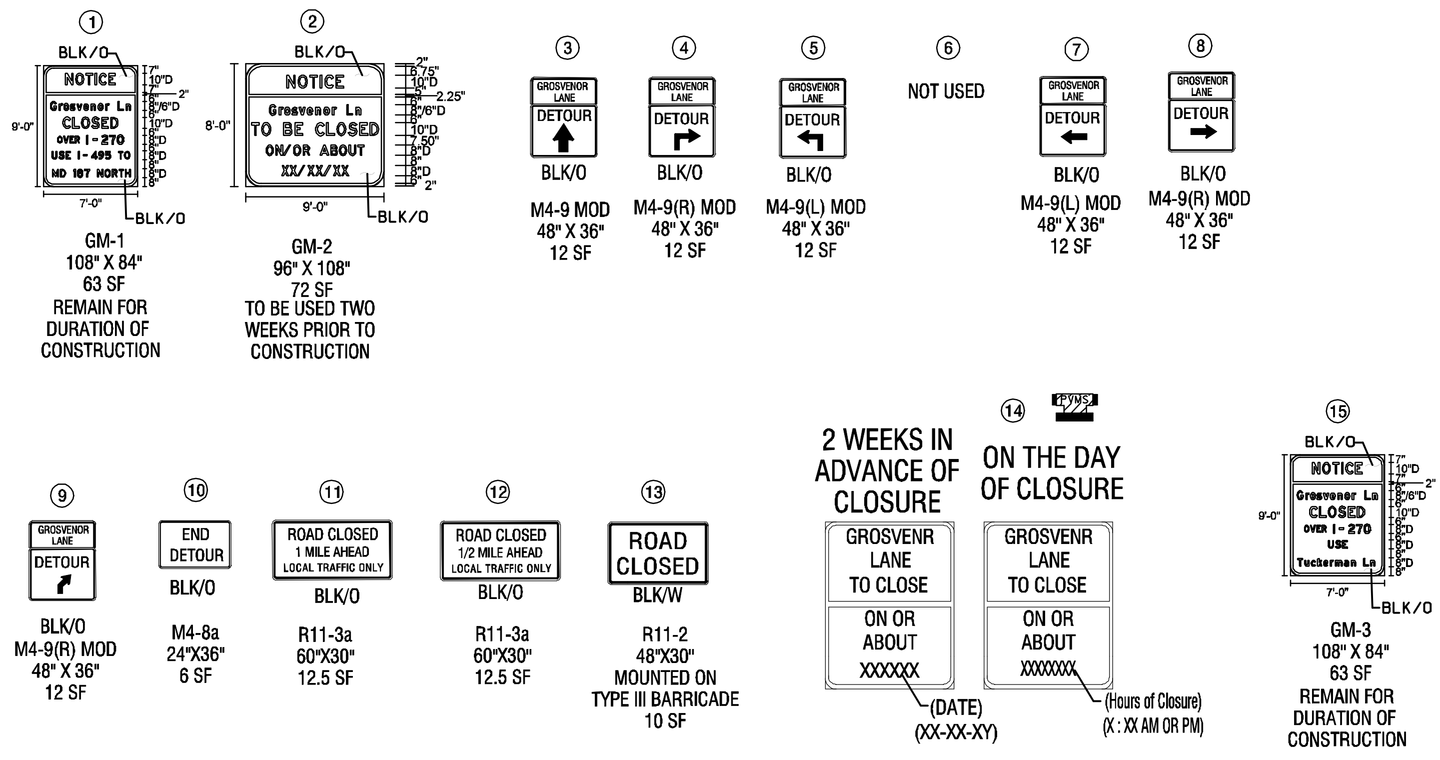
   By obtaining the signal timings from SHA's Signal Shop and the Montgomery County Transportation Management Center, it is evident that MD 355 and MD 187 are part of a coordinated signal system. However, due to the length of the signal system, it is not feasible to include the entire system in the analysis model. Therefore, the study network will be limited to intersections on Grosvenor Lane and along the proposed detour routes.

2. **Data Collection.** Signal timings and phasing for all intersections in the study network were obtained from the Montgomery County Transportation Management Center and SHA's Signal Shop. Turning movement counts for the intersections along MD 355 and MD 187 were obtained from the SHA-maintained database. AM and PM peak hour spot turning movement counts were collected at the intersection of Tuckman Lane with Sugarbush Lane and the intersections of Grosvenor Lane with Tuckman Lane, Grosvenor Place, Hurst Street, and Cheshire Drive. Additionally, network volumes were balanced using the results of the spot intersection counts. Preliminary lane configurations were obtained from SHA-provided Syncrho models of the MD 187 and MD 355 corridors, and were verified during field visits. Field observations included queue lengths, general travel patterns, and overall traffic operations.

DETOUR ROUTE FOR GROSVENOR LANE CLOSURE

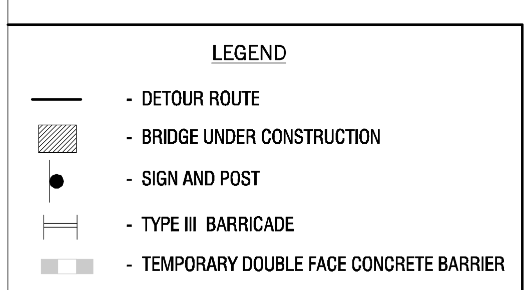


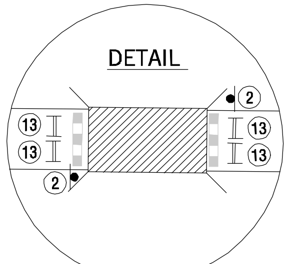
DETOUR SIGNS

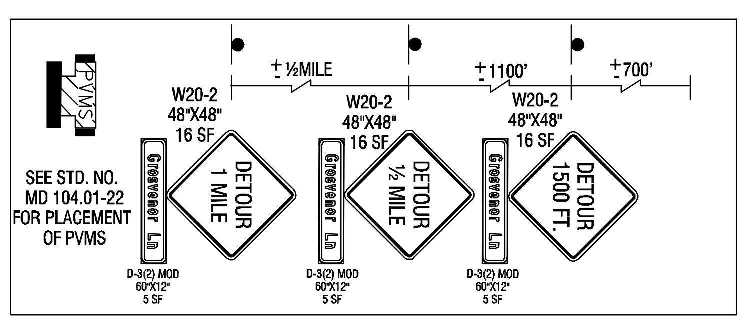


SIGN COLOR LEGEND

O - ORANGE
BLK - BLACK







DETAIL "A"

A. Origin-Destination Study

Origin-destination studies were performed in both directions of Grosvenor Lane to determine the amount of cut-through traffic between MD 355 and MD 187. This data was collected to help define the assumptions for volume redistribution under the detour scenario. The studies were performed using the license plate methodology. The cut-through percentages obtained during these studies are presented in **Table 1**. Based on the results presented in this table and field observations, there is very little cut-through traffic traveling along Grosvenor Lane.

Table 1. Origin-Destination Study – Percentage Cut-Through Traffic

Direction	AM Peak (%)	PM Peak (%)
Eastbound	0	< 10%
Westbound	5	8

B. Travel Times

In addition to the origin destination study performed for the study network, travel times were collected. Travel times were collected based on the concept that local traffic will not use the proposed detour route if there is an alternate route that is faster. Travel times were measured for traffic from the south and the east (via MD 355 and I-495). Travel times were not measured for traffic from the west since the origin-destination study indicates that motorists coming from the west would already use MD 187 to access Tuckerman, and would therefore not be affected by the bridge closure.

Travel times were measured between I-495 at the MD 355 interchange and MD 187 at Cheshire Drive using Tuckerman Lane, I-495 and Grosvenor Lane. The field-measured travel times are presented in **Table 2**.

Table 2. Travel Time Study Results

MD 355/I-495 to MD 187, via:	AM Peak (min:sec)	PM Peak (min:sec)
Tuckerman Lane	11:30	9:30
I-495	3:30	4:00
Grosvenor Lane	4:30	5:00

Based on the travel times collected, the most likely detour route is I-495 rather than Tuckerman Lane because travel times along I-495 are faster than those along Tuckerman Lane by 8 minutes during the AM peak and 5.5 minutes during the PM peak. Travel times were not measured from the north as it was assumed that the fastest alternative route would be Tuckerman Lane.

3. **Modeling – Existing Conditions.** Synchro models of intersections along MD 355 and MD 187 were obtained from the SHA-maintained database. These models were consolidated and the intersections along Tuckman and Grosvenor Lanes were added to the model. All data from the SHA-obtained models was verified using the data previously collected for this study.

4. **Modeling – Calibration and Validation.** The SHA-obtained model for MD 355 was created as part of a signal timing optimization project, and hence was already calibrated and validated when the model was created. Given the fact that volume redistributions will be performed for the work zone model, which will impact lane utilization factors and saturation flow rates, it was determined that further calibration of the model was not necessary, as values calibrated could not be used in the work zone conditions model.

5. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for each of the signalized intersections within the study network and the *HCM Unsignalized* report was printed for the stop-controlled intersection of Grosvenor Lane with Cheshire Drive. **Table 3** summarizes the control delays and levels of service for each intersection in the study network. Because the work zone involves a detour, it is necessary to evaluate the mobility thresholds for arterial segments. Five (5) SimTraffic simulations with seeding times of 15 minutes and running times of 30 minutes were performed for the existing conditions model and average travel times along the proposed detour route (via Tuckerman Lane) were obtained using SimTraffic's *Arterial Report*, and reported in Table 3.

Table 3. Synchro Model Outputs – Existing Conditions

Intersection	Control Delay		Level of Service	
	AM Peak	PM Peak	AM Peak	PM Peak
MD 355/Grosvenor Ln	35.0	44.3	D	D
MD 355/Tuckerman Ln	13.9	8.3	B	A
MD 355/Tuckerman Ln	39.3	46.7	D	D
Tuckerman Ln/Grosvenor Pl	11.5	6.9	B	A
Tuckerman Ln/Sugarbush Ln	20.2	21.7	C	C
MD 187/Tuckerman Ln	66.4	52.5	E	D
MD 187/I-270 NB Ramps	18.5	14.6	B	B
MD 187/I-270 SB Ramps	36.0	28.9	D	C
MD 187/Rock Spring Dr	20.9	32.9	C	C
MD 187/Democracy Blvd	31.0	45.6	C	D
MD 187/Cheshire Dr	14.4	19.1	B	B
Cheshire Dr/Grosvenor Ln	12.6	11.4	B	B
MD 187/I-495 WB Ramps	20.3	27.1	C	C
MD 187/I-495 EB Ramps	74.1	41.0	E	D
EB Detour Travel Time			**8.2 min**	**8.3 min**
WB Detour Travel Time			**13.0 min**	**10.8 min**

6. **Modeling – Code Work Zone Model.** Because the road closure is along a road segment, no changes to the existing lane configurations are needed for the work zone model. Therefore, the only changes that need to be made to the existing conditions model are to the traffic volumes as a result of volume redistributions.

A. Redistribution of Traffic Volumes

Based on the data collected for this study, several conclusions, as noted below, were made to form the basis for redistributing existing traffic volumes under the proposed roadway closure scenario.

- From the origin-destination survey results, it is concluded that traffic using Grosvenor Lane is generally local traffic with trip origins and destinations within the communities served by Grosvenor Lane.
- Based on the travel time runs, the fastest route for the vehicles traveling from the south and east to the west side of Grosvenor Lane is via I-495 and MD 187. Although Tuckerman Lane will be signed as the official detour route, the nature of traffic using Grosvenor Lane is mostly local traffic. It was assumed that local traffic will adapt their travel patterns to use the fastest route based on their familiarity with the roadways.
- Although the above conclusions would lead to assigning nearly 100% of the trips from the south and east to I-495, a conservative assumption was made that only 75% of the trips would divert to I-495. The remaining 25% (note that this is higher than the 10% cut-through traffic value collected in the origin-destination study) would use the official Tuckerman Lane detour route. This 25% would account for the local deliveries, out-of-town visitors, and cut-through traffic currently using Grosvenor Lane.
- A similar assumption was made regarding trips from the north on MD 355. The signed detour route will be to use I-495 to MD 187. Since the signed detour route will have a longer travel time than using Tuckerman Lane, only 25% of the trips are distributed to the signed detour route.

Therefore, the following assumptions are made for traffic redistribution.

- Existing traffic using Grosvenor Place to WB Grosvenor Lane will be redistributed to use Tuckerman Lane.
- Of the existing traffic using SB MD 355 to WB Grosvenor Lane:
  - 25% will be redistributed to use I-495, and
  - 75% will be redistributed to use Tuckerman Lane
- Of the existing traffic using NB MD 355 to WB Grosvenor Lane:
  - 50% will be redistributed to use I-495, and
  - 50% will be redistributed to use Tuckerman Lane
- Of the existing traffic using EB Grosvenor Lane west of Grosvenor Place:
  - 100% of the traffic that is headed north on MD 355 will be redistributed to use MD 187 north to Tuckerman Lane, and
  - 100% of the traffic headed south on MD 355 will be redistributed to use MD 187 south to I-495.
- The remainder of existing traffic on eastbound and westbound Grosvenor Lane between MD 187 and the study bridge will not be redistributed. It is assumed that this is local traffic with an origin/destination in the community.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for each of the signalized intersections within the study network and the *HCM Unsignalized* report was printed for the intersection of Grosvenor Lane with Cheshire Drive. **Table 4** summarizes the control delays and levels of service for each intersection in the study network. Five (5) SimTraffic simulations with seeding times of 15 minutes and running times of 30 minutes were performed for the existing conditions model and average travel times along the proposed detour route were obtained using SimTraffic's *Arterial Report*, and reported in Table 4.

Table 4. Synchro Model Outputs – Detour Conditions

Intersection	Control Delay		Level of Service	
	AM Peak	PM Peak	AM Peak	PM Peak
MD 355/Grosvenor Ln	22.6	17.2	C	B
MD 355/Tuckerman Ln	16.3	9.2	B	A
MD 355/Tuckerman Ln	46.8	53.1	D	D
Tuckerman Ln/Grosvenor Pl	14.1	9.7	B	A
Tuckerman Ln/Sugarbush Ln	21.7	22.5	C	C
MD 187/Tuckerman Ln	***115.1***	57.1	***F***	E
MD 187/I-270 NB Ramps	18.5	14.6	B	B
MD 187/I-270 SB Ramps	37.0	29.8	D	C
MD 187/Rock Spring Dr	20.9	34.5	C	C
MD 187/Democracy Blvd	31.0	45.6	C	D
MD 187/Cheshire Dr	21.5	41.6	C	D
Cheshire Dr/Grosvenor Ln	***81.5***	***67.1***	***F***	***F***
MD 187/I-495 WB Ramps	***55.3***	35.3	***E***	D
MD 187/I-495 EB Ramps	71.7	42.0	E	D
EB Detour Travel Time			**7.9 min**	**10.8 min**
WB Detour Travel Time			***29.0 min***	**11.7 min**

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 3 and 4, it is expected that mobility thresholds will be violated at the intersections of Grosvenor Lane with Cheshire Drive (maximum LOS D and control delay of 30 seconds is violated during AM and PM peaks) and MD 187 with Tuckerman Lane (maximum 30% increase in control delay is violated during AM Peak) and the WB I-495 Ramps (maximum LOS D and control delay of 45 seconds is violated during AM Peak). Performance measures shown in ***bold red*** in the table are those where the mobility thresholds are violated. Evaluating the roadway segment mobility threshold shows that the work zone will result in maximum increases in average travel times along the detour route of 16.0 (which exceeds the 15-minute limit mobility threshold) and 2.5 minutes during the AM and PM peaks, respectively.

   Because the nature of the work requires that the Grosvenor Lane bridge over I-270 be completely closed for the duration of construction, the only other available work zone alternatives are mitigation measures. These methods could include implementing alternate signing methods to adjust the trip redistribution assumptions or adjusting signal timings to improve intersection operations. A cursory look at adjusting trip redistribution assumptions indicates that any adjustments would take away volume from one of the failing intersections, but would add volume to the other failing intersection. Therefore, this alternative will not be considered and the next alternative to be evaluated will be adjusting intersection signal timings. To address to failing detour conditions at the unsignalized intersection of Grosvenor Lane with Cheshire Drive, the next alternative will also include the installing a temporary traffic signal at this intersection for the duration of the bridge closure.

6. **Modeling – Code Alternate Work Zone Model.** The work zone conditions model was adjusted to include a traffic signal at the intersection of Grosvenor Lane with Cheshire Drive and signal timings at the intersections of MD 187 with Tuckerman Lane and the WB I-495 Ramps were optimized during the AM peak only.

7. **Modeling – Obtain Model Outputs.** Synchro's *HCM Signals* reports were printed for modified intersections. **Table 5** summarizes the control delays and levels of service for each of those intersections. Five (5) SimTraffic simulations with seeding times of 15 minutes and running times of 30 minutes were performed for the alternate detour model for the AM peak and average travel times along the proposed detour route were obtained using SimTraffic's *Arterial Report*, and reported in Table 5. Note that simulations were not performed on the PM peak model because this model did not involve any changes in signal timings along the detour route.

Table 5. Synchro Model Outputs – Alternate Detour Conditions

Intersection	Control Delay		Level of Service	
	AM Peak	PM Peak	AM Peak	PM Peak
MD 187/Tuckerman Ln	***90.0***	57.1	***F***	E
Cheshire Dr/Grosvenor Ln	25.2	28.0	C	C
MD 187/I-495 WB Ramps	***49.2***	35.3	***D***	D
EB Detour Travel Time			**7.8 min**	
WB Detour Travel Time			**17.2 min**	

8. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Tables 3 and 5, control delays at the intersections of MD 187 with Tuckerman Lane and the WB I-495 Ramps will continue to violate the mobility thresholds (see the performance measures shown in the table in ***bold red***) even after signal optimization. However, the installation of a temporary traffic signal at the intersection of Grosvenor Lane with Cheshire Drive will permit the intersection to operate at an acceptable level of service. SimTraffic simulations of the model show that adjusting signal timings would reduce the travel time along the detour route such that the route would meet mobility thresholds for roadway segments.

   Due to the characteristics of the work to be performed and of the study area, there are no other available work zone alternatives that can be considered. However, a sensitivity analysis was performed to determine the number of trips that would have to be diverted away from the two critical intersections on MD 187 so that these intersections would meet the mobility thresholds. Based on this analysis, the left-turning volume from westbound Tuckerman Lane onto MD 187 would have to be reduced by 250 vehicles per hour for the intersection to have a control delay below 80 seconds, and the right-turning volume from the westbound I-495 Off-Ramp onto MD 187 would have to be reduced by 75 vehicles per hour for this intersection to have a control delay below 45 seconds. This analysis was performed based on the assumption that no signal timings in the network would be adjusted from the existing peak hour signal timings.

9. **Recommend an Alternative.** Based on the analysis performed, it appears that the installation of a temporary traffic signal at the intersection of Cheshire Drive and Grosvenor Lane may be necessary; however, it is recommended that further study be performed to determine if a traffic signal would be warranted and the Montgomery County Transportation Management Center should be consulted to determine if they feel that the installation of the temporary traffic signal is necessary given the expected during of construction. Based on the results of the sensitivity analysis performed, it is recommended that mitigation measures (such as public information and outreach efforts to shift demand) be considered to divert trips away from the two critical intersections.

APPENDIX B – ARTERIAL WORK ZONE ANALYSIS CHECKLIST

APPENDIX B: ARTERIAL WORK ZONE ANALYSIS CHECKLIST

1. Does the network include all impacted intersections/interchanges?

2. Is the study network large enough to be able to estimate the impact of residual queues among the MOT alternatives? If not, explain why the study network was limited.

3. Does the proposed mitigation plan include modifications to signal timings? If so, and if the work zone impacts a coordinated signal system, does the mitigation plan cover the entire limits of the coordinated signal system? If not, provide justification.

4. Were traffic volumes less than 3 years old used for the analysis? If not, provide justification.

5. Were appropriate adjustment factors applied to traffic volumes to account for traffic volumes expected during construction? If not, provide justification.

6. Were field observations of existing conditions performed?

7. Were existing traffic signal plans, signal timings, and signal phasing obtained and field verified? If not, provide justification.

8. Was an existing Synchro model provided by SHA OOTS for this project? If so, was it verified prior to use?

9. If a detour was evaluated, was origin-destination data collected? If not, how was origin-destination data estimated?

10. For simulations, does the animation visually resemble existing field conditions within the acceptable tolerances?

11. Was the model calibrated and validated? If not, provide justification.

12. Were buffer length and tapers lengths included in the traffic analysis?

13. Does the recommended alternative meet all mobility thresholds? If not, provide justification, and list recommended mitigation strategies.

14. If all mobility thresholds are satisfied, are there any other operational or safety impacts expected? If so, are they outlined in the report?

15. Does the recommendation include a lane closure schedule (number of lanes to be closed, permitted work hours, proposed construction sequence, etc.)?

16. Were all analysis objectives met through the course of the study?

APPENDIX C – FREEWAY WORK ZONE ANALYSIS EXAMPLES

APPENDIX C: FREEWAY WORK ZONE ANALYSIS EXAMPLES

To illustrate the application of the analysis steps presented in this Guide, several examples have been developed. Each example represents the analysis procedures for different site conditions and includes explanations of the analysis process and, where necessary, the process of developing additional alternatives. The site conditions evaluated are as follows:

Example	Analysis Tool	Objective
A. Freeway Lane Reduction(s) Without Ramp Influences	LCAP	Lane Closure Schedule
B. Freeway Lane Reduction(s) With Ramp Influences[1]	CORSIM/VISSIM/ HCS	Queue Length/Network Impacts
C. Work Zone Adjacent to Freeway Lanes	LCAP/Spreadsheet	Capacity Reduction Impacts (No Lane Closures)
D. Full Roadway Closure With Detour	CORSIM	Determine Allowable Closure Type and Duration
E. Multi-Lane Arterial Segment With Lane Reductions	QuickZone	Determine Number of Construction Phases
F. Arterial/Freeway Network – Full Roadway Closure with Detour	QuickZone/HCS/ CORSIM/Synchro	Network Impacts from Full Closure

1. No detailed example is provided for this scenario

A. Freeway Lane Reduction(s) Without Ramp Influences

Work zones on freeways often require the reduction of travel lanes. Such lane reductions can either be along freeway segments with or without ramp influences. Lane reductions along segments without ramp influences may be used for maintenance activities (such as resurfacing) and construction activities (such as widening). To illustrate the type of analysis required for lane reductions on a freeway segment without ramp influences, an example work zone was developed along I-95 in Howard County. For this example, resurfacing of the full roadway width was proposed. The complete example is included.

B. Freeway Lane Reduction(s) With Ramp Influences

Work zones along freeways at or near interchanges may impact existing ramps. Impacts to existing ramps could include changes to existing acceleration/deceleration lengths, reduction in number of ramp lanes, or work zones downstream of ramps where the work zone queue may extend onto existing ramps. For such work zones, analysis of mainline operations can be estimated using the same methods used for freeway sections without ramp influences. For analysis of ramp operations, CORSIM/VISSIM simulations and/or HCS analysis may be the best methods. When ramp operations are analyzed, the primary concern is to ensure that ramp queues do not extend beyond the limits of the ramp and that no other significant operational problems are observed. Because analysis of these sites is similar to the analysis of freeway sections without ramp influences, an example of work zone analysis for this type of work zone is not included.

C. Work Zone Adjacent to Freeway Lanes

Work zones on freeways may not require lane reductions on the mainline. Instead, work may be limited to the shoulder or traffic may be shifted onto the existing shoulder in order to maintain the existing number of lanes. To illustrate the type of analysis required for road work adjacent to travel lanes, an example work zone was developed along MD 97 (Georgia Avenue) in Olney, Montgomery County. For this example, the construction of two bridges on MD 97 to go over the proposed Intercounty Connector was proposed. This example focuses on determining the reduction in capacity due to reduced lane and shoulder widths during a temporary roadway crossover. The complete example is included.

D. Full Roadway Closure with Detour

There are several types of work zones that will require a full roadway closure on a freeway for some duration. Most common work zones requiring full roadway closures are work zones related to the demolition, construction, or reconstruction of bridges on or over the freeway. Full roadway closures may require the redistribution of traffic volumes onto detour routes and lane reductions on the freeway to fit traffic onto interchange ramps. For this type of work zone, it was assumed that impacts will be limited to freeways. To illustrate the type of analysis required for such a work zone, an example work zone was developed on I-95/I-495 (Capital Beltway) at MD 5 (Branch Avenue). For this example, the complete reconstruction of the existing I-95/I-495 overpass was proposed, and the analysis focused on the allowable hours for a full roadway closure with detour or a multi-lane closure without detours. The complete example is included.

E. Multi-Lane Arterial Segment with Lane Reductions

Analysis of this type of site can generally be performed using freeway work zone analysis techniques. Generally, for such a project, lanes will be reduced in one or both directions of the roadway while maintaining at least one lane in each direction. Analysis of these conditions can be performed using freeway analysis techniques and by using the freeway work zone mobility thresholds. To illustrate the type of analysis required for such a work zone, an example work zone was developed along US 1 over Little Gunpowder Falls on the Baltimore/Harford County line. For this example, the complete reconstruction of the existing bridge was proposed, and the analysis focused on determining the number of construction phases needed. The complete example is included.

F. Arterial/Freeway Network – Full Roadway Closure with Detour

There are several types of work zone that can involve impacts to traffic on both arterials and freeways that are a part of a network. Example work zones include the reconstruction of a bridge on an arterial (or freeway) over a freeway (or arterial), a full or partial roadway closure that will detour vehicles from an arterial (or freeway) onto a freeway (or arterial), and the construction (or reconstruction of an interchange between an arterial and a freeway. Work zones that impact both freeway and arterial operations require the evaluation of freeway mobility thresholds on freeway sections and arterial mobility thresholds on arterial sections. To illustrate the type of analysis required for such a work zone, an example work zone was developed on MD 5 (Branch Avenue) over I-95/I-495 in Prince George's County. For this example, the erection of structural steel for a new ramp over MD 5 was proposed, and the analysis focused on determining allowable hours for a full roadway closure on MD 5 and subsequent detour of all traffic onto I-95/I-495. The complete example is included.

EXAMPLE A: FREEWAY LANE REDUCTION(S) WITHOUT RAMP INFLUENCES
I-95 IN HOWARD COUNTY (ROADWAY RESURFACING)

SITE DESCRIPTION:

I-95 is an eight-lane, two-way divided interstate highway that runs in a north-south direction through Howard County, Maryland. **Figure 1** shows an area map of the study location.

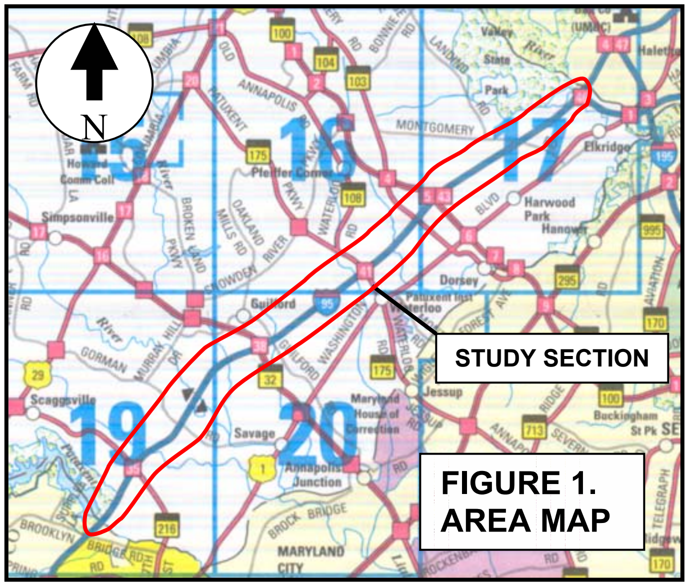


FIGURE 1.
AREA MAP

OBJECTIVE:

Roadway resurfacing of the full roadway width of northbound and southbound I-95 is proposed, excluding any resurfacing on the interchange ramps. It is anticipated that this work will be accomplished by resurfacing two travel lanes at a time (in one mile long segments) while providing a one-lane buffer with drums adjacent to the work zone. The objective of this analysis is to determine the time periods when three lanes on the mainline may be closed.

ANALYSIS:

1. **Determine the Limits of the Study Network.** For this analysis, it was assumed that resurfacing will be performed in one-mile long sections along I-95. Therefore, the length of the study network will be the one-mile work zone length plus the appropriate buffer and taper lengths approaching the work zone. The area required for buffer and taper lengths for a three-lane closure is approximately ½ mile, so the work zone length that will be used for this analysis will be 1.5 miles.

2. **Data Collection.** Existing traffic volume data from permanent count station P0039 (I-95 South of MD 103) were obtained from the SHA TMS website. Traffic volumes obtained from this count station were for the month of May which, based on Common Reports from *Traffic* Trends, is representative of the highest traffic volumes during the year. Therefore, it is not necessary to adjust this traffic data for seasonal fluctuations. The SHA's *Highway Location Reference* manual was used to verify the number of mainline lanes throughout the study section.

3. **Determine the Analysis Method.** Due to the simplicity of this work zone situation, LCAP is the recommended analysis method. Because simulation modeling will not be required for example, the creation of an existing conditions model and subsequent model calibration and validation are unnecessary.

4. **Modeling – Code Work Zone Model.** The first step in modeling work zone conditions with LCAP is to determine the work zone capacity. For this example, the work zone capacity was

calculated using the three available capacity approximations. The results of these calculations are summarized below.

- Model 1: SHA Work Zone Guidelines: Work zone capacity using SHA's Lane Closure Analysis Guidelines is not available from four lanes to one lane. However, from three lanes to one lane the work zone capacity is 1170 vphpl.
- Model 2: University of Maryland Equation: Assuming 13% trucks, 1.5 mile work zone length, and 1 ft lateral clearance, the UMD equation approximates the work zone capacity as 1277 vphpl.
- Model 3: HCM 2000 Short-Term Work Zone: Assuming 13% trucks and rolling terrain, the HCM Short Term Work Zone equation approximates the work zone capacity as 1339 vphpl.

For this analysis, the average estimation of capacity from these models, which is 1260 vphpl, will be used.

After determining the work zone capacity, an LCAP model was created using the existing traffic volumes and the number of lanes (existing and work zone). This information was entered into the "Input Demand" window in LCAP. An existing capacity of 2200 vphpl and the average calculated work zone capacity were entered into the model. Additionally, it was assumed that a time period of at least four consecutive hours will be required for mobilization, resurfacing, and demobilization. In order to determine suitable hours for the lane closures, a trial and error method was utilized.

5. **Modeling – Obtain Model Outputs.** For each iteration of the trial-and-error process, the proposed hours of the lane closure were entered into the Work Zone Information window and the Show Analysis Results option was selected. In the analysis results screen the queue length during each hour was extracted from one of the columns. **Table 1** summarizes the maximum queue length and duration of lane closure for each day.

Table 1. LCAP Model Outputs – Closure Periods and Maximum Queues

	Day of the Week	Closure Period	Maximum Queue
Northbound I-95	Sunday	Midnight – 5 AM (Mon.)	0.15 miles
	Monday	11 PM – 5 AM (Tues.)	0.61 miles
	Tuesday	11 PM – 5 AM (Wed.)	0.50 miles
	Wednesday	11 PM – 5 AM (Thur.)	0.85 miles
	Thursday	Midnight – 5 AM (Fri.)	0.29 miles
	Friday	Midnight – 5 AM (Sat.)	0.70 miles
	Saturday	Midnight – 7 AM (Sun.)	0.54 miles
Southbound I-95	Sunday	Midnight – 5 AM (Mon.)	0.57 miles
	Monday	11 PM – 5 AM (Tues.)	0.79 miles
	Tuesday	Midnight – 5 AM (Wed.)	0.57 miles
	Wednesday	Midnight – 5 AM (Thur.)	0.62 miles
	Thursday	Midnight – 5 AM (Fri.)	1.04 miles
	Friday	1 AM (Sat.) – 5 AM (Sat.)	0.61 miles
	Saturday	Midnight – 8 AM (Sun.)	0.89 miles

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Table 1, the queue for each closure period will be less than one mile with the exception of the southbound I-95 queue during the Thursday night closure. For this closure period, the maximum queue will be 1.04 miles which will have a duration of less then one hour. Therefore, this alternative will meet the freeway lane closure mobility thresholds (queue less than one mile for any duration and queue between 1 and 1½ mile for less than two hours). Sample LCAP outputs for NB I-95 Wednesday closures between 11 PM and 5 AM, and between 10 PM and 5 AM are shown on the following pages to illustrate the trial-and-error process.

7. **Recommend an Alternative.** Based on the results of this study, there is a time period of at least four hours during every night when three lanes may be closed along I-95 for this resurfacing project. **Table 2** summarizes the recommended work zone alternative.

Table 2. Recommended Work Zone Alternative

Roadway Direction	Day of the Week	Closure Period
Northbound I-95	Sunday	Midnight – 5 AM (Mon.)
	Monday	11 PM – 5 AM (Tues.)
	Tuesday	11 PM – 5 AM (Wed.)
	Wednesday	11 PM – 5 AM (Thur.)
	Thursday	Midnight – 5 AM (Fri.)
	Friday	Midnight – 5 AM (Sat.)
	Saturday	Midnight – 7 AM (Sun.)
Southbound I-95	Sunday	Midnight – 5 AM (Mon.)
	Monday	11 PM – 5 AM (Tues.)
	Tuesday	Midnight – 5 AM (Wed.)
	Wednesday	Midnight – 5 AM (Thur.)
	Thursday	Midnight – 5 AM (Fri.)
	Friday	1 AM (Sat.) – 5 AM (Sat.)
	Saturday	Midnight – 8 AM (Sun.)

It should be noted that the contractor may also desire to close either one or two lanes at a time for work. Typically, lane closure schedules for these conditions would also be provided. The purpose of this example is to illustrate how to use LCAP for lane closure scheduling purposes and therefore schedules for only the three lane closure scenario are presented.

Project: I-95 Resurfacing - Howard County (Columbia Area)
Analyst:
Date: 04/01/2007

Start Time	End Time	Base Demand	Approach Volume	Roadway Volume	Vehicles In Queue	Queue Length (Miles)	Workzone Up
Wed-12:00	Wed-13:00	5804	5804	5804	0	0.00	
Wed-13:00	Wed-14:00	6317	6317	6317	0	0.00	
Wed-14:00	Wed-15:00	6526	6526	6526	0	0.00	
Wed-15:00	Wed-16:00	7438	7438	7438	0	0.00	
Wed-16:00	Wed-17:00	7871	7871	7871	0	0.00	
Wed-17:00	Wed-18:00	7617	7617	7617	0	0.00	
Wed-18:00	Wed-19:00	7314	7314	7314	0	0.00	
Wed-19:00	Wed-20:00	5195	5195	5195	0	0.00	
Wed-20:00	Wed-21:00	3965	3965	3965	0	0.00	
Wed-21:00	Wed-22:00	3489	3489	3489	0	0.00	
Wed-22:00	Wed-23:00	2585	1260	2585	1325	1.74	X
Wed-23:00	Thr-0:00	1904	1260	3229	1969	2.59	X
Thr-0:00	Thr-1:00	1257	1260	3226	1966	2.59	X
Thr-1:00	Thr-2:00	848	1260	2814	1554	2.04	X
Thr-2:00	Thr-3:00	737	1260	2291	1031	1.36	X
Thr-3:00	Thr-4:00	782	1260	1813	553	0.73	X
Thr-4:00	Thr-5:00	1121	1260	1674	414	0.54	X
Thr-5:00	Thr-6:00	2381	2795	2795	0	0.00	
Thr-6:00	Thr-7:00	4604	4604	4604	0	0.00	
Thr-7:00	Thr-8:00	6456	6456	6456	0	0.00	
Thr-8:00	Thr-9:00	6678	6678	6678	0	0.00	
Thr-9:00	Thr-10:00	5786	5786	5786	0	0.00	
Thr-10:00	Thr-11:00	5348	5348	5348	0	0.00	
Thr-11:00	Thr-12:00	5903	5903	5903	0	0.00	
Thr-12:00	Thr-13:00	6138	6138	6138	0	0.00	
Thr-13:00	Thr-14:00	6193	6193	6193	0	0.00	
Thr-14:00	Thr-15:00	6754	6754	6754	0	0.00	

LCAP Output: Closure from 10PM Wed. to 5AM Thur.

Project: I-95 Resurfacing - Howard County (Columbia Area)
Analyst:
Date: 04/01/2007

Start Time	End Time	Base Demand	Approach Volume	Roadway Volume	Vehicles In Queue	Queue Length (Miles)	Workzone Up
Wed-13:00	Wed-14:00	6317	6317	6317	0	0.00	
Wed-14:00	Wed-15:00	6526	6526	6526	0	0.00	
Wed-15:00	Wed-16:00	7438	7438	7438	0	0.00	
Wed-16:00	Wed-17:00	7871	7871	7871	0	0.00	
Wed-17:00	Wed-18:00	7617	7617	7617	0	0.00	
Wed-18:00	Wed-19:00	7314	7314	7314	0	0.00	
Wed-19:00	Wed-20:00	5195	5195	5195	0	0.00	
Wed-20:00	Wed-21:00	3965	3965	3965	0	0.00	
Wed-21:00	Wed-22:00	3489	3489	3489	0	0.00	
Wed-22:00	Wed-23:00	2585	2585	2585	0	0.00	
Wed-23:00	Thr-0:00	1904	1260	1904	644	0.85	X
Thr-0:00	Thr-1:00	1257	1260	1901	641	0.84	X
Thr-1:00	Thr-2:00	848	1260	1489	229	0.30	X
Thr-2:00	Thr-3:00	737	966	966	0	0.00	X
Thr-3:00	Thr-4:00	782	782	782	0	0.00	X
Thr-4:00	Thr-5:00	1121	1121	1121	0	0.00	X
Thr-5:00	Thr-6:00	2381	2381	2381	0	0.00	
Thr-6:00	Thr-7:00	4604	4604	4604	0	0.00	
Thr-7:00	Thr-8:00	6456	6456	6456	0	0.00	
Thr-8:00	Thr-9:00	6678	6678	6678	0	0.00	
Thr-9:00	Thr-10:00	5786	5786	5786	0	0.00	
Thr-10:00	Thr-11:00	5348	5348	5348	0	0.00	
Thr-11:00	Thr-12:00	5903	5903	5903	0	0.00	
Thr-12:00	Thr-13:00	6138	6138	6138	0	0.00	
Thr-13:00	Thr-14:00	6193	6193	6193	0	0.00	
Thr-14:00	Thr-15:00	6754	6754	6754	0	0.00	

LCAP Output: Closure from 11PM Wed. to 5AM Thur.

EXAMPLE C: WORK ZONE ADJACENT TO TRAVEL LANES
MD 97 (GEORGIA AVENUE)

SITE DESCRIPTION:

MD 97 (Georgia Avenue) is a five-lane (three lanes southbound and two lanes northbound), two-way divided roadway that runs in a north-south direction. Although MD 97 is classified as an arterial, it can be analyzed as a freeway section due to the high speed and long distance between intersections. **Figure 1** shows an area map of the study location.

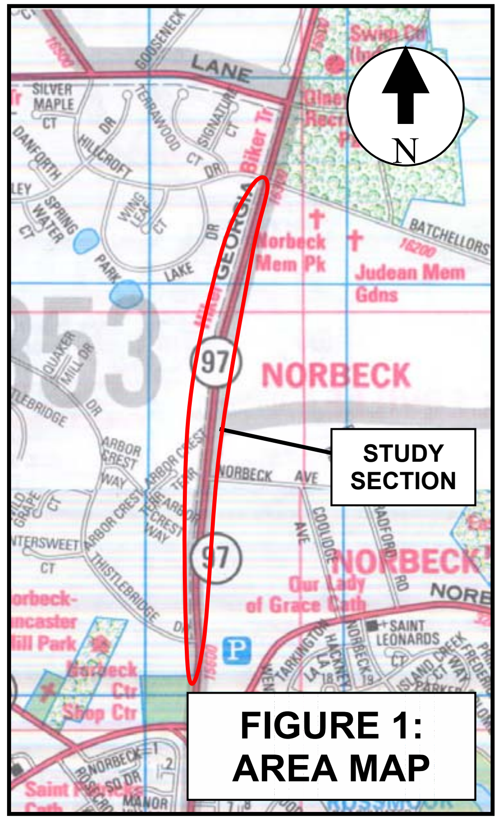


FIGURE 1: AREA MAP

OBJECTIVE:

The example project is for the construction of a new interchange with the Intercounty Connector (ICC) (MD 200). This construction project will involve the construction of two bridges on MD 97 (one bridge northbound and one bridge southbound) over the proposed ICC and raising the roadway profile for the approaches to the new bridges. A preliminary phasing concept has been developed and the objective of this work zone analysis is to determine if the proposed construction phasing will meet the mobility thresholds.

PROPOSED CONSTRUCTION PHASING:

The preliminary construction phasing concept involves five construction phases, as described below:

- **Phase 1:** Temporary pavement will be installed along the east side of southbound MD 97 to be used by northbound traffic in Phase 2 for the proposed temporary roadway crossover. The existing lanes will be shifted to the outside of the existing roadway in order to tie in the temporary pavement with the existing roadway.
- **Phase 2:** Southbound traffic will be reduced to two 11' lanes along the west edge of the existing southbound roadway. Northbound traffic will be shifted (through the use of the crossovers constructed in Phase 1) to the east edge of the widened southbound MD 97. Northbound and southbound traffic will be separated by 6" shoulders and a temporary concrete traffic barrier. With traffic in this pattern, the northbound bridge will be constructed. Note that southbound MD 97 was reduced to two lanes in order to provide the most separation between travel lanes and the excavation required for the construction of the bridge.
- **Phase 3:** Northbound traffic will be shifted to the newly constructed northbound MD 97 bridge. The southbound travel lane closed during Phase 2 will be reopened. Temporary pavement will be installed in the medians to be used by southbound traffic in Phase 4 for the proposed temporary roadway crossover.

- **Phase 4:** Southbound traffic will be shifted (through the use of the crossovers constructed in Phase 3) to the west edge of the new northbound bridge and travel lanes. With traffic in this pattern, the southbound bridge will be constructed. Note that southbound MD 97 will have three 11' travel lanes.
- **Phase 5:** Southbound traffic will be shifted to the west edge of the newly constructed southbound MD 97 while all unnecessary temporary pavement is removed and the new medians are constructed.

Phasing diagrams for the proposed construction phasing are presented at the conclusion of this example. It should be noted that the radii of curvature for the proposed crossovers will be sufficient for the existing speed limit (50 mph) on the roadway. Based on the proposed construction phasing, traffic analysis will be required for the following, as these construction phases are expected to result in the greatest reduction in roadway capacity:

- Phase 2: SB MD 97 – To analyze the impact of a single lane closure for the duration of the construction phase.
- Phase 4: NB MD 97 – To analyze the impacts of reduced shoulder/lane widths on roadway capacity throughout the temporary crossover alignment.

ANALYSIS:

1. **Determine the Limits of the Study Network.** Due to the fact that this analysis will only involve a lane closure analysis on southbound MD 97 and a capacity reduction due to changes in lane widths on northbound MD 97, LCAP/spreadsheet analysis will be sufficient. Therefore, the limits of the study network will be necessary in determining the work zone length to be used in the capacity approximation. Based on the proposed construction phasing, the length of the work zone, including necessary buffer and taper lengths will be approximately 0.75 miles (which will not extend through the adjacent signalized intersections).

2. **Data Collection.** Forecasted Year 2010 peak hour traffic volumes were provided by the SHA for this project. Additionally, a 48-hour volume traffic count for MD 97 0.30 miles north of the intersection with MD 28 was obtained from the SHA TMS website. Field measurements of lane widths, lane configurations, and storage lengths were performed.

3. **Determine the Analysis Method.** Due to the simplicity of this work zone situation, LCAP/spreadsheet analysis is the recommended analysis method. Because simulation modeling will not be required for example, the creation of an existing conditions model and subsequent model calibration and validation are unnecessary.

4. **Modeling – Code Work Zone Model.** The first step in evaluating work zone conditions is to approximate the work zone capacity. Because the proposed construction phasing involves lane reduction, lane width reductions, and a reduction in median width, the University of Maryland capacity equation was used in conjunction with HCM lane width adjustment factor to approximate the work zone capacity. The HCM lane width adjustment factor is as follows:

$$f = 1 + \frac{(W - 12)}{30}$$ where, *W* is the lane width and *f* is the adjustment factor

The following assumptions were made for both directions of MD 97 when determining the work zone capacities:

- Truck percentage = 5%
- 6" (0.5') lateral clearance to temporary traffic barrier
- Work zone length of approximately 0.75 miles
- High work zone intensity (*WI*=1)
- Lane widths reduced from 12' to 11'
- Maximum grade on NB MD 97 = 5%
- Maximum grade on SB MD 97 = 1%

The inputs used to determine the unadjusted work zone capacities are presented in **Table 1**. The capacity values presented in this table were then multiplied by the number of open lanes under each scenario and the lane width reduction factor (*f* = 0.9667).

Table 1. Work Zone Capacity Calculation Inputs

Direction	*N*	*L*	*HV*	*LD*	*WL*	*WG*	*WI*	C_a
NB MD 97	0	0	5	0.5	0.75	5%	1	1,669 / lane
SB MD 97	1	0	5	0.5	0.75	1%	1	1,547 / lane

Based on the aforementioned assumptions, the work zone capacity for northbound MD 97 during Phase 4 was approximated as 3,227 vph. This estimated work zone capacity (3,227 vph) was compared to peak hour traffic volumes (1,000 vph during the AM peak and 2,900 vph during the PM peak), which showed that capacity will exceed demand therefore resulting in no queue.

Based on the aforementioned assumptions, the work zone capacity for southbound MD 97 during Phase 2 was approximated as 2,991 vph. This estimated work zone capacity (2,991 vph) along southbound MD 97 was compared to peak hour traffic volumes (3,175 vph during the AM peak and 1,450 vph during the PM peak), which showed that demand will exceed capacity during the AM peak.

The 48-hour traffic count data obtained along MD 97 was utilized to determine the proportional relationship between traffic volumes along MD 97 during each hour of the day. Based on this information, the peak hour forecasted volumes were converted into hourly traffic volumes in order to determine work zone queue length and duration.

5. **Modeling – Obtain Model Outputs.** The hourly traffic volumes that were approximated based on the provided volume forecasts were compared to the estimated work zone capacity to determine residual queues, using the spreadsheet method. **Table 2** presents the portion of the spreadsheet where the traffic volumes exceed the demand. As shown in the table, the

maximum queue length on southbound MD 97 will be less than ½ mile in each of the two approach lanes, with queuing existing for approximately two hours.

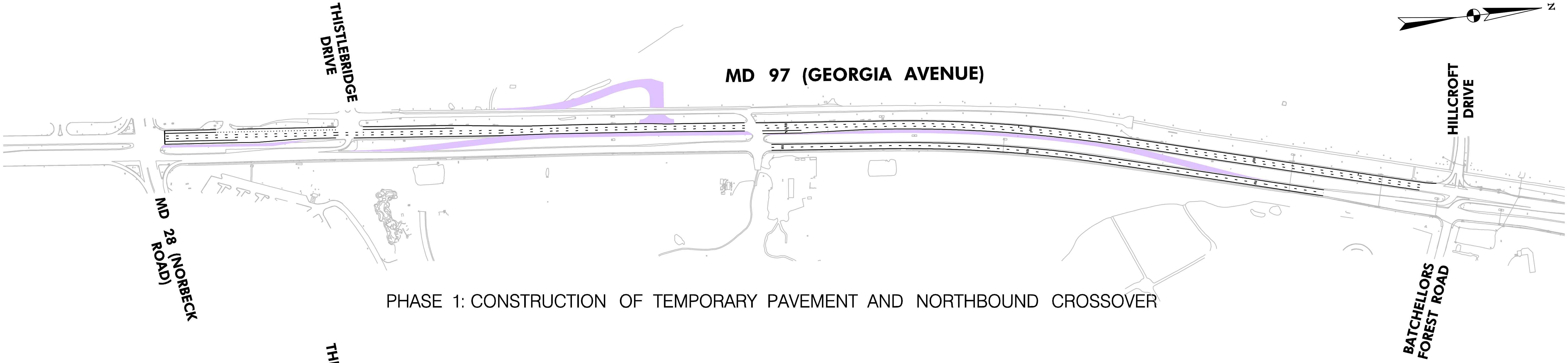
Table 2. Southbound MD 97 Queue Approximation

Time	Demand	Capacity	Queue Length (veh/lane)	Queue Length* (miles/lane)
6-7 AM	2,819	2,991	-	-
7-8 AM	3,175	2,991	92	0.44
8-9 AM	2,927	2,991	60	0.28
9-10 AM	2,236	2,991	-	-

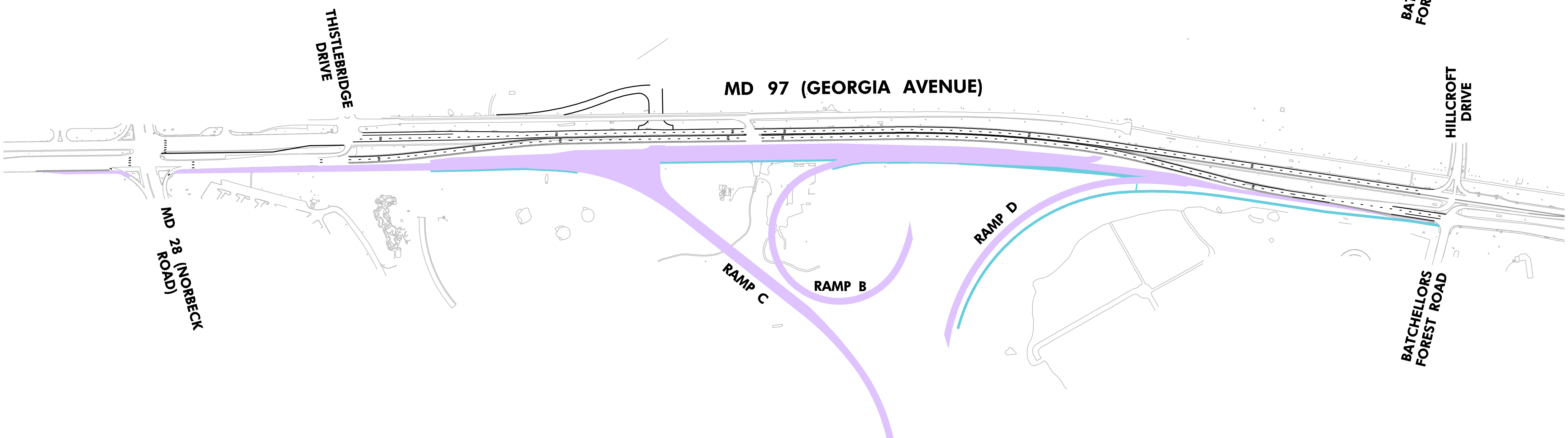
*Assumes average vehicle length of 25 ft.

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the analysis performed, there is not expected to be any queuing on northbound MD 97 during any phase of construction and queues of up to ½ mile per lane are expected on southbound MD 97 during Phase 4. Therefore, this alternative will meet the freeway lane closure mobility thresholds (queue less than one mile for any duration).

7. **Recommend an Alternative.** Based on the results of the analysis presented in this study, it is recommended that this project be constructed using the proposed 5-phase construction sequence with no time-of-day restrictions on the proposed single lane closure during Phase 4. It is not anticipated that temporary lane closures will be needed to perform the proposed construction activities; however, if temporary lane closures are required, LCAP or spreadsheet analyses may be performed utilizing the 48-hour traffic data in order to determine allowable hours for these temporary lane closures.



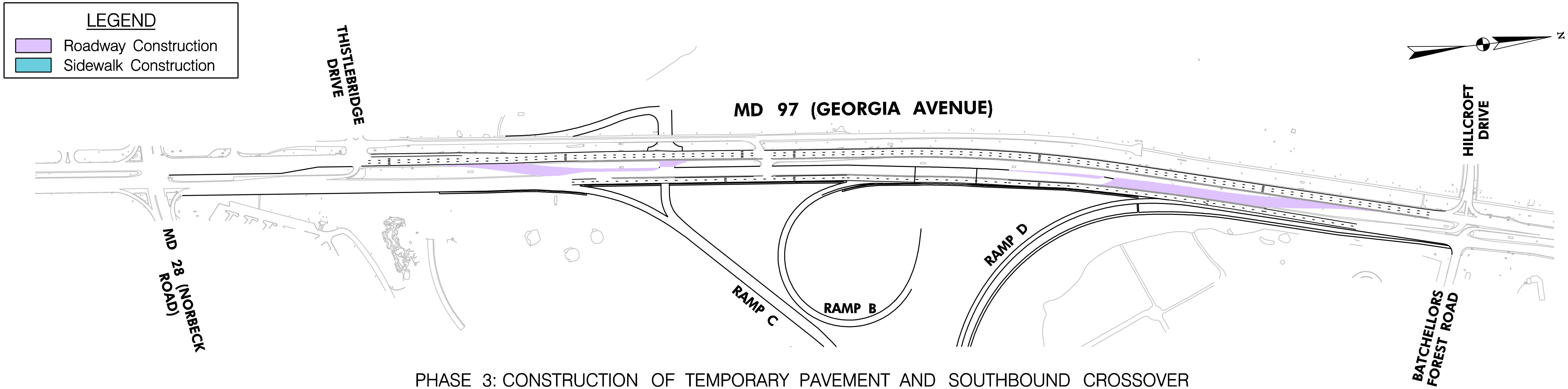
PHASE 1: CONSTRUCTION OF TEMPORARY PAVEMENT AND NORTHBOUND CROSSOVER



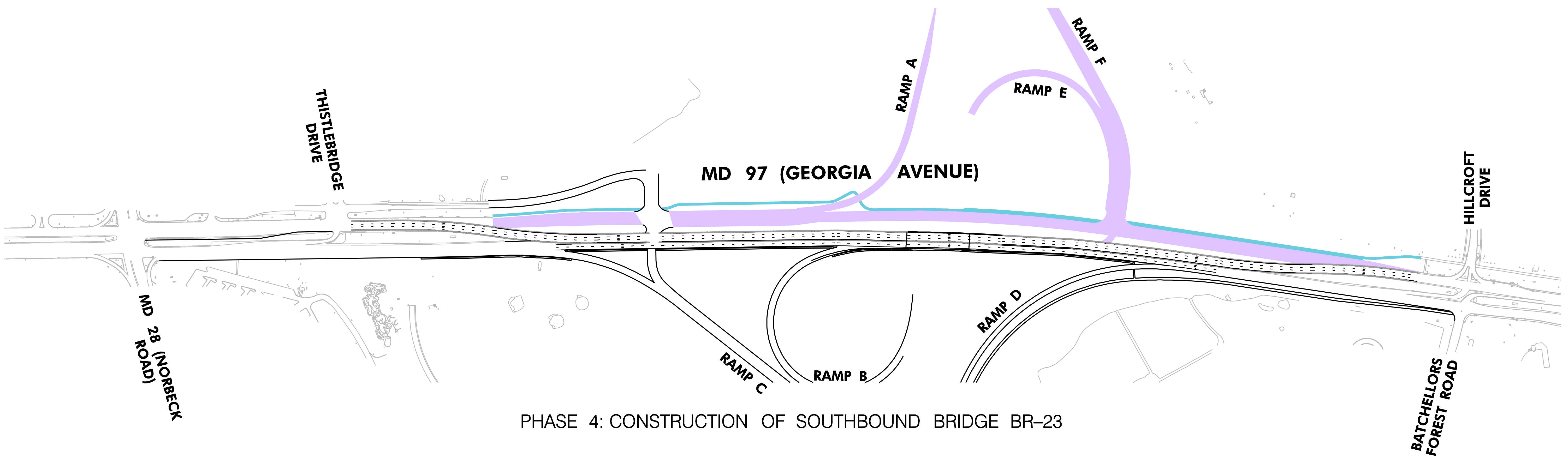
PHASE 2: CONSTRUCTION OF THE NORTHBOUND BRIDGE BR–23

LEGEND

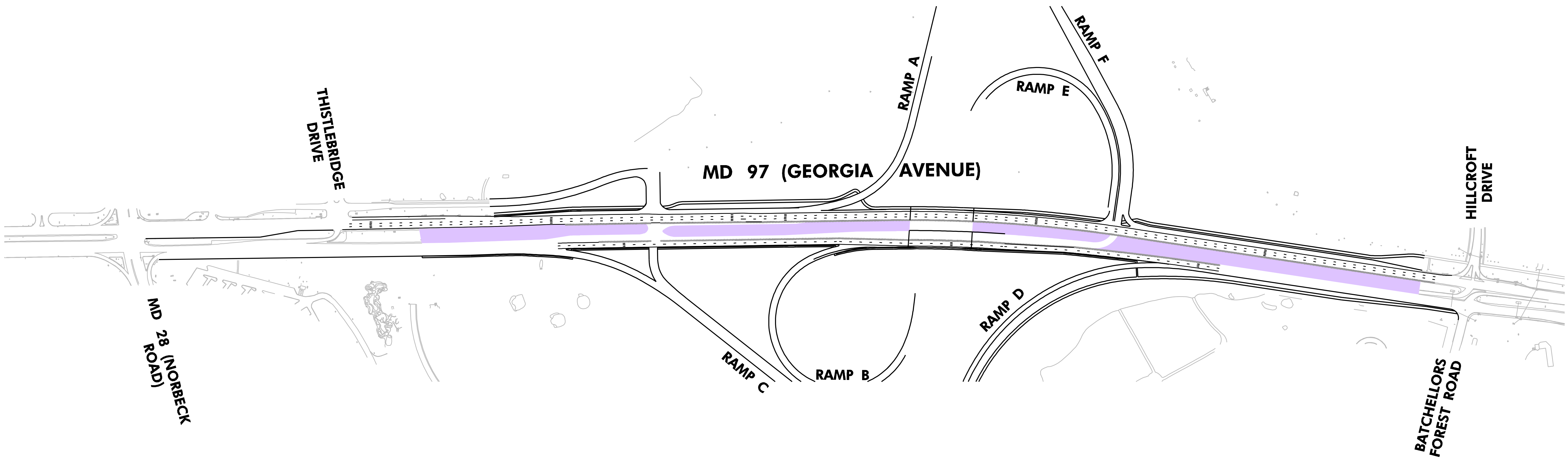
- Roadway Construction
- Sidewalk Construction



PHASE 3: CONSTRUCTION OF TEMPORARY PAVEMENT AND SOUTHBOUND CROSSOVER



PHASE 4: CONSTRUCTION OF SOUTHBOUND BRIDGE BR-23



PHASE 5: MEDIAN CONSTRUCTION

LEGEND

- Roadway Construction
- Sidewalk Construction

INTERCOUNTY CONSTRUCTORS
TWO TAFT COURT * ROCKVILLE, MARYLAND 20850 * 301-354-8600

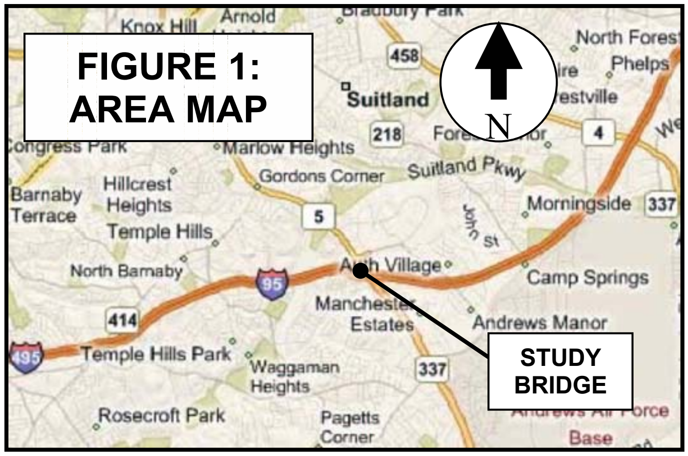
Intercounty Connector – Contract A
ProjectWide MOT Plan
Construction Phasing Diagrams

MD 97 (Georgia Avenue)
Phase 5

EXAMPLE D: FULL ROADWAY CLOSURE WITH DETOUR
I-95/I-495 (CAPITAL BELTWAY) AT MD 5 (BRANCH AVENUE)

SITE DESCRIPTION:

I-95/I-495 (Capital Beltway) is an eight-lane, two-way, interstate freeway that runs in a north-south direction in the vicinity of MD 5 (Branch Avenue). **Figure 1** shows an area map of the study location. **Figure 2** shows the existing interchange configuration.



OBJECTIVE:

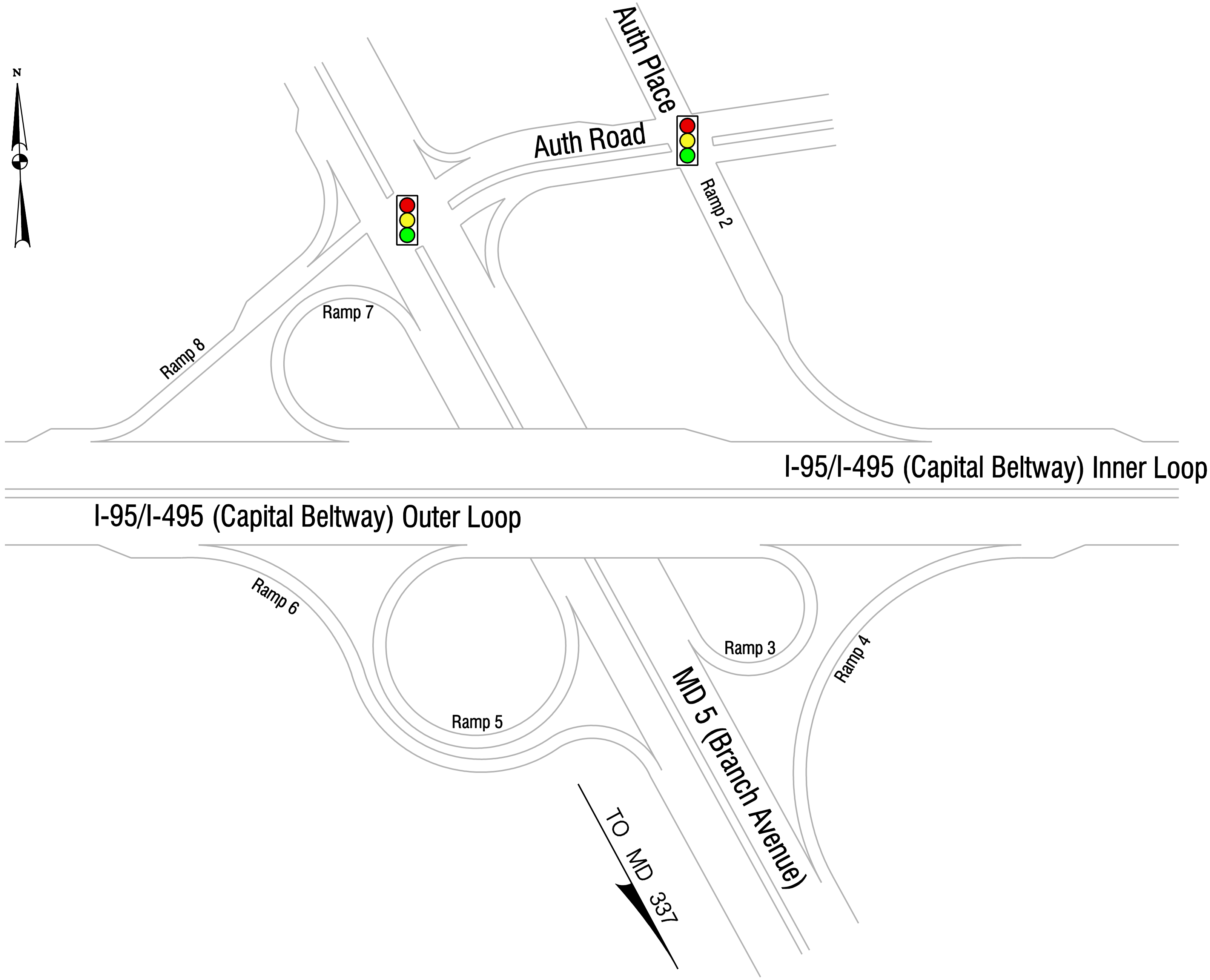
The example project is for the widening of the interchange of MD 5 with I-95/I-495. During the proposed interchange reconstruction, a new flyover ramp will be constructed over I-95/I-495 and it will be necessary to close travel lanes on I-95/I-495 in order to erect the bridge steel. **Figure 3** shows the proposed interchange configuration. Several alternatives were developed for the duration and type or closures required for erect the structural steel, as follows:

1. A full roadway closure in both directions for 10 continuous hours on a weekend, which would allow the contractor to erect the steel in two nights (separate occasions).
2. A 3-lane closure in both directions for 10 continuous hours on a weekend, which would allow the contractor to erect the steel in three nights (separate occasions).
3. A 3-lane closure in both directions for 8 continuous hours on a weeknight, which would allow the contractor to erect the steel in five nights (separate occasions).

The objective of this analysis will be to determine which one of the three road closure alternatives should be selected.

ANALYSIS:

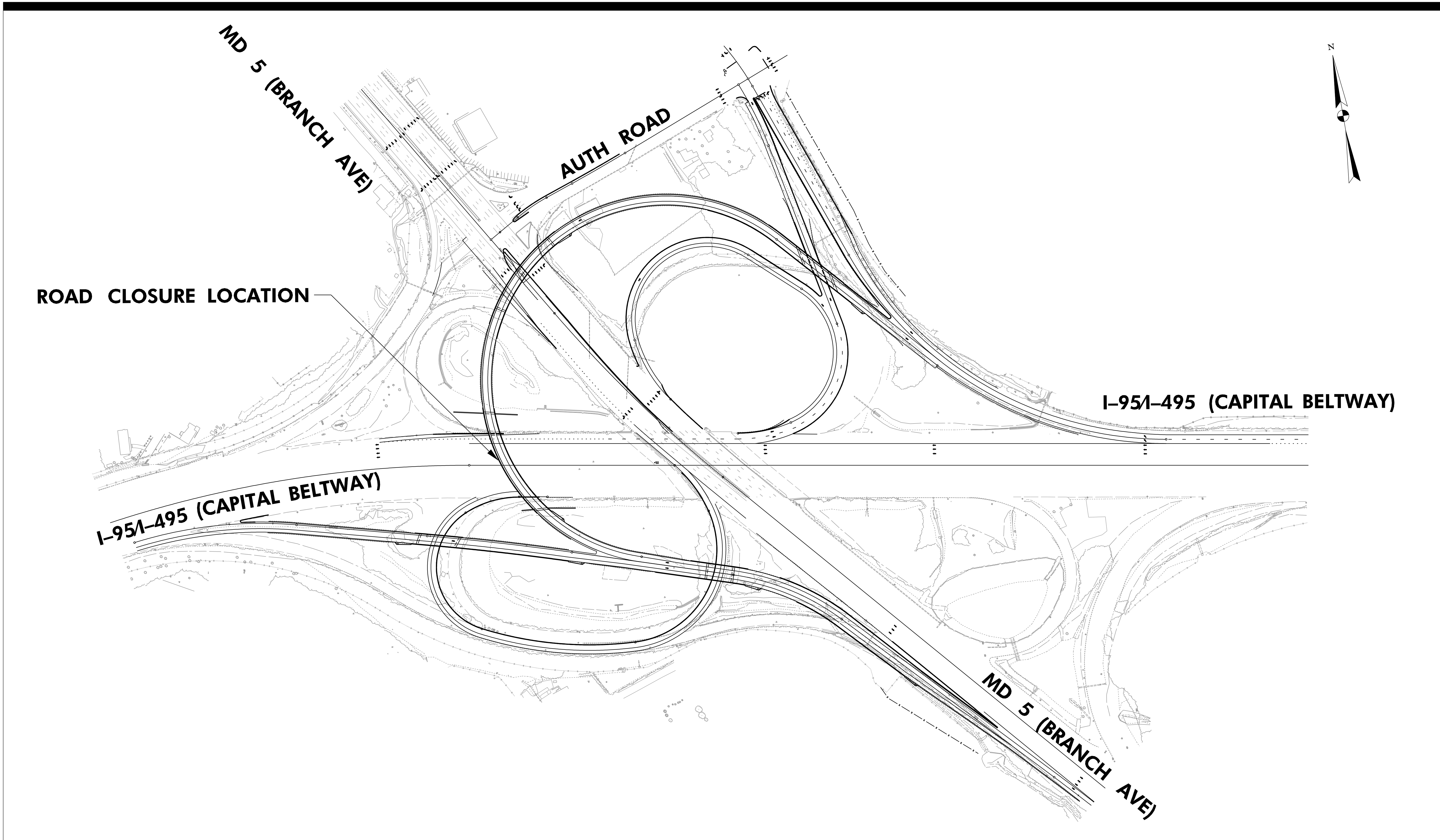
1. **Determine the Limits of the Study Network.** As a result of the proposed road closure under alternative 1, it will be necessary to detour existing traffic around the bridge location. The proposed northbound I-95/I-495 detour is to reroute traffic onto Ramp 6 to southbound MD 5, then to a u-turn at the SPUI at MD 337 (Allentown Road), and then onto Ramp 4 back to northbound I-95/I-495. The proposed southbound detour is to reroute traffic onto Ramp 2, then turn left onto Auth Road at the traffic signal and then continue straight through the traffic signal onto Ramp 8. Therefore, the study network should include the I-95/MD 5 interchange, including all ramps, and the MD 5/MD 337 interchange. Additionally, the study network should include the signalized intersection of the ramp from southbound I-95/I-495 with Auth Road.



Bridge Reconstruction Analysis

Figure 2

Existing Interchange Configuration



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Work Zone Analysis Guide
Example D: I-95/I-495 (Capital Beltway) at MD 5 (Branch Avenue)

Full Roadway Closure and Detour Analysis

Figure 3

Proposed Interchange Configuration

2. **Data Collection.** Existing traffic volumes on all interchange ramps and at the intersection of Ramp 1 with Auth Road were obtained from the SHA-maintained database. The analysis volumes were developed using conversion factors from SHA's *Traffic Trends.* Existing traffic volumes were converted to hourly weekend and weekday night traffic volumes. Existing lane configurations to be used for the analysis were obtained from a review of aerial photography.

3. **Determine the Analysis Method.** A CORSIM model of the existing interchange conditions was created, including intersections along the proposed detour route. Adjusted traffic volumes were entered into the model and a simulation was created. Observation of the simulation showed that there were no coding errors and that simulated traffic operations resembled existing operations. Therefore, additional calibration and validation of the model is not required.

Alternative #1

4. **Modeling – Code Work Zone Model.** The first alternative evaluated for this example was the 10-hour full roadway closure with detour onto MD 5. For this alternative, the number of lanes on I-95/I-495 under MD 5 was reduced to zero in the model. It was assumed that temporary widening would be performed on all ramps involved in the detour in order to provide two lanes, and that there would be a two-lane closure on I-95/I-495 approaching the interchange in order to feed into the two-lane off-ramps. The lane configurations on the ramps and mainline I-95/I-495 were adjusted in the CORSIM model to reflect these assumptions. Signal timings at the signalized intersections between the ramps and MD 5 were optimized for this condition. Additionally, existing traffic volumes were redistributed based on the detour route and detour traffic volumes were entered into the work zone model.

5. **Modeling – Obtain Model Outputs.** The maximum queue lengths along mainline I-95/I-495 were obtained from the CORSIM output file and observations of average travel times in the simulation were made. After a trial-and-error process, it was determined that the optimal 10-hour time period for the full road closure occurs between 9 PM Saturday and 7 AM Sunday. Average travel time observations from the existing conditions and work zone conditions models were used to determine approximate delay per vehicle. **Table 1** summarizes the analysis results for this closure scenario. As shown in the table, the road closure is expected to result in excessive queues (in excess of 6 miles in length) along northbound I-95/I-495.

Table 1. Summary of the Analysis Results (Full Road Closure with Detour)

	Closure Time Period	Average Delay at Midnight (minutes)	Max. Queue
NB I-95/I-495	9 PM-7 AM	120+	>6 miles at 12:15 AM
SB I-95/I-495	9 PM-7 AM	3	0.5 miles at 11:30 PM

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the queuing analysis performed, the maximum queue expected on northbound I-95/I-495 will exceed 6

miles and the maximum queue on southbound I-95/I-495 will be 0.5 miles. Therefore, this alternative will meet the freeway lane closure mobility threshold for SB I-95/I-495 (queue less than 1 mile for any duration) but not for NB I-95/I-495 (queue may not exceed 1½ miles). Therefore, another alternative must be evaluated.

<u>**Alternative #2**</u>

4. **Modeling – Code Modified Work Zone Model.** Because Alternative #1 will not meet the mobility thresholds, Alternative #2 (10-hour, 3-lane weekend closure) was developed and evaluated. It should be noted that a three-lane closure was considered for this alternative because significant delays were observed at the SPUI on MD 5 at MD 337 in the simulation of Alternative #1, and because of the significant length of the northbound I-95/I-495 detour route under Alternative #1. For this alternative, the lane configurations on the existing conditions model were adjusted to have a 3-lane closure (closing one lane at a time and using appropriate buffer lengths between each closure). Additionally, rubberneck factors and link speeds in the work zone were modified to represented work zone driver behavior. These factors were adjusted using a trial-and-error process so that the throughput in the simulation approximated the estimated work zone capacity. Work zone capacity was estimated by extrapolation from the HCM table (since a reduction from four lanes to one lane was not included in the table) as 1,050 vph. Existing traffic volumes were not modified for this alternative, as it was expected that no vehicles will detour from the existing roadway.

5. **Modeling – Obtain Model Outputs.** The maximum queue lengths along mainline I-95/I-495 were obtained from the CORSIM output file and observations of average travel times in the simulation were made. After a trial-and-error process, it was determined that the optimal 10-hour time period for the three-lane closure occurs between 9 PM Saturday and 7 AM Sunday. Average travel time observations from the existing conditions and work zone conditions models were used to determine approximate delay per vehicle. **Table 2** summarizes the analysis results for this closure scenario. As shown in the table, the lane closure is expected to result in excessive queues (3 miles in length) along northbound I-95/I-495. It should be noted that the three-lane closure will result in a more delay along SB I-95/I-495 than the full roadway closure. This is due to the fact that the full roadway closure is essentially a two-lane closure onto the exit ramp with relatively short delays at the traffic signal at the intersection of Ramp 2 with Auth Road due to the optimization of signal timings. Along NB I-95/I-495, the three-lane closure results in shorter delays than the full roadway closure. This is due to the fact that there were high delays at the MD 5/MD 337 traffic signal, even though signal timings were optimized.

Table 2. Summary of the Analysis Results (10-Hour, 3-Lane Weekend Closure)

	Closure Time Period	Average Delay at Midnight (minutes)	Max. Queue
NB I-95/I-495	9 PM-7 AM	47	3 miles at 1:00 AM
SB I-95/I-495	9 PM-7 AM	52	2.1 miles at 1:00 AM

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the queuing analysis performed, the maximum queue expected on northbound I-95/I-495 will be 3 miles

and the maximum queue on southbound I-95/I-495 will be 2.1 miles. Therefore, this alternative will not meet the freeway lane closure mobility threshold (queue may not exceed 1½ miles) in either direction on I-95/I-495. Therefore, another alternative must be evaluated.

Alternative #3

4. **Modeling – Code Modified Work Zone Model.** Because Alternatives #1 and #2 will not meet the mobility thresholds, Alternative #3 (8-hour, 3-lane weeknight closure) was developed and evaluated. For this alternative, the traffic volumes in the model created for Alternative #2 were modified to reflect the weekday night traffic volumes (obtained from the SHA-maintained database), and the closure duration was reduced to 8 hours. It should be noted that a weeknight closure was considered due to the fact that weeknight traffic volumes are lower than weekend night traffic volumes.

5. **Modeling – Obtain Model Outputs.** The maximum queue lengths along mainline I-95/I-495 were obtained from the CORSIM output file and observations of average travel times in the simulation were made. After a trial-and-error process, it was determined that the optimal 8-hour time period for the three-lane closure occurs between 9 PM and 5 AM. Average travel time observations from the existing conditions and work zone conditions models were used to determine approximate delay per vehicle. **Table 3** summarizes the analysis results for this closure scenario. As shown in the table, the lane closure is expected to result in queues as long as 2 miles along southbound I-95/I-495.

Table 3. Summary of the Analysis Results (8-Hour, 3-Lane Weeknight Closure)

	Closure Time Period	Average Delay at Midnight (minutes)	Max. Queue
NB I-95/I-495	9 PM-5 AM	1	Stop & Go at 10:30 PM
SB I-95/I-495	9 PM-5 AM	11	2 miles at 11:00 PM

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the queuing analysis performed, the maximum queue expected on southbound I-95/I-495 will be 2 miles, and the queue on northbound I-95/I-495 will be a rolling queue. Therefore, this alternative will meet the freeway lane closure mobility threshold for NB I-95/I-495 (queue less than 1 mile for any duration) but not for SB I-95/I-495 (queue may not exceed 1½ miles). Because there are no other viable construction alternatives based on the requirements to erect structural steel (the contractor needs a minimum 8-hour window), no other alternatives were evaluated.

7. **Recommend an Alternative.** Based on the results of the analysis presented in this study, none of the proposed construction alternatives will meet the freeway mobility thresholds. However, this project must be constructed and no other alternatives are available due to the requirements for erecting structural steel. Therefore, one of the three proposed alternatives must be chosen. Considering the maximum queues and average delays expected under each alternative, scenario #3 (8-hour, 3-lane weeknight closure) offers the least impact to existing traffic operations. Therefore, this is the recommended alternative. In order to help reduce the potential impacts, it is also recommended that advance signing and public information

campaigns be utilized to encourage motorists to use alternate routes during the lane closure. **Table 4** summarizes the recommended work zone alternative.

Table 4. Recommended Work Zone Alternative

Work Zone Alternative Staging	Work Hour Restrictions
Three-lane closures in both directions on I-95/I-495	9 PM – 5 AM Mon.-Thurs.

PROJECT UPDATE:

The work described in this example was performed in April 2008. **Table 5** presents a summary of the closures utilized for the construction of the flyover ramp. During construction, the decision was made to erect all of the beams in one night. By doing this, the contractor only needed to mobilize equipment and execute the maintenance of traffic and detour plan once. While a noe-night, longer duration closure had a greater impact on traffic operations than the other options considered, it minimized the contractor's total exposure time and safety risks.

Table 5. Summary of the Closures Used

Roadway Closed	Closure Type	Closure Duration	Closure Time Period
NB I-95/I-495	2 Lane Closure	2 hours	Sat., April 19 8PM-10PM
	Full Roadway Closure	11 hours	Sat., April 19 10PM- Sun., April 20 9AM
SB I-95/I-495	Full Roadway Closure	14 hours	Sat., April 19 8PM- Sun., April 20 10AM
SB MD 5 Ramp to NB I-95/I-495	Full Ramp Closure	14 hours	Sat., April 19 8PM- Sun., April 20 10AM

In order to reduce the impacts to traffic operations during these closures, several mitigation techniques were utilized. The first method of mitigation was the use of signed detours and the installation of several temporary signs and temporary overlays along MD 295 (Baltimore-Washington Parkway) and I-95/I-495. Additionally, 20 PVMSs were installed throughout the area, along I-95/I-495, MD 5, US 301, MD 228, and MD/DC 295. The locations of the PVMSs were determined through a collaborative effort between the Contractor, the Office of Traffic and Safety, the Statewide Operations Center (SOC), District 3 Traffic, the Woodrow Wilson Bridge Project, and VDOT. A public outreach campaign (utilizing the CHART website, and radio announcements) was also used to help warn motorists to stay away from the area during the hours of the closure.

Field observations during the closure indicated that the public outreach campaign and the PVMSs helped to reduce traffic volumes through the work zone during the hours of the closure. Queues were observed along both NB and SB I-95/I-495 during the first two and last two hours of the closure, with queues extending on NB I-95/I-495 to the Temple Hill Road bridge (approximately 1.6 miles) and on SB I-95/I-495 to the Suitland Road overpass (approximately 1.75 miles). Additionally, modifications to signal operations at the intersections of Ramp 2 with Auth Road, MD 5 with Auth Road, and MD 337 with MD 5 worked well, providing smooth operations along the detour routes.

EXAMPLE E: MULTI-LANE ARTERIAL SEGMENT WITH LANE CLOSURES
US 1 (BELAIR ROAD) OVER LITTLE GUNPOWDER FALLS

SITE DESCRIPTION:

US 1 is a four-lane, two-way, undivided roadway that runs in a north-south direction over Little Gunpowder Falls at the Baltimore/Harford County line. The nearest intersections are ½ mile in either direction of the bridge. **Figure 1** shows an area map of the study location.

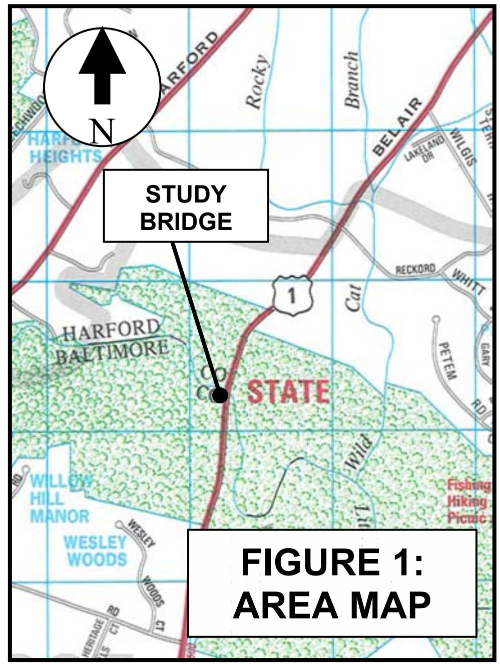


FIGURE 1: AREA MAP

OBJECTIVE:

The proposed work for this example is a complete reconstruction of the existing bridge. The objective of this work zone analysis is to determine the number of construction phases necessary to complete this bridge reconstruction. Possible work zone alternatives include (1) two-stage construction reducing traffic to one lane in each direction at all times and (2) four-stage construction maintaining two lanes in the peak direction and one lane in the non-peak direction through the use of a reversible lane system. If option 2 is selected, it will be necessary to determine the time of day when the peak direction lane should be changed.

ANALYSIS:

1. **Determine the Limits of the Study Network.** The first step in determining the limits of the study network is to estimate the work zone queue length. Because the nearest adjacent intersections are ½ mile from the study bridge, it will be desirable to ensure that the queue from the work zone will not impact those intersections. Therefore, the study area will extend for ½ mile in either direction from the study bridge.

2. **Data Collection.** A 13-hour traffic count for a nearby intersection was obtained from the SHA-maintained database. Traffic count data at this intersection was then used to determine traffic volume over the study bridge. SHA's *Traffic Trends* manual was then used to adjust the traffic volumes to the highest month of the year. Historical AADT data for the area was used to approximate the average annual growth rate (1.2%) and the traffic volumes were adjusted for the estimated 2010 construction year. **Table 1** summarizes the factored hourly traffic volumes for 2006 and the construction year of 2010.

Table 1. Traffic Volumes on US 1 at the Little Gunpowder Falls Bridge

Beginning Hour	2006 Factored Weekday Average Volume (Veh/hr)		2010 Factored Weekday Average Volume (Veh/hr)	
	NB	SB	NB	SB
6: 00 AM	242	738	254	774
7: 00 AM	602	1,701	631	1,784
8: 00 AM	750	1,456	787	1,527
9: 00 AM	640	775	671	813
10: 00 AM	459	565	481	593
11: 00 AM	507	542	532	568
12: 00 PM	558	531	585	557
1: 00 PM	695	597	729	626
2: 00 PM	713	592	748	621
3: 00 PM	1,054	738	1,105	774
4: 00 PM	1,238	644	1,299	675
5: 00 PM	1,249	660	1,310	692
6: 00 PM	1,034	622	1,085	652

3. **Determine the Analysis Method.** Due to the simplicity of this work zone situation, QuickZone (using the lane closure function) or LCAP analysis are the recommended analysis methods. Because simulation modeling will not be required for example, the creation of an existing conditions model and subsequent model calibration and validation are unnecessary.

4. **Modeling – Code Work Zone Model.** The first step in evaluating work zone conditions is to estimate the work zone capacity. Because the proposed construction phasing involves lane reductions, the University of Maryland capacity equation was used to approximate the work zone capacity. The following assumptions were made when determining the work zone capacity:
   - Truck percentage = 3%
   - 3% grade along northbound US 1
   - -3% grade along southbound US 1
   - No lateral clearance
   - Work zone length of approximately 0.78 miles
   - High work zone intensity
   - Location of lane closure = right

   Based on the aforementioned assumptions, the work zone capacities under a lane closure were approximated as 1,471 vph along northbound US 1 and 1,513 vph along southbound US 1. The 2010 factored traffic volumes and the estimated work zone capacities were entered into QuickZone's lane closure schedule function in addition to the existing number of lanes.

5. **Modeling – Obtain Model Outputs.** In QuickZone, the scheduler was run assuming permanent lane closures in both directions. **Table 2** summarizes the maximum queue lengths and durations reported in the QuickZone scheduler during the AM and PM peak hours.

Table 2. Peak Hour QuickZone Queues

Peak Period	Work Zone Capacity (veh/hr)	Maximum Queue (mi.)	Queue Duration (hr)
Northbound US 1			
AM Peak	1,471	No Queue	No Queue
PM Peak	1,471	No Queue	No Queue
Southbound US 1			
AM Peak	1,513	1.35	1
PM Peak	1,513	No Queue	No Queue

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the queue lengths and durations presented in Table 2, the only queue that is expected under this alternative is during the AM peak along southbound US 1. Although the queue meets the mobility thresholds (queue between 1 and 1½ mile for less than 2 hours) under this alternative, the queue is expected to extend through the adjacent intersection on US 1 (located ½ mile north of the study bridge). Because this alternative does not meet one of the analysis constraints, the reversible lane alternative will be evaluated.

4. **Modeling – Code Modified Work Zone Model.** Under the reversible lane alternative, construction would be staged so that there would be two lanes going southbound during the AM peak (with one lane northbound) and two lanes going northbound during the PM peak (with one lane southbound). This revised lane closure schedule was entered into QuickZone's scheduler to determine the queuing impacts of this alternative. Work zone capacities were approximated using the University of Maryland capacity equation for both directions on US 1 with no travel lanes closed. The inputs that were used to approximate the work zone capacities are summarized in **Table 3**. Based on the assumptions presented for the first alternative and the fact that no travel lanes will be closed, the work zone capacities were approximated as 3,352 vph along northbound US 1 during the PM peak and 3,436 vph along southbound US 1 during the AM peak.

Table 3. Work Zone Capacity Calculation Inputs

Direction	*N*	*L*	*HV*	*LD*	*WL*	*WG*	*WI*	C_a
NB US 1	0	0	3	0	0.78	3%	1	1,676 / lane
SB US 1	0	0	3	0	0.78	-3%	1	1,718 / lane

5. **Modeling – Obtain Model Outputs.** QuickZone's scheduler was utilized to approximate the queue lengths and durations under the reversible lanes alternative. **Table 4** summarizes the maximum queue lengths and durations reported in the QuickZone scheduler.

Table 4. Peak Hour QuickZone Queues – Reversible Lanes Alternative

Peak Period	# Open Lanes	Work Zone Capacity (veh/hr)	Maximum Queue (mi.)	Queue Duration (min)
Northbound US 1				
AM Peak	1	1,471	No Queue	No Queue
PM Peak	2	3,352	No Queue	No Queue
Southbound US 1				
AM Peak	2	3,436	No Queue	No Queue
PM Peak	1	1,513	No Queue	No Queue

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the results presented in Table 3, there are no queues expected along either direction of US 1 during either peak period. Therefore, the reversible lanes alternative will meet the mobility thresholds.

7. **Recommend an Alternative.** Based on the results of the analysis presented in this study, the recommended work zone alternative is to use a reversible lanes system to adjust the directional roadway capacity depending on the time of day. This may be accomplished through the use of a movable barrier or other system to change the directional of the middle travel lane. Based on the QuickZone analysis, southbound US 1 must have two travel lanes between 7 AM and 9 AM in order to avoid the creation of a queue. However, to reduce the potential for the formation of queues, it is recommended that two lanes be maintained on southbound US 1 between 6 AM and 10 AM. **Table 5** summarizes the recommendations.

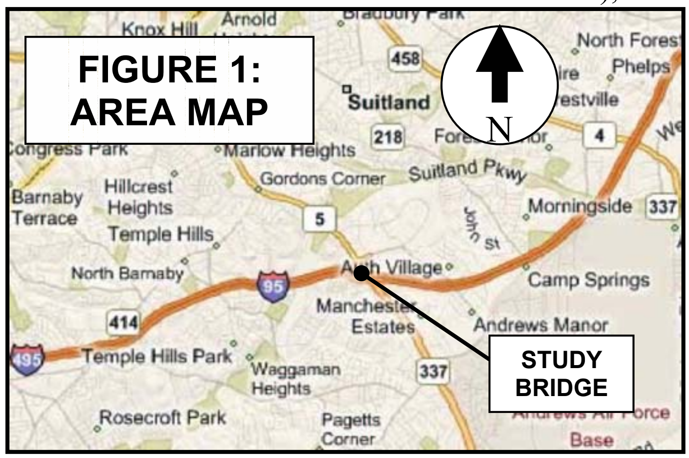
Table 5. Recommended Reversible Lane Work Zone Alternative

Work Zone Alternative	Work Hour Restrictions
Maintain two southbound lanes while reducing northbound US 1 to one lane	At least 6 AM to 10 AM
Maintain two northbound lanes while reducing southbound US 1 to one lane	Not between 6 AM and 10 AM

EXAMPLE F: ARTERIAL/FREEWAY NETWORK – FULL ROADWAY CLOSURE WITH DETOUR MD 5 (BRANCH AVENUE) OVER I-95/I-495 (CAPITAL BELTWAY)

SITE DESCRIPTION:

MD 5 (Branch Avenue) is a seven-lane (four lanes northbound and three lanes southbound), two-way, divided arterial roadway that runs in a north-south direction in the vicinity of I-95/I-495 (Capital Beltway). **Figure 1** shows an area map of the study location. **Figure 2** shows the existing interchange configuration, and **Figure 3** shows the proposed interchange configuration. It should be noted that although the location for this example is the same as in Example D, the analysis shown for this example is for a different construction project.



OBJECTIVE:

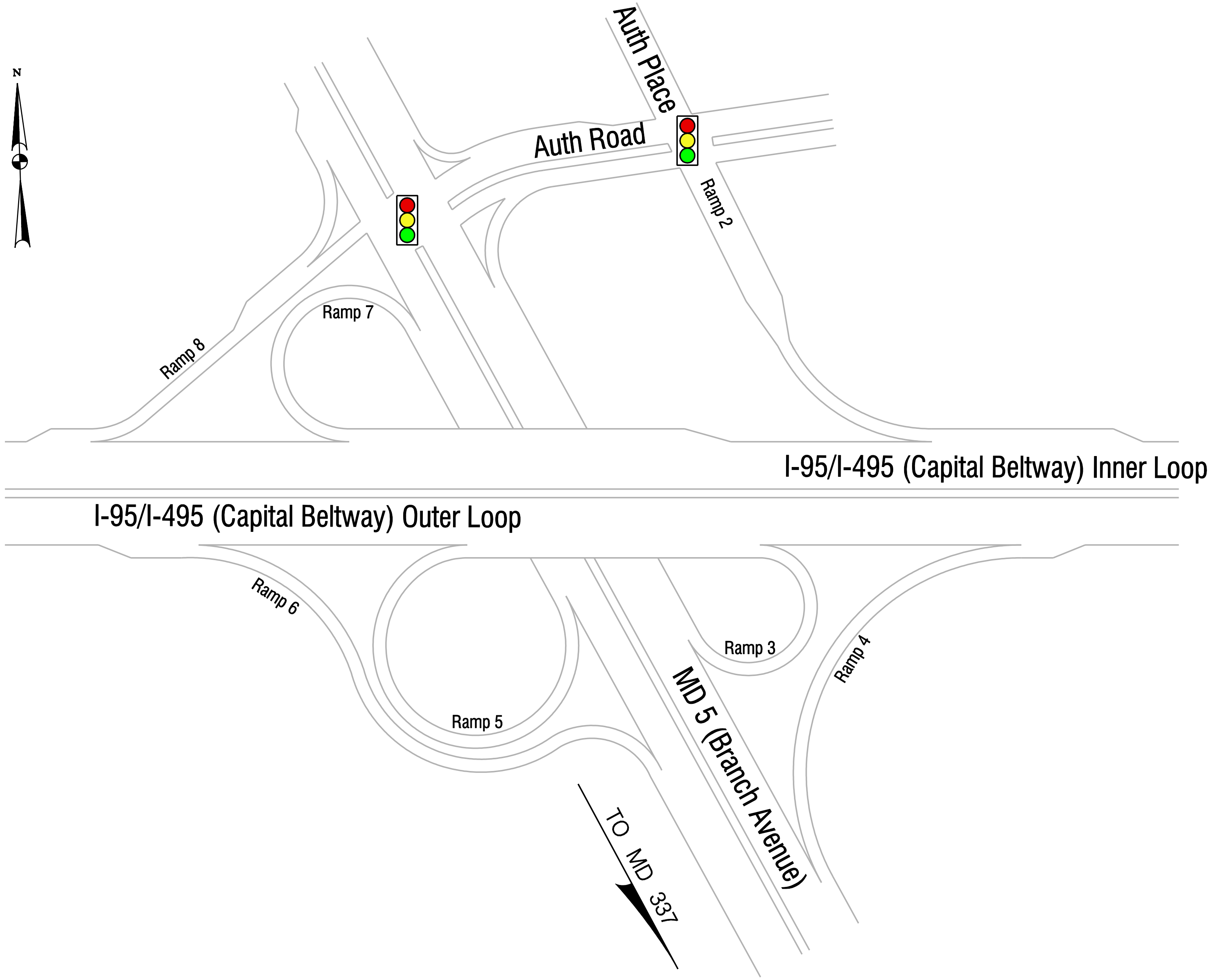
The example project is for a modification to the existing MD 5/I-95 interchange, including the construction of a new flyover ramp over MD 5. During the construction of the new ramp bridge over MD 5, the contractor identified the need to close all lanes on MD 5 under the proposed ramp bridge in both directions in order to erect the bridge steel. Erection of the bridge steel was expected to occur in September 2007, and the contractor provided the following three alternatives for the duration of the roadway closure that would permit the work to be completed safely:

1. A continuous 36-hour closure which would allow the contractor to erect and completely secure all steel.
2. A continuous 24-hour closure which would allow the contractor to erect and minimally secure all steel. The contractor can finish securing steel using standard 15-minute closures at a later time.
3. A continuous 17-hour closure which would allow the contractor to erect and minimally secure 2/3 of the steel, followed by a 7-hour closure on another night erect the remaining steel and completely secure all steel

The objective of this analysis will be to determine which one of the three road closure alternatives should be selected.

ANALYSIS:

1. **Determine the Limits of the Study Network.** As a result of the proposed road closure, it will be necessary to detour existing MD 5 traffic along I-95 to the nearest interchange and make a u-turn to come back to MD 5. Therefore, the study network should include all merge, diverge, weave, and basic sections along the proposed detour route, and mainline MD 5 in both directions. Additionally, the study network should include the signalized intersection of



Work Zone Analysis Guide
I–95/I–495 (Capital Beltway) at MD 5 (Branch Avenue) Example

Bridge Reconstruction Analysis

Figure 2

Existing Interchange Configuration

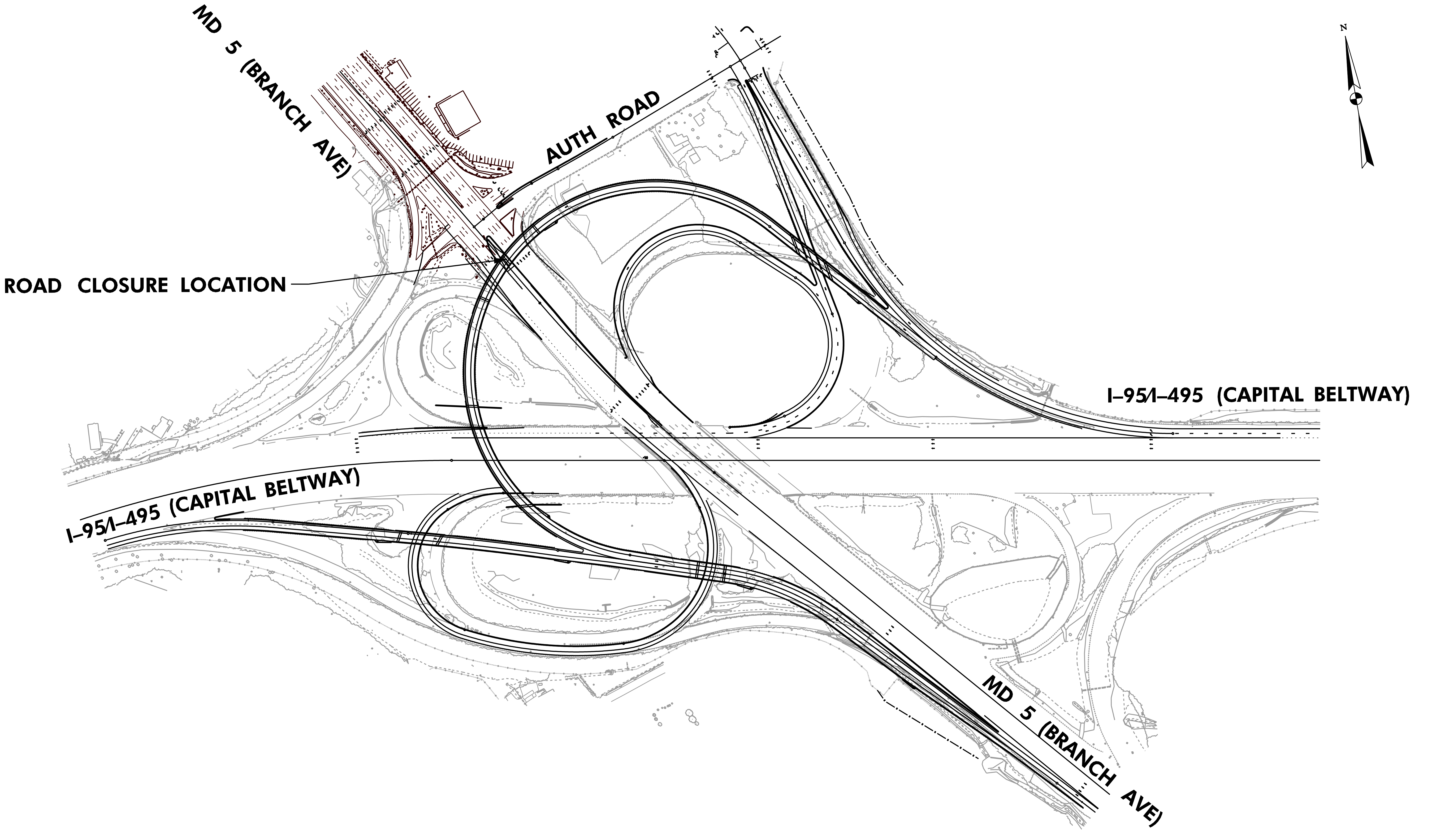
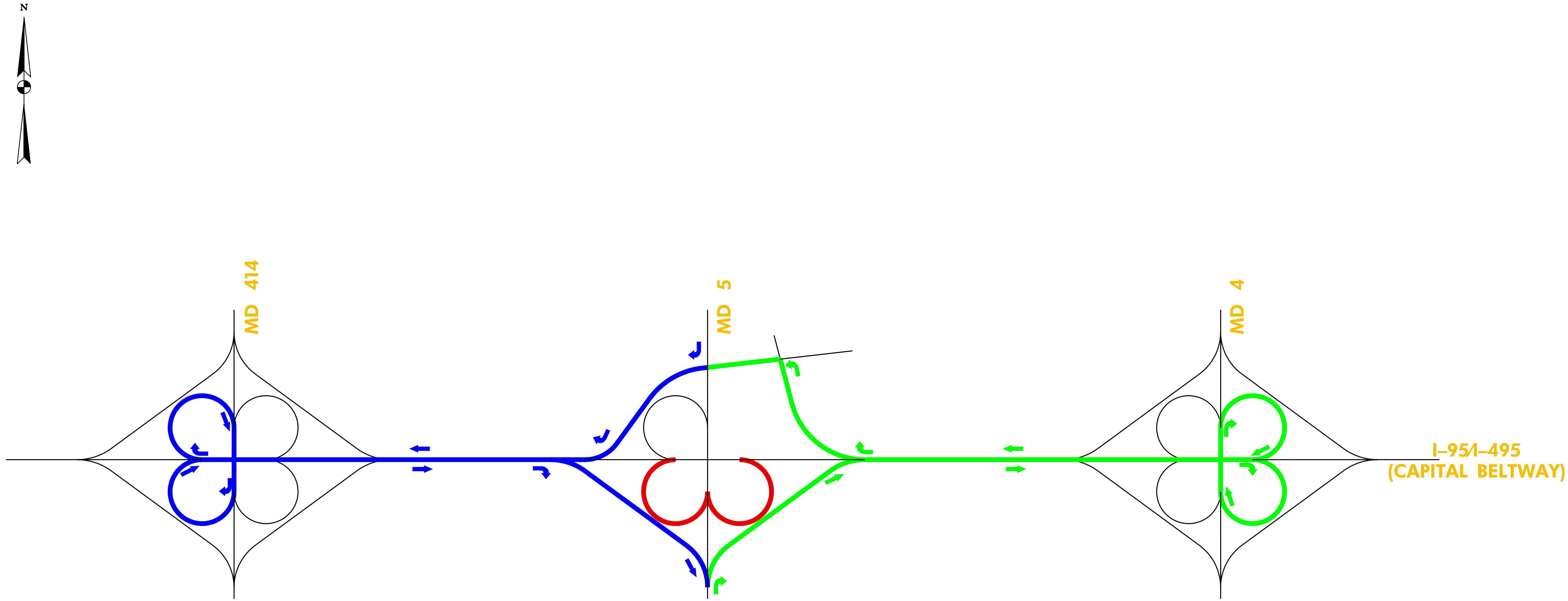


Figure 3

Proposed Interchange Configuration



LEGEND

NB MD 5 DETOUR ROUTE

SB MD 5 DETOUR ROUTE

EXISTING RAMP TO BE CLOSED DURING MOT

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Work Zone Analysis Guide
Example F: I-95/I-495 (Capital Beltway) at MD 5 (Branch Avenue)

Full Roadway Closure and Detour Analysis

Figure 4

Detour Routes

the ramp from southbound I-95 with Auth Road. **Figure 4** shows the assumed detour routes. It was assumed that all traffic on northbound MD 5 will be detoured as follows:

- The four existing lanes on northbound MD 5 will be reduced to one lane which will exit onto northbound I-95.
- All traffic desiring to go either southbound on I-95 or northbound on MD 5 will take Exit 11B (westbound MD 4), then stay in the weaving lane and take the exit for southbound I-95.
- Traffic desiring to go northbound on MD 5 will take Exit 7B to Auth Road, turn left onto Auth Road at the traffic signal, and turn right onto northbound MD 5.

It was assumed that all traffic on southbound MD 5 will be detoured as follows:

- The three existing lanes on southbound MD 5 will be reduced to one lane which will exit onto southbound I-95.
- All traffic desiring to go either northbound on I-95 or southbound on MD 5 will take Exit 4A (southbound MD 414), then stay in the weaving lane and take the exit for northbound I-95.
- Traffic desiring to go southbound on MD 5 will take Exit 7A (southbound MD 5).

2. **Data Collection.** Existing average daily traffic (ADT) data was obtained from the SHA's Project Planning Division for the movements at the I-95 interchanges with MD 4 and MD 414. Historical count data collected in May 2005 and May 2006 were obtained from the SHA's Highway Information Services Division (HISD) for the movements at the I-95/MD 5 interchange.

   The analysis volumes were developed using conversion factors from SHA's *Traffic Trends 2006.* A review of *Traffic Trends* showed that the lowest traffic volumes occur Saturday nights into Sunday mornings. Therefore, existing ADTs were converted to September weekend ADTs and then to hourly Saturday traffic volumes. Annual growth rate adjustments were not made to the existing traffic volumes because a review for the annual average daily traffic (AADT) for the study area between 2002 and 2005 showed little, if any, annual traffic growth. **Table 1** on the following page summarizes the mainline MD 5 Saturday traffic data utilized in the study. It should be noted these traffic volumes were reduced by 11% to approximate Sunday hourly traffic volumes. This reduction factor was derived from factors obtained through the *Traffic Trends* tables.

   Existing lane configurations to be used for the analysis were obtained from a review of aerial photography.

3. **Determine the Analysis Method.** Due to the characteristics of the proposed work zone and the objective of this analysis, the analysis methods that will be used for this example are spreadsheet analysis for the mainline MD 5 lane closure and HCS analysis for the merge, diverge, weave, and basic freeway sections along the proposed detour routes. Because simulation modeling will not be used for example, the creation of an existing conditions model and subsequent model calibration and validation are unnecessary.

Table 1. Summary of the Hourly Analysis Traffic Data (September Saturday)

Hour Ending	NB MD 5: South of I-95	SB MD 5: North of I-95
1 AM	1144	567
2 AM	794	393
3 AM	639	316
4 AM	472	234
5 AM	466	231
6 AM	700	347
7 AM	1116	553
8 AM	1632	809
9 AM	2127	1053
10 AM	2676	1326
11 AM	3170	1570
12 Noon	3481	1724
1 PM	3731	1848
2 PM	3665	1815
3 PM	3709	1837
4 PM	3698	1832
5 PM	3770	1867
6 PM	3687	1826
7 PM	3431	1700
8 PM	3104	1537
9 PM	2693	1334
10 PM	2304	1141
11 PM	1888	935
12 Midnight	1421	704

4. **Modeling – Code Work Zone Model.** Due to the nature of the available road closure alternatives, it was determined that Option #3 (a continuous 17-hour closure followed by a 7-hour closure on a separate occasion) would be evaluated first, since this would result in the least impacts to existing traffic operations when compared with the other alternatives. In essence, if this alternative will not work, neither will the other alternatives.

   The first step in evaluating work zone conditions is to evaluate the impact of work zone activities on mainline MD 5. For this analysis, queue lengths were calculated for each 60-minute interval over a 48-hour period (midnight Saturday to midnight Monday) using the spreadsheet method. The following assumptions were made in performing this analysis:

- The existing capacity on MD 5 is 2,300 vphpl (Exhibit 23-2 from the *HCM 2000*)
- Truck percentage in both directions on MD 5 = 5%
- Low work zone intensity
- Approximate work zone length of 1.0 mile
- NB MD 5 will be reduced from four lanes to the one-lane ramp
- SB MD 5 will be reduced from three lanes to the one-lane ramp
- Flat work zone grade
- No lateral clearance

Based on the aforementioned assumptions and the UMD capacity equation, the work zone capacities on the one-lane sections of MD 5 approaching the proposed detours were approximated as 1,273 vph along northbound MD 5 and 1,442 vph along southbound MD 5. These capacity approximations were entered into the analysis spreadsheet and utilized for the queuing analysis.

5. **Modeling – Obtain Model Outputs.** The hourly traffic volumes were compared to the estimated work zone capacity to determine residual queues. After a trial and error process, it was determined that the optimal time for a 17-hour road closure is between 8PM Saturday and 1PM Sunday. **Table 2** presents a summary of the analysis results for each hour of the bridge closure. As shown in the table, the bridge closure is expected to result in excessive queues (in excess of 1.5 miles in length) along northbound MD 5. It should be noted that time intervals during which the demand exceeds the capacity and the maximum queue for the northbound approach are ***highlighted in red***. It should also be noted that the queues presented in this table do not take into account the impacts of signalized or unsignalized intersections on the approaches.

Table 2. Summary of the Queuing Analysis Results (Lane Closure from Saturday 8 PM to Sunday 1 PM)

Hour Ending	NB MD 5: South of I-95			SB MD 5: North of I-95		
	Capacity	Demand	Cumulative Queue[1] (mi)	Capacity	Demand	Cumulative Queue[1] (mi)
9 PM	1,273	***2,693***	2.43	1,442	1,334	-
10 PM	1,273	***2,304***	3.65	1,442	1141	-
11 PM	1,273	***1,888***	4.38	1,442	935	-
12 Midnight	1,273	***1,421***	4.55	1,442	704	-
1 AM	1,273	1,014	4.25	1,442	502	-
2 AM	1,273	703	3.57	1,442	348	-
3 AM	1,273	566	2.73	1,442	280	-
4 AM	1,273	418	1.72	1,442	207	-
5 AM	1,273	413	-	1,442	205	-
6 AM	1,273	620	-	1,442	307	-
7 AM	1,273	989	-	1,442	490	-
8 AM	1,273	***1,446***	0.82	1,442	717	-
9 AM	1,273	***1,885***	1.68	1,442	933	-

10 AM	1,273	***2,371***	2.98	1,442	1,175	-
11 AM	1,273	***2,809***	4.80	1,442	1,391	-
12 Noon	1,273	***3,084***	6.94	1,442	***1,527***	0.41
1 PM	1,273	***3,306***	***9.59***	1,442	***1,637***	1.11
2 PM	8,976	3,247	2.56	6,732	1,608	-
3 PM	8,976	3,286	-	6,732	1,628	-

1. This queue length assumes that the lane reduction will have a length of 1 mile, with all queues in excess of 1 mile dispersed across the existing number of lanes.

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the queuing analysis performed, the maximum queue expected on northbound MD 5 will exceed 9 miles and the maximum queue on southbound MD 5 will be 1.11 miles (with a one-hour duration). Therefore, this alternative will meet the freeway lane closure mobility thresholds (queue between 1 and 1½ miles for less than two hours) along southbound MD 5, but will not meet the mobility threshold along northbound MD 5 (queue may not exceed 1½ miles for any duration). In order to improve traffic operations along northbound MD 5, another alternative was developed assuming a two-lane ramp from MD 5 onto northbound I-95.

4. **Modeling – Code Modified Work Zone Model.** Under this alternative, the right lane on northbound I-95 will be closed prior to the merge from northbound MD 5 and the ramp from northbound MD 5 to northbound I-95 will be modified to a two-lane ramp with one acceleration lane of length 400’ (matching the existing acceleration length) and one add lane. This alternative will help to increase the capacity for the traffic detoured from northbound MD 5. Based on these new assumptions, the work zone capacity was recalculated using the UMD equation and estimated to be 2,884 vph.

   In addition to the lane reduction analysis, traffic operations were also evaluated along the proposed detour routes. HCS and Synchro were used to evaluate the detour route assuming that a two-lane ramp is provided from northbound MD 5 to northbound I-95. HCS models were coded for all merge, diverge, weave, and basic freeway sections and a Synchro model was created to evaluate traffic signal operations at the intersection of the ramp from southbound I-95 to MD 5 with Auth Road. It should be noted that HCS analysis cannot analyze merges that involve add lanes, so a quick CORSIM model was created to evaluate traffic operations at the merge from northbound MD 5 onto northbound I-95. Based on this simulation, this merge is expected to operate acceptably. It should be noted that detour route analyses were performed using peak hour traffic volumes from the traffic data used for the lane reduction analysis.

5. **Modeling – Obtain Model Outputs.** For the analysis of the lane reductions approaching the detours, the hourly traffic volumes were compared to the estimated work zone capacity to determine residual queues. The same 17-hour time period that was used for the one lane ramp analysis (between 8PM Saturday and 1PM Sunday) was utilized for this evaluation. **Table 3** presents a summary of the analysis results for each hour of the bridge closure. As shown in the table, the bridge closure is expected to result in queues shorter than 1.5 miles in both directions on MD 5, thereby meeting SHA’s mobility thresholds. It should be noted that

time intervals during which the demand exceeds the capacity and the maximum queue for the northbound approach are ***highlighted in red***. It should also be noted that the queues presented in this table do not take into account the impacts of signalized or unsignalized intersections on the approaches.

Table 3. Summary of the Queuing Analysis Results (Lane Closure from Saturday 8 PM to Sunday 1 PM)

Hour Ending	NB MD 5: South of I-95			SB MD 5: North of I-95		
	Capacity	Demand	Cumulative Queue[1] (mi)	Capacity	Demand	Cumulative Queue[1] (mi)
9 PM	2,884	2,693	-	1,442	1,334	-
10 PM	2,884	2,304	-	1,442	1141	-
11 PM	2,884	1,888	-	1,442	935	-
12 Midnight	2,884	1,421	-	1,442	704	-
1 AM	2,884	1,014	-	1,442	502	-
2 AM	2,884	703	-	1,442	348	-
3 AM	2,884	566	-	1,442	280	-
4 AM	2,884	418	-	1,442	207	-
5 AM	2,884	413	-	1,442	205	-
6 AM	2,884	620	-	1,442	307	-
7 AM	2,884	989	-	1,442	490	-
8 AM	2,884	1,446	-	1,442	717	-
9 AM	2,884	1,885	-	1,442	933	-
10 AM	2,884	2,371	-	1,442	1,175	-
11 AM	2,884	2,809	-	1,442	1,391	-
12 Noon	2,884	***3,084***	0.47	1,442	***1,527***	0.41
1 PM	2,884	***3,306***	1.24	1,442	***1,637***	1.11
2 PM	8,976	3,247	-	6,732	1,608	-
3 PM	8,976	3,286	-	6,732	1,628	-

1. This queue length assumes that the lane reduction will have a length of 1 mile, with all queues in excess of 1 mile dispersed across the existing number of lanes.

For the analysis of the detour route, Level of Service (LOS), density, and speed measures were extracted from the HCS reports and LOS and average intersection delay were extracted from Synchro's *HCM Signalized* report. **Table 4** summarizes the results of the traffic analyses at critical locations along the proposed detour routes. As shown in the table, the detour routes will result in several locations with LOS F. Included at the conclusion of this example, are some sample HCS and Synchro worksheets from the northbound MD 5 detour route.

Table 4. Summary of HCS Analyses along Detour Routes

Location	Detour LOS	Density (pc/mi/ln)	Speed (mph)
Northbound MD 5 Detour Route			
NB I-95 Merge from NB MD 5	CORSIM shows acceptable operations		
NB I-95 North of MD 5 (4 Lanes) [1]	E	38.8	57.9
NB I-95 Diverge to WB MD 4 [2]	***F***	***80.3***	***25.1***
WB MD 4 Diverge to SB I-95 [2]	***F***	***48.5***	***37.3***
SB I-95 Merge from WB MD 5 [2]	***F***	***78.6***	***25.1***
SB I-95 South of MD 4 (4 Lanes) [1]	***F***	***N/A***	***N/A***
SB I-95 Diverge to NB MD 5/Auth Road [3]	***F***	***53.1***	***61.7***
MD 5 Ramp 1 at Auth Road (Traffic Signal) [4]	***F***	***Avg. Delay: 107.5 sec***	
Southbound MD 5 Detour Route			
SB I-95 Merge from SB MD 5 [3]	C	27.4	60.4
SB I-95 South of MD 5 (4 Lanes) [1]	E	36.7	59.6
SB I-95 Diverge to SB MD 414 [2]	***F***	***53.4***	***32.3***
SB MD 414 Diverge to NB I-95 [2]	D	30.7	52.0
NB I-95 Merge from SB MD 414 [2]	***F***	***52.8***	***31.6***
NB I-95 North of MD 414 (4 Lanes) [1]	D	34.7	61.2
NB Diverge to SB MD 5 [3]	***F***	***47.9***	***58.9***
NB I-95 North of Diverge to SB MD 5 (3 Lanes) [1]	C	25.6	66.3

1. Basic section analysis
2. Weaving section analysis
3. Merge/Diverge section analysis
4. Synchro analysis

6. **Determine if the Alternative Meets the Mobility Thresholds.** Based on the analysis performed, the lane reductions will meet the freeway mobility thresholds (queue between 1 and 1½ miles for less than two hour). There are no established mobility thresholds for freeway sections along detour routes, however engineering judgment would indicate that LOS F along a detour route would not be acceptable. Additionally, the arterial mobility threshold for signalized intersection of Ramp 1 at Auth Road will be violated when over 2,300 detoured vehicles will turn left from Ramp 1 onto westbound Auth Road (causing LOS F). However, there is no way to construct erect the bridge steel other than to have a full roadway closure for at least 17 consecutive hours. Therefore, it is recommended that advance signing be provided along MD 5 in order to encourage motorists to take alternate routes, which should reduce the traffic volumes along the detour routes. A public outreach campaign may also be useful to alert motorists to the closure in advance of leaving their homes.

7. **Recommend an Alternative.** Based on the results of the analysis presented in this study, it is recommended that this project be constructed using a 17-hour road closure followed by a 7-hour road closure on another night. Based on the estimated queue lengths presented in Table 3, it is recommended that the subsequent 7-hour closure occur at sometime between 12 Midnight and 7AM Sunday. Additionally, it is recommended that a two-lane ramp be provided from northbound MD 5 to northbound I-95 and that advance signing and public information campaigns be utilized to encourage motorists to use alternate routes during the road closure. **Table 5** summarizes the lane closure hours for the proposed alternative.

Table 5. Recommended Work Zone Alternative

Alternative #3: Work Zone Staging	Work Hour Restrictions
17-hour Closure	
Northbound lane reduction to two-lane ramp	8 PM Sat. – 1 PM Sun.
Southbound lane reduction to one-lane ramp	8 PM Sat. – 1 PM Sun.
7-hour Closure	
Northbound lane reduction to two-lane ramp	12 Midnight – 7 AM Sun.
Southbound lane reduction to one-lane ramp	12 Midnight – 7 AM Sun.

HCS+: Basic Freeway Segments Release 5.21

Phone: Fax:
E-mail:

Operational Analysis

Analyst:	Aneesha Griffin
Agency or Company:	Sabra, Wang & Associates
Date Performed:	5/14/2007
Analysis Time Period:	September Weekend Peak
Freeway/Direction:	NB I-95
From/To:	North of NB MD 5
Jurisdiction:	
Analysis Year:	

Description: Work Zone Analysis Guide

Flow Inputs and Adjustments

Volume, V	7516	veh/h
Peak-hour factor, PHF	0.90	
Peak 15-min volume, v15	2088	v
Trucks and buses	5	%
Recreational vehicles	0	%
Terrain type:	Rolling	
Grade	0.00	%
Segment length	0.00	mi
Trucks and buses PCE, ET	2.5	
Recreational vehicle PCE, ER	2.0	
Heavy vehicle adjustment, fHV	0.930	
Driver population factor, fp	1.00	
Flow rate, vp	2244	pc/h/ln

Speed Inputs and Adjustments

Lane width	12.0	ft
Right-shoulder lateral clearance	6.0	ft
Interchange density	0.50	interchange/mi
Number of lanes, N	4	
Free-flow speed:	Base	
FFS or BFFS	70.0	mi/h
Lane width adjustment, fLW	0.0	mi/h
Lateral clearance adjustment, fLC	0.0	mi/h
Interchange density adjustment, fID	0.0	mi/h
Number of lanes adjustment, fN	1.5	mi/h
Free-flow speed, FFS	68.5	mi/h
	Urban Freeway	

LOS and Performance Measures

Flow rate, vp	2244	pc/h/ln
Free-flow speed, FFS	68.5	mi/h
Average passenger-car speed, S	57.9	mi/h
Number of lanes, N	4	
Density, D	38.8	pc/mi/ln

Level of service, LOS	E

Overall results are not computed when free-flow speed is less than 55 mph.

Phone: Fax:
E-mail:

Operational Analysis

Analyst: Aneesha Griffin
Agency/Co.: Sabra, Wang & Associates
Date Performed: 5/15/2007
Analysis Time Period: September Weekend Peak
Freeway/Dir of Travel: WB MD 4
Weaving Location: I-95
Jurisdiction:
Analysis Year:
Description: MD 5 MOT Analysis

Inputs

Freeway free-flow speed, SFF	70	mph
Weaving number of lanes, N	3	
Weaving segment length, L	350	ft
Terrain type	Rolling	
Grade		%
Length		mi
Weaving type	A	
Volume ratio, VR	0.19	
Weaving ratio, R	0.49	

Conversion to pc/h Under Base Conditions

	Non-Weaving		Weaving		
	V A-C	V B-D	V A-D	V B-C	
Volume, V	630	3063	418	427	veh/h
Peak-hour factor, PHF	0.90	0.90	0.90	0.90	
Peak 15-min volume, v15	175	851	116	119	v
Trucks and buses	5	5	5	5	%
Recreational vehicles	0	0	0	0	%
Trucks and buses PCE, ET	2.5	2.5	2.5	2.5*	
Recreational vehicle PCE, ER	2.0	2.0	2.0	2.0	
Heavy vehicle adjustment, fHV	0.930	0.930	0.930	0.930	
Driver population adjustment, fP	1.00	1.00	1.00	1.00	
Flow rate, v	752	3658	499	510	pc/h

Weaving and Non-Weaving Speeds

	Weaving	Non-Weaving
a (Exhibit 24-6)	0.15	0.0035
b (Exhibit 24-6)	2.20	4.00
c (Exhibit 24-6)	0.97	1.30
d (Exhibit 24-6)	0.80	0.75
Weaving intensity factor, Wi	2.90	1.47
Weaving and non-weaving speeds, Si	30.37	39.32

Number of lanes required for

unconstrained operation, Nw (Exhibit 24-7)	0.75
Maximum number of lanes, Nw (max) (Exhibit 24-7)	1.40
Type of operation is	Unconstrained

Weaving Segment Speed, Density, Level of Service and Capacity

Weaving segment speed, S	37.27	mph
Weaving segment density, D	48.46	pc/mi/ln
Level of service, LOS	F	
Capacity of base condition, cb	5123	pc/h
Capacity as a 15-minute flow rate, c	4766	pc/h
Capacity as a full-hour volume, ch	4289	pc/h

Limitations on Weaving Segments

	Analyzed	Maximum	If Max Exceeded See Note Note
Weaving flow rate, Vw	1009	2800	a
Average flow rate (pcphpl)	1806	2400	b
Volume ratio, VR	0.19	0.45	c
Weaving ratio, R	0.49	N/A	d
Weaving length (ft)	350	2500	e

Notes:

a. Weaving segments longer than 2500 ft. are treated as isolated merge and diverge areas using the procedures of Chapter 25, "Ramps and Ramp Junctions".

b. Capacity constrained by basic freeway capacity.

c. Capacity occurs under constrained operating conditions.

d. Three-lane Type A segments do not operate well at volume ratios greater than 0.45. Poor operations and some local queuing are expected in such cases.

e. Four-lane Type A segments do not operate well at volume ratios greater than 0.35. Poor operations and some local queuing are expected in such cases.

f. Capacity constrained by maximum allowable weaving flow rate: 2,800 pc/h (Type A), 4,000 (Type B), 3,500 (Type C).

g. Five-lane Type A segments do not operate well at volume ratios greater than 0.20. Poor operations and some local queuing are expected in such cases.

h. Type B weaving segments do not operate well at volume ratios greater than 0.80. Poor operations and some local queuing are expected in such cases.

i. Type C weaving segments do not operate well at volume ratios greater than 0.50. Poor operations and some local queuing are expected in such cases.

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Aneesha Griffin
Agency/Co.:	Sabra, Wang & Associates
Date performed:	5/15/2007
Analysis time period:	September Weekend Peak
Freeway/Dir of Travel:	SB I-95
Junction:	NB MD 5
Jurisdiction:	
Analysis Year:	
Description:	Work Zone Analysis Guide

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	70.0	mph
Volume on freeway	8224	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	55.0	mph
Volume on ramp	2952	vph
Length of first accel/decel lane	560	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	No	
Volume on adjacent ramp		vph
Position of adjacent ramp		
Type of adjacent ramp		
Distance to adjacent ramp		ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	8224		2952			vph
Peak-hour factor, PHF	0.90		0.90			
Peak 15-min volume, v15	2284		820			v
Trucks and buses	5		5			%
Recreational vehicles	0		0			%
Terrain type:	Rolling		Rolling			
Grade	0.00	%	0.00	%		%
Length	0.00	mi	0.00	mi		mi
Trucks and buses PCE, ET	2.5		2.5			
Recreational vehicle PCE, ER	2.0		2.0			

Heavy vehicle adjustment, fHV	0.930	0.930	
Driver population factor, fP	1.00	1.00	
Flow rate, vp	9823	3526	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 25-8 or 25-9)

P_{FD} = 0.436 Using Equation 8

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 6271 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	9823	9600	Yes
$v_{FO} = v_F - v_R$	6297	9600	No
v_R	3526	2200	Yes
v_3 or v_{av34}	1776 pc/h	(Equation 25-15 or 25-16)	
Is v_3 or v_{av34} > 2700 pc/h?		No	
Is v_3 or v_{av34} > 1.5 v_{12}/2		No	
If yes, v_{12A} =		(Equation 25-18)	

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	6271	4600	No

!

Level of Service Determination (if not F)

Density, $D = 4.252 + 0.0086\ v_{12} - 0.009\ L_D$ = 53.1 pc/mi/ln

Level of service for ramp-freeway junction areas of influence F

Speed Estimation

Intermediate speed variable,	D_S = 0.485	
Space mean speed in ramp influence area,	S_R = 56.4	mph
Space mean speed in outer lanes,	S_0 = 73.8	mph
Space mean speed for all vehicles,	S = 61.7	mph

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)	4.0	4.0			4.0		4.0	4.0	4.0	4.0		4.0
Lane Util. Factor	1.00	0.95			0.95		0.97	1.00	1.00	1.00		1.00
Frt	1.00	1.00			0.99		1.00	1.00	0.85	1.00		0.85
Flt Protected	0.95	1.00			1.00		0.95	1.00	1.00	0.95		1.00
Satd. Flow (prot)	1770	3539			3502		3433	1863	1583	1770		1583
Flt Permitted	0.18	1.00			1.00		0.95	1.00	1.00	0.95		1.00
Satd. Flow (perm)	339	3539			3502		3433	1863	1583	1770		1583
Volume (vph)	12	83	0	0	392	30	2681	87	184	39	0	88
Peak-hour factor, PHF	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Adj. Flow (vph)	13	92	0	0	436	33	2979	97	204	43	0	98
RTOR Reduction (vph)	0	0	0	0	4	0	0	0	55	0	0	4
Lane Group Flow (vph)	13	92	0	0	465	0	2979	97	149	43	0	94
Turn Type	Perm						Split		Perm	Prot		custom
Protected Phases		6			2		8	8		4		
Permitted Phases	6								8			4
Actuated Green, G (s)	22.0	22.0			22.0		130.0	130.0	130.0	14.2		14.2
Effective Green, g (s)	22.0	22.0			22.0		130.0	130.0	130.0	14.2		14.2
Actuated g/C Ratio	0.12	0.12			0.12		0.73	0.73	0.73	0.08		0.08
Clearance Time (s)	4.0	4.0			4.0		4.0	4.0	4.0	4.0		4.0
Vehicle Extension (s)	3.0	3.0			3.0		3.0	3.0	3.0	3.0		3.0
Lane Grp Cap (vph)	42	437			432		2504	1359	1155	141		126
v/s Ratio Prot		0.03			c0.13		c0.87	0.05		0.02		
v/s Ratio Perm	0.04								0.09			c0.06
v/c Ratio	0.31	0.21			1.08		1.19	0.07	0.13	0.30		0.75
Uniform Delay, d1	71.2	70.3			78.1		24.1	6.9	7.2	77.3		80.3
Progression Factor	1.00	1.00			1.00		1.00	1.00	1.00	1.00		1.00
Incremental Delay, d2	18.2	1.1			65.7		89.7	0.0	0.1	1.2		21.3
Delay (s)	89.3	71.4			143.8		113.8	6.9	7.2	78.6		101.6
Level of Service	F	E			F		F	A	A	E		F
Approach Delay (s)		73.6			143.8			104.0			94.6	
Approach LOS		E			F			F			F	

Intersection Summary			
HCM Average Control Delay	107.5	HCM Level of Service	F
HCM Volume to Capacity ratio	1.14		
Actuated Cycle Length (s)	178.2	Sum of lost time (s)	12.0
Intersection Capacity Utilization	103.7%	ICU Level of Service	G
Analysis Period (min)	15		
c Critical Lane Group			

APPENDIX D – FREEWAY WORK ZONE ANALYSIS CHECKLSIST

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1. Does the network include all impacted intersections/interchanges?

2. Is the study network large enough to be able to estimate the impact of residual queues among the MOT alternatives? If not, explain why the study network was limited.

3. Does the proposed MOT alternative impact an arterial? If so, were the arterial mobility thresholds evaluated? If not, provide justification.

4. Were traffic volumes less than 3 years old used for the analysis? If not, provide justification.

5. Were appropriate adjustment factors applied to traffic volumes to account for traffic volumes expected during construction? If not, provide justification.

6. Was an existing conditions model coded? If so, were field observations of existing conditions performed?

7. If a detour was evaluated, was origin-destination data collected? If not, how was origin-destination data estimated?

8. For simulations, does the animation visually resemble existing field conditions within the acceptable tolerances?

9. Was the model calibrated and validated? If not, provide justification.

10. Were buffer length and tapers lengths included in the traffic analysis?

11. Does the recommended alternative meet all mobility thresholds? If not, provide justification, and list recommended mitigation strategies.

12. If all mobility thresholds are satisfied, are there any other operational or safety impacts expected? If so, are they outlined in the report?

13. Does the recommendation include a lane closure schedule (number of lanes to be closed, permitted work hours, proposed construction sequence, etc.)?

14. Were all analysis objectives met through the course of the study?